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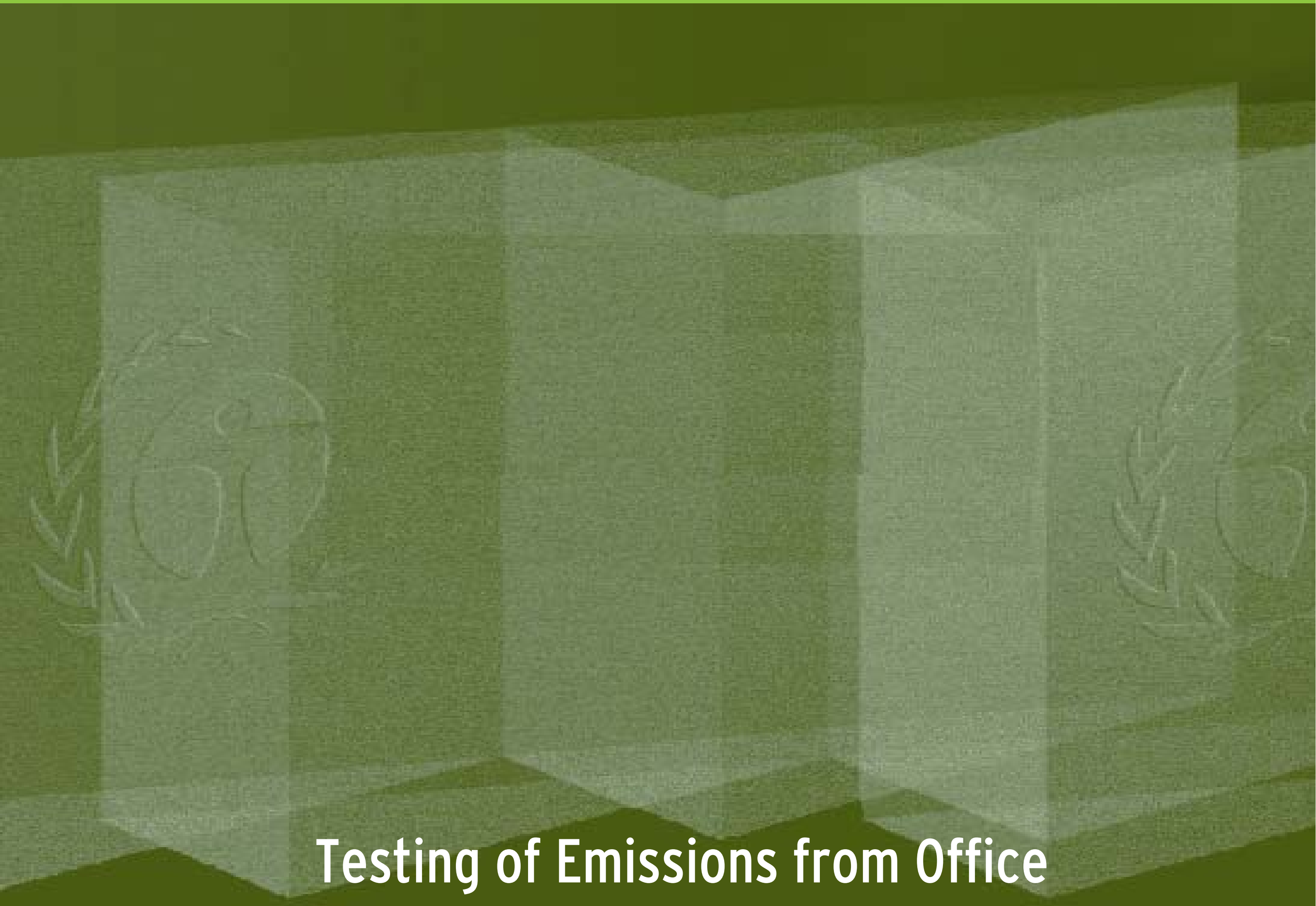

Testing of Emissions from Office Devices during the Printing Phase for the Advancement of the Blue Angel Environmental Award for Laser Printers and Multi-function Devices with Special Consideration of Ensuring Good Indoor Air Quality

Umwelt
Bundes
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Für Mensch und Umwelt

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On behalf of the German Federal Environment Agency

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COMMISSIONED
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Preamble

The research project was commissioned by the Federal Environment Agency and supported by means of the Environmental Research Programme as a project for the advancement of the Blue Angel environmental award for laser printers and multi-function devices.

Issues concerning the emission behaviour of hardcopy devices, conclusions for a test method and the preliminary results of the project were presented and discussed in three meetings of a project-advisory working group. The members of the working group belonged to German testing institutes for RAL-UZ 114, ECMA, JBMIA, BITKOM and the Federal Environment Agency (UBA). The names of all members of this expert panel are listed in Section 14.5 in the Appendix.

The members of the expert panel have provided helpful guidance to the project, which is gratefully acknowledged. Contribution by companies that made investigation material and devices available within the framework of the project is also acknowledged.

The investigations presented in this report were preceded by a research project whose results have been published under the number 71/03 of the UBA text series. In addition, the report of 2003 discussed important fundamentals for indoor air quality, test chamber measurement and assessment of emissions and made theoretical considerations about the concentration profiles observed in test chamber measurements. These fundamentals have not been reiterated in this report, instead, reference is made to the report of 2003.

1 Introduction

1.1 Background and objectives

In order to improve the indoor air quality it is necessary to gain information about the contribution to the overall emission of individual emission sources and purposefully reduce those emissions. Furnishing materials, building products, furniture, printers and copiers belong to the main emission sources of volatile organic compounds (VOC). An identification of the emission behaviour of the products used in interiors can only be performed under standardised test conditions in emission test chambers or cells [Leovic 1998, Black 1999, Brown 1999, Hohensee 2000, Heimann 2001, Wensing 2002, Jann 2003, Rockstroh 2003, Jann 2006, Seeger 2006, Kagi 2007].

Many products, which contribute to the avoidance of substantial environmental and health problems, can already be marked with the "Blue Angel" environmental symbol (RAL - UZ). The use of the label is voluntary and must be applied with RAL, German Institute for Quality Assurance and Marking (Deutsches Institut für Gütesicherung und Kennzeichnung e.V.). Adherence to specific criteria has to be proved.

The base line was the test procedure for the determination of emissions from hard-copy devices according to RAL-UZ 62, 85 and 114, the DIN ISO 16000-9 as a test chamber standard and DIN ISO 16000-6 for the air sampling and analysis methodology. These regulations complement each other and make possible the determination of VOC emissions from materials such as building products but, in principle, also from electronic devices. Both computers and printers and copiers summarized under the term of "hardcopy devices" belong to this group.

Environmental label criteria for office printers and copiers have been there since 1996. RAL-UZ 85 has so far been applied to printers, RAL-UZ 62 to copiers and RAL-UZ 114 to multi-function devices. The assignment principles were published in 2003 together with a new test method (Jann 2003) and were valid until the end of 2006. RAL-UZ 122 has been available since 1 January 2007 which uniformly covers the three groups of office devices with printing functionality.
The assignment principles of 2003 limited the permissible emission rates as shown in Table 1.

Table 1: Permissible maximum emission rates determined for RAL-UZ 62, 85, 114 as indicated in Appendix 4

Substance	Emission rate Printing phase (mg/h)	Emission rate Desktop devices Pre-operating phase (mg/h)	Emission rate Freestanding devices Pre-operating phase (mg/h)
TVOC	10	1	3
Benzene	0.05	-	-
Styrene	1.0	-	-
Ozone	2	-	-
Dust	4	-	-

When the permissible emission rates for the printing process (printing phase) were specified, the assumption was made that the devices under normal circumstances will not be in the printing phase for more than 10 per cent of a ten-hour working day. The TVOC has been limited for the pre-operating phase only, taking into account the different sizes and thus masses, and specific material surfaces of desk-top and free-standing devices. No limits have been specified for the other substances for the pre-operating phase since no significant emission was expected in this operating phase.
The assignment criteria mentioned applied up to December 2006. Starting from June 2006 a new, parallel, assignment basis was introduced for office devices with printing functionality (RAL-UZ 122) with an updated test method and adjusted permissible emission rates, which starting from January 2007 summarized and replaced the previous assignment basis

For this purpose the requirements raised so far had to be checked, and, in particular, criteria for colour printing had to be specified, which had not previously existed.

A test method has been developed on the basis of the investigations carried out and in agreement with the project-advisory working group. This resulted in the publication of a revised test method in June 2006 (Appendix of the assignment basis for RAL-UZ 122).

The investigations were supplemented by an interlaboratory cooperative test in which all certified test institutes had to participate.

Further questions to be answered concerned the contribution of operational materials to the emission behaviour of the overall system such as toner and paper. The first question of prime interest was about characterisation of the dust (distinction toner dust / paper dust), questions about the occurrence of ultra fine dust particles came up at a later stage in the project.

In addition, contribution was made to the revision of the ECMA standard 328 published by ECMA (European Computer Manufacturer Association) in 2001, which also describes the determination of chemical emissions from electronic devices. This revision was finished in 2006 and harmonization work took place with RAL-UZ 122. The resulting ECMA standard 328 (2nd edition) was the precursor of the ISO/IEC-Standard 28360 of September 2007.

2 Methods / devices

2.1 Emission test chambers

Emission test chambers enable the reproducible measurement of substances emitted from a material into the air under standardised and to a large extent constant test conditions.

DIN ISO 16000, Part 9 - 11, includes the determination of VOC emissions using emission test chambers and cells and, in addition, describes extraction, treatment and preparation of emission samples.

In Germany, 1-m³ emission test chambers are frequently used for emission tests. A temperature of 23 °C and a relative humidity of 50 % have been specified as climatic parameters.

Further important criteria, such as air exchange rate (n) and product loading factor (L), and the ratio of air exchange rate to product loading factor called area-specific air flow rate (q) according to DIN ISO 16000-9 have been defined differently. The term unit-specific air exchange rate has been introduced for devices, since the determination of the surface of complex devices is impractical.

In order to determine the emission behaviour of volatile organic compounds in small concentrations down to the lower µg m^{-3} range, not only must the usual parameters such as temperature, relative humidity, air exchange rate and air flow velocity be kept constant at specific values, but the test chambers must also satisfy a number of further special requirements. In particular:

- Inert chamber walls of glass or polished high-grade steel to minimize wall effects
- Efficient air mixing
- Minimise sealing materials capable of causing intrinsic emissions and adsorption and desorption effects
- Ability to clean the chamber, for example through firing
- Clean air and water supply with low VOC and dust content

The reason for choosing extremely inert chamber wall materials is to keep adsorption effects near the chamber walls to a minimum so that pollutant concentration in the air is not influenced by so-called wall effects. In addition to influencing pollutant concentration in the air during emission measurements, wall effects can impair subsequent investigations in the form of memory effects from the preceding measurements. A blank run is also necessary between two chamber tests and adequate desorption should be enabled for organic compounds that may have been adsorbed on the chamber walls.

Investigations within the framework of this project used 1-m³ and 20-m³ emission chambers with the same standard environmental conditions (T = 23 °C and 50 % relative humidity) being applied throughout.

Furthermore all test chambers were equipped with the same clean air supply system. Clean air was provided by an oil-free compressor in which a downstream cleaning unit removed moisture, VOC and dust from the compressed air. The cleaning unit (Ultrafilter Oilfreepac) consists of a pre-filter (dust and aerosol separation), air drying (heatless dryer - silica gel with automatic regeneration), activated carbon cartridge for VOC absorption and a fine filter and an afterfilter (submicrofilter < 0.01 µm, degree of separation 99.99999 %) to restrain both fine dust from the ambient air and abraded activated carbon particles.

Various humidification principles and equipment were used to achieve the necessary relative humidity: either a mixed humidification combining dry and moist partial currents, a condensation point humidifier or a steam humidifier.

Ultrapure water was used for humidification which was obtained from desalinated water. In the case of $\leq$ 1m³ chambers the water was sent through an aftercleaning unit (EASYpure UV D7402) for further desalination and removal of possible organic compounds. An overview of the parameters in the individual emission test chambers is given in Table 2.

Table 2: Parameters of the emission test chambers used

Parameter	Unit	1-m³ chamber	20-m³ chamber
Volume	m³	1	20
Wall material		High-grade steel	
Temperature (T)	°C	23	
Relative humidity (R.H.)	%	50	
Air exchange rate (n)	h^{-1}	1 - 5	1 – 2
Air flow rate (V°)	$m^3\ h^{-1}$	1 - 5	20 – 40
Device-specific air flow rate (q)	$m^3\ unit^{-1}\ h^{-1}$	1 - 5	20 - 40
Air supply		Clean air	

2.1.1 1-m³ chambers

A standard VOC emission test chamber from the firm Vötsch Industrietechnik GmbH was used as the 1-m³ emission test chamber within the framework of this project, which has been commercially available for a long time, and conforms to DIN ISO 16000-9 and has been extensively reported in the literature (Meyer, 1994). This chamber is schematically illustrated in Figure 1.

This chamber has an interior test space of high-grade steel with a smooth surface hermetically sealed from the surroundings. This separation is achieved, among other things, by the magnetic clutch applied to the test space fan which is driven from the outside. Air conditioning of the chamber is performed using a thermally regulated blanket and condensation point humidification. To clean the chamber a heating system is available which eliminates memory effects through thermal desorption at up to 240 °C. The surface of the walls and fittings, which in principle are capable of adsorption of semivolatile compounds, is approximately 7 m².

Figure 1: View of the 1-m³ emission test chamber loaded with a printer

Figure 2: 1-m³ emission test chamber, complete measuring station

2.1.2 20-m³ chamber

ECA Report Number 2 describes the emission test chamber method for test chambers with a volume of ≥ 12 m³ to determine formaldehyde equilibrium concentration. DIN EN 717-1 also describes large chambers with a volume of ≥ 12 m³ for the measurement of formaldehyde equilibrium concentration. Figure 3 shows a photograph of the 20-m³ chamber used.

Figure 3: 20-m³ emission test chamber with a printer

This chamber was connected to the same clean-air supply system used for the other chambers too. Chamber blank tests performed without the clean-air supply system provided unacceptably large, unstable blank values.

Since this chamber was originally conceived for formaldehyde measurements, it fails to correspond substantially to the requirements of VOC emission test chambers.

In particular this concerns temperature control and air distribution devices. Instead of the recommended thermally regulated jacket, temperature adjustment is applied in the 20m³ chamber by a large-area heat exchanger through which air is kept in circulation. Surfaces introduced by heat exchangers may have undesired adsorption effects on the internal surfaces within the chamber. The extent to which measurement results are affected was examined in the report of 2003 using comparative measurements including other chambers.

The advantage of a large chamber is that complex material combinations and/or large freestanding hardcopy devices can also be tested. The 20-m³ chamber is usually operated with an air exchange rate of $n = 1\ h^{-1}$ i.e. a volumetric air flow rate of $20\ m^3\ h^{-1}$.

2.2 Climate

Climate measurements were carried out on the basis of calibrated devices. Climate sensors combined with a datalogger of Type 3290-8 of the ALMEMO company were used as external measuring instruments. This enabled continuous measurement at different measuring points. Calibration of the individual sensors took place with the help of measurements using the Aßmann aspiration psychrometer and a calibrated thermometer.

Measurement accuracy of climate sensors

Moisture sensor : Type FH A 646-R
Range of measurement : 5% to 98% R. H.
Maximum linearity deviation : ± 2% R. H.
Operational temperature : - 30 °C to +100 °C
Nominal temperature : 25 °C ± 3 K

Temperature sensor : NTC Type N
Accuracy : 0 °C to 70 °C ± 0.1 K
Air pressure sensor : Type FD A 612 MA
Range of measurement : 0 mbar to 1050 mbar
Accuracy : ± 0.5% (typical ± 0.1% of end value)
Operational temperature : 25 °C ± 3 K

2.3 Dust (Fine dust and/or ultra fine dust)

The gravimetric method was used as a conventional method for the determination of dust emission rate. This method is primarily sensitive to fine dust > 1 µm particle diameter. Ultra fine particles can barely be detected using gravimetry due to their usually low contribution to the total mass of an aerosol. Therefore particle spectrometers have been used additionally in the 1-m³ emission test chamber to expand the measurement range of particle emissions for ultra fine particles of > 10 nm diameters and achieve a time-resolved and detailed determination of particle number concentrations, particle size distributions and particle emission rates.

2.3.1 Determination of fine dust emission using gravimetry

The basis of the procedure is measuring the difference in weight of a glass-fibre filter by means of an ultra microscale (Type UMX2/M; manufacturer Mettler - Toledo) through which a defined air sample volume from the emission test chamber has been drawn. The ultra microscale is shown in Figure 60 in the Appendix.

Measurement procedure

Air sampling is carried out over a defined time interval (total printing and follow-up phase). Air taken from the test chamber during this time interval is drawn by a pump (Müller; GSA 50) through a glass-fibre filter (Schleicher & Schuell, diameter 50 mm). The volume of air drawn through the filter is determined by a gas flow meter (Schlumberger, REMUS 4 G 1.6). The absolute dust mass weight is obtained by differential weighing of the filter. The medium fine dust concentration in the test chamber can be determined from both values as per Formula 2 and from this the specific fine dust emission rate as per Formula 1.

Standard conditions of gravimetric dust measurement

Dust filter	Glass-fibre filter with container
Sampling point	In the middle of chamber wall for type A and B 1m³ chambers Direct in the chamber approx. 30 cm above the test object for the 20m³ chamber
Sampling flow rate	Up to maximum 90 % of air flow rate in the chamber during the sampling phase
Sampling time	Total printing and follow-up time

Calculation of fine dust concentration and emission rate

$$\boxed{SER_{u_D} = \frac{m_D * n * V * t_T}{V_P * t_T}} \quad \text{Formula 1} \qquad \boxed{c_D = \frac{m_D}{V_P}} \quad \text{Formula 2}$$

c_D:	Dust mass concentration in the test chamber	[µg m^{-3}]
$SER_{u\,D}$:	Dust mass emission rate	[µg $unit^{-1} h^{-1}$]
m_D:	Weighed dust mass (climate-corrected)	[µg]
n:	Air exchange rate	[h^{-1}]
t_{Pr}:	Net printing and copying time	[min]
t_T:	Total sampling time	[min]
V:	Test chamber volume	[m³]
V_P:	Air volume sucked through glass-fibre filter	[m³]

Glass-fibre filters (measuring filters) used for gravimetric fine dust measurement must be stored before measurement in an air-conditioned room (weighing room: temperature: 23°C ± 2 K; relative humidity: 50 % ± 5 %) and conditioned in the dominant climate until the mass remains constant. Since even the smallest unavoidable fluctuations of relative humidity in the weighing room affect the mass of glass-fibre filters, at least one empty glass-fibre filter (reference filter) is weighed simultaneously to the measuring filters before dust sampling (tare), in order to be able to minimize the influence of climate on the filter mass using a climatic correction value.

During dust sampling in the climate chamber, air is sucked through the measuring filter. Since the relative humidity of this air can deviate from that in the weighing room, the measuring filter must again be conditioned in the weighing room after dust sampling until the mass remains constant.

The reference filter will remain in the weighing room over the entire time and weighed again when weighing the dust measuring filter (gross weighing). Mass difference between the first and second weights, determined on the reference filter, is due to climatic changes. The weighed fine dust mass separated on the measuring filter is corrected by this mass difference accordingly.

Determining the climate-corrected fine dust mass

$$\boxed{m_D = (m_{MF_{gross}} - m_{MF_{tare}}) + (m_{RF_1} - m_{RF_2})} \qquad \text{Formula 3}$$

m_D:	Climate-corrected fine dust mass	[µg]
$m_{MF\ gross}$:	Mass of conditioned measuring filter after dust sampling	[µg]
$m_{MF\ tare}$:	Mass of conditioned measuring filter before dust sampling	[µg]
$m_{RF\ 1}$:	Mass of conditioned reference filter simultaneous to weighing measuring filter before dust sampling	[µg]
$m_{RF\ 2}$:	Mass of conditioned reference filter simultaneous to weighing measuring filter after dust sampling	[µg]

Quality assurance

The scale was calibrated by German Calibration Services (Deutscher Kalibrierdienst, DKD) per DKD Guideline 7-1 for Calibration of Electronic Non-automated Scales and the calibration was repeated within appropriate periods. For a maximum load of 2.1 g and a readability of 0.0001 mg, standard deviation determined with a load of 1 g amounted to 0.00039 mg.

Detection limit (LOD) and determination limit (LOQ)

LOD and LOQ were estimated by considering the measurement inaccuracy of the scale indicated by the manufacturer, assuming a complete climatic correction via the reference filters and a determined average mass of the empty glass-fibre filters of 140 ± 5 mg. Table 3 displays LOD and LOQ of gravimetric dust measurement.

Table 3: Detection limit (LOD) and determination limit (LOQ) of gravimetric dust measurement

Test chamber	**Dust emission rate [mg / h]**	
	LOD [mg / h]	**LOQ [mg / h]**
Type A and B 1-m³ chamber	0.035	0.106
20-m³ chamber	0.150	0.450

2.3.2 Determination of ultra fine dust emission by particle spectroscopy (size-resolved particle count)

A combination of two time-resolved particle spectrometers was used:

1.) The Type 1.108 laser particle counter from Grimm Labortechnik GmbH company, illustrated in Figure 57 in the Appendix, uses the principle of the Lorenz-Mie light scattering. The particles contained in air are passed in an isolated stream at a specified flow rate (typically 1.2 l/min) through a small measuring chamber in the measuring instrument and illuminated by a monochromatic laser light. The diameter of each particle is determined automatically by the analysis of the scattered laser light and recorded in one of 15 size classes. The centres of the size classes are: 0.3, 0.4, 0.5, 0.65, 0.8, 1, 1.6, 2, 3, 4, 5, 7.5, 10, 15 and 20 µm. This grading yields approximately constant logarithms for the class widths and a logarithmic normal distribution is assumed for the particle size spectrum which can often be found in nature. The determination of the frequency of particles in the size classes yields snapshots of the particle size distribution in an aerosol in a rapid time sequence – typically every 6 seconds. Alternatively, the measurements can be performed to provide particle number concentration in each size class [particle number/unit volume] or as particle mass concentration in each size class [particle mass/unit volume], a subsequent conversion of the spectra is not possible however. The operational range of the spectrometer is $< 2 \times 10^6$ particles/litre for number concentrations and between 0.1 and 10^5 µg/m³ for mass concentrations in the aerosol.

2.) The particle spectrometer of Type 3080 SMPS (Scanning Mobility Particle Sizer), illustrated in Figure 58 in the Appendix, is based on an electrical measuring method. The aerosol is sucked in at a constant flow rate (1 l/min). By irradiation with a radioactive β emitter (Kr-85) a specified electrical charge pattern is produced in the aerosol at the inlet. The electrically charged polydisperse particles are carried in a laminar air flow through a separation tube (DMA, Differential Mobility Analizer) and there experience a radial drift movement toward a central electrode in a radial-symmetric electrical field perpendicular to their movement i.e. perpendicular to the longitudinal tube axis. Having selected a constant flow rate the, the height of the electrical voltage then determines the field strength and thus the narrow-band size class of the particles, which can be drawn off through a discharge slot. Thus the DMA functions as an adjustable particle filter which, depending on a voltage that can be changed stepwise, allows monodisperse aerosols of specified sizes to pass serially successively, but retains all other particles with a high efficiency of separation. The monodisperse aerosols are then continuously subjected to a counting procedure. This technique enables a rapid scanning of, for example, 100 particle size classes within 2 minutes for the determination of size spectra and is thus also suitable for particles of a few nanometres diameter, and for the size range which cannot be detected by optical particle measuring methods. Larger particles off approx. 250 nm diameter could be optically counted directly after passing the DMA (see laser particle counter). However, after passing the DMA, the particles are first past through a zone of saturated water vapour in a condensation counter. There they provide condensation nuclei, the small particles rapidly increasing in size by adsorption of condensed liquid (to a few µm diameter) until they are easy to count using optical methods. The control software guarantees that the data from size classifying and concentration measurements are always correctly assigned.

Measuring data are gathered on-line from the start of the printing phase to the end of the follow-up phase and transferred over an interface to a PC in real time and stored there as ASCII data files. The evaluation of time-resolved particle number concentrations and particle size distributions, as well as the calculation of particle emission rates and total emissions was carried out using self-programmed algorithms based on the ORIGIN PRO 7.5 analysis software.

In contrast to gravimetry, the methods of particle spectroscopy described above enable the measurement of detailed time-profiles of emission events and the calculation of particle emission rates and total particle emissions from the measurement data. Figure 59 in the Appendix shows the connection of the particle spectrometer to the 1-

m³ test chamber by approx. 50-cm long inlets (Grimm) of high-grade steel and/or conductive silicon (TSI), which extend approx. 10 cm into the chamber and draw off aerosol at the same position.

Calculation of particle emission rate

$$\boxed{SEP(t) = V\ \left(\dot{C}_{P\ meas}(t)\ +\ \beta \cdot C_{P\ meas}(t)\right)}$$ Formula 4

SEP(t):	Time-dependent particle emission rate	[particle min^{-1}]
$C_{P\ meas}(t)$:	Time-dependent measured particle number concentration	[particle cm^{-3}]
G:	Total particle emission	[particle]
β:	Effective aerosol dilution rate	[h^{-1}]
V:	Test chamber volume	[m³]
$\dot{C}_{P\ Mess}(t)$:	Derivative of measured particle number concentration with respect to time	[particle $min^{-1}cm^{-3}$]

$C_{P\ meas}$ results from the addition of the particle number concentration of all measuring channels of a particle spectrometer, thus covers the number concentration in the entire range of size measurement for a particle spectrometer. The effective aerosol dilution rate β is in principle affected by 1) the constant air exchange in the chamber during printing and follow-up phase, 2) particle loss due to particle adsorption at the chamber wall, and 3) by particle agglomeration and other processes which can reduce the particle number concentration. Therefore β does not usually correspond to air exchange rate n, but deviates from it, sometimes quite substantially. However, β can be estimated from the time-dependent measured particle number concentration $C_{P\ meas}$, in as much as it is assumed that the particle number concentration decreases exponentially with the characteristic constant β after the end of a printing job, thus satisfies the following equation:

$$C_{P\ meas}(t) \propto e^{-\beta t}, \quad for\ t > t_{pr\ end}$$

Formula 5

The time derivative of the measured particle number concentration can be determined numerically from the measuring data. Thus all quantities can be determined from Formula 4. The total particle emission can be numerically calculated from the time integral of $C_{P\ meas}$:

$$G = \int_{pr\ start}^{pr\ end} SEP(t)\, d\, t$$

Formula 6

Analogous to the gravimetric method the total particle emission can be standardized for the printing process:

$G_{\Delta t}$:	Total particle emission / printing time	[Particle/min]

Size-resolved statements are also possible, i.e., the above measurands can also be referred to individual particle size classes or size ranges (ΔD: size range of particle diameter):

$SEP_{\Delta D}(t)$:	Time-dependent size-selective particle emission rate	[Particle min^{-1}]
$G_{\Delta D}$:	Size-selective total particle emission	[Particle]

Quality assurance

The particle spectrometers were calibrated by the manufacturers and the calibration was repeated within appropriate periods.

2.4 Ozone

A model 3010 ozone analyser of UPM was used to determine ozone concentration, shown in Figure 56 in the Appendix. The basis of the measurement method is the flameless reaction of ozone with ethylene accompanied with chemiluminescence which can be recorded photometrically. Ozone concentration is continuously determined. In addition to taking notes manually, data recording is performed by electronic data acquisition. Three working modes can be distinguished:

a) ’Zeroing’: ozone-free air enters the reactor. Chemiluminescence does not occur and zero point alignment can take place.
b) ’Calibrating’: an ozone generator is operated which produces an ozone concentration of 0.160 ppm at the reactor. The calibration point is adjusted to match.
c) ’Measurement’: after completing the two-point calibration the measurement procedure can start. A permanent measurement signal is produced. The output voltage values are recorded electronically (datalogger). A conversion factor between voltage, measurement range adjustment and standardisation curve in ppm values has to be considered here.

Measurement procedure

Ozone emission of printers and copiers was tested as follows:

a) Chamber blank valuation without any device tested
b) Determining the ozone concentration in the cold and pre-operating phase
c) Ozone determination during printing and copying

Ozone determination for printing or copying started immediately at the beginning of the printing job and continued up to the end of the follow-up phase. Concentration was recorded at least every 10 seconds. Ozone concentration was permanently recorded by an electronic datalogger. The ozone half-life was determined from the decay curve in the follow-up phase. An initial approximation shows the same conditions still prevail at this time as during the printing job.

Contrary to RAL-UZ 114, ozone half-life is not determined at RAL-UZ 122 at low ozone emission via injection of ozone into the test chamber after the follow-up phase. In these cases the ozone emission rate is calculated with the smallest ozone half-life ever measured in a test in a relevant test chamber.

Calculation of ozone emission rate

c_{max} and k´ are the crucial variables for the determination of ozone emission rate and they are closely connected. If the ozone half-life is small, the attainable maximum ozone concentrations are also small, compared with those with larger ozone half-life. A direct statement on ozone emission rate through the maximum ozone concentration is therefore not possible. Formulae 7 and 8 were used to calculate ozone emission rate taking account of ozone half-life:

$$\boxed{SER_u = \frac{c_{\max} * k' * V * p}{T * R}} \quad \text{Formula 7} \qquad \boxed{k' = \frac{\ln 2}{H'}} \quad \text{Formula 8}$$

SER_u:	Ozone emission rate	[µg $unit^{-1}$ h^{-1}]
c_{max}:	Maximum ozone concentration	[µg m^{-3}]
k':	Proportionality factor	[min^{-1}]
H':	Ozone half-life under test conditions	[min]
V:	Test chamber volume	[m^3]
p:	Air pressure	[Pa]
T:	Absolute temperature	[K]
R:	Gas constant (339.8 [Pa K^{-1}] for ozone)	[Pa K^{-1}]

Quality assurance

First of all human reading error in the measuring ranges had to be reduced to a minimum to ensure the quality of ozone determination. Different ranges can be selected for the determinations. Accordingly, measurement errors depend on the measurement range selected and are about 2 % of that range. A permanent recording of the measurement voltage values over two signal outputs (voltage signal/current signal) was used for data monitoring. Measurement range change-overs caused problems during evaluation, therefore they were recorded separately.

Detection limit (LOD) and determination limit (LOQ)

LOD and LOQ were estimated by considering measurement inaccuracy indicated by the manufacturer of the ozone analyser using a measurement under standard conditions.

Table 4 shows LOD and LOQ of the ozone measurement.

Table 4: Detection limit and determination limit for ozone measurement

Test chamber	Ozone emission rate [mg / h]	
	LOD [mg / h]	LOQ [mg / h]
Type A and B 1-m³ chambers	0.006	0.018
20-m³ chamber	0.033	0.099

2.5 VOC

VOC sampling from the test chamber air took place as per DIN ISO 16000-6. The air sample was drawn through a glass tube filled with Tenax TA [178 mm tube length, OD 6 mm, ID 4 mm, 200 mg Tenax TA (60 - 80 mesh) secured with glass frit and glass wool stuffing / wire net on the side towards the pump]. Before sampling, the Tenax tubes were spiked using cyclodecane as an internal standard diluted in methanol (1 µl). The sample volume was between 2 and 9 litres. The sampling flow rate amounted to 100 or 50 ml/min.

TDS was performed in a TDS system (Gerstel TDS-3) coupled with a cold feed system (Gerstel KAS-4) to cryofocus the thermodesorbed analytes. The temperature programme of the thermodesorption unit began at 40 °C with a heating rate of 40°C/minute up to 290°C. The final temperature of 290 °C was held for 5 minutes. Cryofocusing in the cold feed system occurred at -100 °C, subsequent heating was carried out with a heating rate of 12°C/s up to 290°C.

Separation of the analytes extracted from the cold feed system was performed gaschromatographically (HP GC 6890 N) by means of a 30-m column (HP-5 MS, 0.25 mm diameter, 1 µm layer thickness) or a 60-m column (HP1-MS, 0.25 mm diameter, 0.25 µm layer thickness). The GC / MS system is illustrated in Figure 61 in the Appendix.

The identification and quantification was performed using a quadruple mass spectrometer as a detector (HP-MSD 5973). The scan range lay at 25 - 400 amu with 3.85 scans per sec at an interface temperature of 300°C. For substance identification the mass spectrum library NIST-02 was available. Using this procedure, semivolatile compounds up to hexacosane can be quantitatively verified (C_{26} alkane, boiling point approx. 413°C).

Calculation of VOC emission rate for the pre-operating phase

All substances whose retention time was between n-hexane and n-hexadecane were identified as far as possible and individually quantified using the relative response factors determined from an internal standard calibration. If it was not possible to identify certain substances or determine their relative response factor, the quantification was performed on the assumption of the response factor of toluene.

The emission rate during the pre-operating phase was calculated with the concentration from the sampling of the last twenty minutes of the one-hour pre-operating phase using Formula 9.

$$\boxed{SER_u = c * n * V}$$ Formula 9

$$\boxed{c = \frac{m_{VOC}}{V_P}}$$ Formula 10

c:	VOC concentration during cold and pre-operating phase	[µg m^{-3}]
SER_u:	VOC emission rate during cold and pre-operating phase	[µg h^{-1}]
m_{VOC}:	Analysed mass of VOC during cold and pre-operating phase	[µg]
n:	Air exchange rate during cold and pre-operating phase	[h^{-1}]
V:	Test chamber volume	[m^3]
V_S:	Sample volume during cold and pre-operating phase	[m^3]

Calculation of VOC emission rate for the printing phase

The emission rate during the printing phase was calculated as per RAL-UZ 114 or RAL-UZ 122

a) RAL-UZ 114: Using the continuous sample from the start of the printing phase to the end of the follow-up phase

$$\boxed{SER_{u_{DN}} = \frac{m_{VOC_{DN}} * n_{DN} * V * t_G}{t_D * V_P}}$$

Formula 11

$SER_{U\,DN}$:	VOC emission rate determined from printing and follow-up phase	[µg h^{-1}]
$m_{VOC_{DN}}$:	Analysed mass of VOC during printing and follow-up phase	[µg]
n_{DN} :	Air exchange rate during printing and follow-up phase	[h^{-1}]
t_D :	Net printing or copying time	[min]
t_G :	Total sampling time	[min]
V:	Test chamber volume	[m³]
V_P:	Sample volume during printing and follow-up phase	[m³]

b) RAL-UZ 122: The emission rate during the printing phase can be calculated using the sampling concentration from the start of the printing phase to the time when a simple air exchange rate is carried out in the follow-up phase, using the following formula:

$$SER_{DN} = \frac{\frac{m_{VOC_{DN}}}{V_P} * n_{DN}{}^2 * V * t_G - SER_B * n_{DN} * t_G}{n_{DN} * t_D - e^{-n_{DN}*(t_G - t_D)} + e^{-n_{DN}*t_G}}$$

Formel 12

SER_{DN} :	VOC emission rate determined from printing and follow-up phase	[µg h^{-1}]
SER_B :	VOC emission rate determined from pre-operating phase	[µg h^{-1}]
$m_{VOC_{DN}}$:	Analysed mass of VOC during printing and follow-up phase	[µg]
n_{DN} :	Air exchange rate during printing and follow-up phase	[h^{-1}]
t_D :	Net printing or copying time	[h]
t_G :	Total sampling time	[h]
V:	Test chamber volume	[m³]
V_P:	Sample volume during printing and follow-up phase	[m³]

Quality assurance

Quality assurance of sampling was performed by regular testing of the flow rate of the pumps used for the sampling. This was measured with the aid of a calibrated electronic flow meter (HP) after charging the pump batteries and adjusted to 100 ± 1 ml/min.

In addition to regular multi-point calibrations of the compounds to be analysed, quality assurance of the analytical instrument (GC MS) was performed by regularly measuring a standard solution and by adding the same amount of the internal standard on Tenax before sampling. Deviations in the quantification of the standard solution or the peak of the internal standard from the standard value indicated malfunction or changes in the instrument's operation.

To be able to perform an exact quantification, a blank evaluation was carried out on an empty chamber before placing the device inside to guarantee that the substances found were in fact emitted from the material tested (see Figure 4). However, this blank value not only includes possible impurities from the test chamber but in particular impurities from the Tenax tube and the GC MS device. Typical substances, which can also come from the Tenax tube, are e.g. benzaldehyde, acetophenone, hexamethyl cyclotrisiloxane and octamethyl cyclotetrasiloxane (use of silanised glass wool stuffing for Tenax or in the liner of the injector). The Tenax tubes were therefore stored no longer than 72 h before sampling, otherwise a new 15-minute cleaning heating was performed in a nitrogen flow at 280°C.

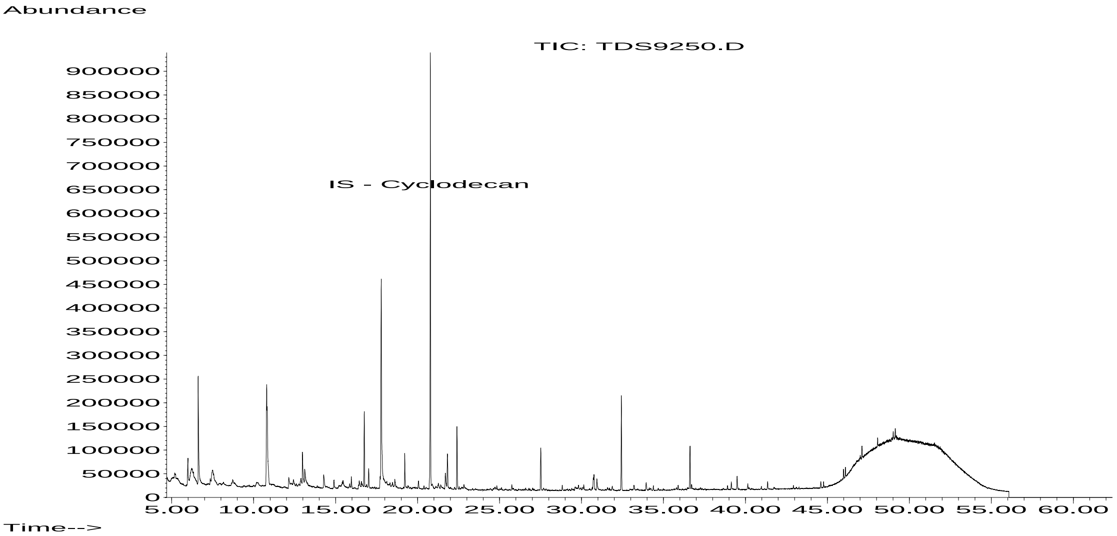


Figure 4: Chromatogram of a sample on an empty chamber (sampling volume 2 L, internal standard cyclodecane, 20 ng)

The laboratory regularly participates in and organizes co-operative tests to enhance quality assurance for the total procedure (test chamber method, sampling and TDS/GC-MS analysis).

Detection limit (LOD) and determination limit (LOQ) for the printing and follow-up phase

Detection and determination limits depend primarily on the sample volume. The sample volume is 2.7 and/or 5.4 litres when sampling is performed in a 1-m³ chamber with an air exchange rate of 4 per hour (at 12 min printing time and 15 min for an air exchange in the post-operating phase; flow rate 100 and/or 200 ml/min).

Generally 1 ng of a VOC can be safely detected by GC/MS in scan modus. Detection and determination limits for single VOCs displayed in Table 5 were obtained from these tests for the emission rates.

Table 5: Detection and determination limits of individual VOC tests

Test chamber	**SER_{VOC}**	**VOC emission rate [mg / h]**	
		LOD [mg / h]	**LOQ [mg / h]**
1-m³ chamber	SER_{PrF} RAL-UZ 122	0.002	0.006
	SER_{PrF} RAL-UZ 114	0.002	0.006
20-m³ chamber	SER_{PrF} RAL-UZ 122	0.025	0.075
	SER_{PrF} RAL-UZ 114	0.013	0.039

3 Procedure

3.1 Devices and expendable material

BAM purchased 8 devices from 6 different manufacturers for the tests, and, in addition, four manufacturers provided further devices. Altogether devices from 8 manufacturers were tested.

Original toners were used for all investigations, some of them from different batches. Desk Top X'tensa paper (manufacturer: IGEPA, distribution: Roy Schulz GmbH) was used.

3.2 Tests performed

All devices were tested for their VOC, dust and ozone emissions. Most of them were tested several times, sometimes under different conditions. For a number of devices additionally particle measurements were carried out.

3.2.1 Test procedure

3.2.1.1 Chamber characterisation and blank evaluation before each test

- Determination of the chamber blank values for VOC, dust and ozone
- Adjustment and determination of the air exchange rate of the chamber as per DIN EN 717-1 (2005) in an empty state
- Determination of the ozone half-life as a quality criterion of the empty chamber with an air exchange rate of 1/h.

3.2.1.2 Preparation of the hardcopy devices for the tests

- General control of the operational capability of the hardcopy devices after delivery
- Execution of printing tests
- Determination of the maximum printing time (black-and-white and coloured)
- Determination of contrast and colour value (L*, A*, b*) of a print
- Control of the collated output paper tray (possible use of an additional paper tray made of inert material, the intake capacities of the paper cartridges and paper stackers had to be considered)

3.2.1.3 Conditioning and pre-operating phase (RAL-UZ 122)

The conditioning phase started the day before the emission measurement with the loading of the chamber. The pre-operating phase was started on the next day and lasted an hour. The conditioning phase was defined as "power switched on, but mains plug not attached to the current supply", in order to be able to start the hardcopy device by simply plugging it in from the outside without opening the chamber in the subsequent pre-operating phase.

At the beginning of the pre-operating phase the hardcopy device was attached to the current supply by plugging in the mains plug. Manufacturer’s settings of the hardcopy device were not changed for the pre-operating phase.

Climate recording started with the loading of the chamber and continued continuously until the end of the follow-up phase. The air exchange rate was adjusted to $n = 1\ h^{-1}$ in all chambers during the conditioning and pre-operating phase.

In the last 20 minutes of the pre-operating phase the VOC sampling was performed using Tenax. Simultaneously a sampling for VVOCs and benzene took place by means of Carbotrap.

3.2.1.4 Printing and follow-up phase (RAL UZ 122)

The printing phase took at least 10 minutes. The immediately succeeding follow-up phase served for the extensive determination of the emitted substances beyond the actual printing process.

The follow-up phase included four air exchanges and took about four hours for the 20-m³ chamber and about one hour in the 1-m³ chambers.

The VOC sampling using Tenax was started at the beginning of printing and was stopped after one air exchange in the follow-up phase. Simultaneous a sampling of VVOCs and benzene took place using Carbotrap.

The ozone determination also started at the beginning of the printing job and was continued until the completion of the follow-up phase. The ozone half-life needed for the calculation of ozone emission rate was determined from the decay curve in the follow-up phase when sufficiently high concentrations were available. At low ozone emissions the shortest half-life measured in the relevant chamber was used for the calculation of the ozone emission rate.

Dust measurement also started at the beginning of the print job and was also continued up to the completion of the follow-up phase.

3.2.1.5 Concluding work

- Device and paper removal
- Chamber cleaning
- Preparation for the next test
- Evaluation of the test results

4 Results of the emission measurements

4.1 General information

The preliminary investigations served as a systematic evaluation of the results from the emission measurements carried out so far according to RAL-UZ 62, 85 and 114.

The main investigations served to further develop the existing test method, especially the requirements for colour printers which were to be derived from them.

4.2 Preliminary investigations

Test results available from other projects were tested systematically according to the test parameters TVOC, benzene, styrene, ozone and dust as well as the most frequent VOCs. For this purpose it was distinguished between pre-operating phase and printing phase as well as freestanding and desktop devices. The study was divided into tests in pre-operating phase and printing phase as well as those on freestanding and desktop devices.

57 different devices from 8 different manufacturers were tested, including printers, copiers and multi-function devices. The devices provided by the manufacturers were either from the current series of production or were prototypes.

30 of the tested devices were desktop devices, five of them colour ink jet and 25 electrophotographic (mainly monochromatic and 4 colour) devices. The desktop devices were all tested in a 1-m^3 chamber. The so-called freestanding devices (27 of them, all electrophotographic: 23 monochromatic and 4 colour) were tested in a 20-m^3 chamber because of their size.

4.2.1 VOC

Figure 5 shows the TVOC emission rates for the 30 tested desktop devices. The top diagram illustrates the results of the measurements in the pre-operating phase, the bottom one those of the printing phase. The individual devices exhibit large differences. The TVOC emission rates from the printing phase are always greater than those in the pre-operating phase.

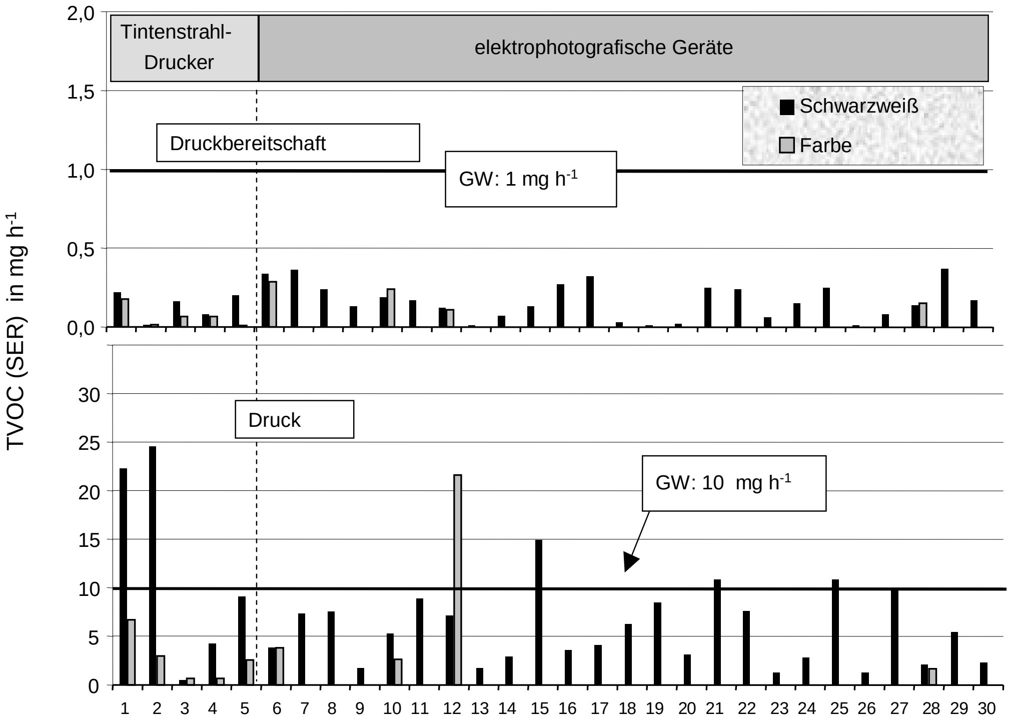


Figure 5: TVOC emission rates for 30 different desktop devices,
top: device in pre-operating phase
bottom: device in printing phase

Tintenstrahldrucker	Ink jet printer
elektrophotographische Geräte	Electrophotographic devices
Druckbereitschaft	Pre-operating phase
GW	Limiting value
Schwarzweiß	Black-and-white
Farbe	Colour
Druck	Printing

Figure 6 shows a similar picture for the TVOC emission rates for larger freestanding devices, whereas the emission rates are clearly higher both in the pre-operating and in the printing phase than those for desktop devices.

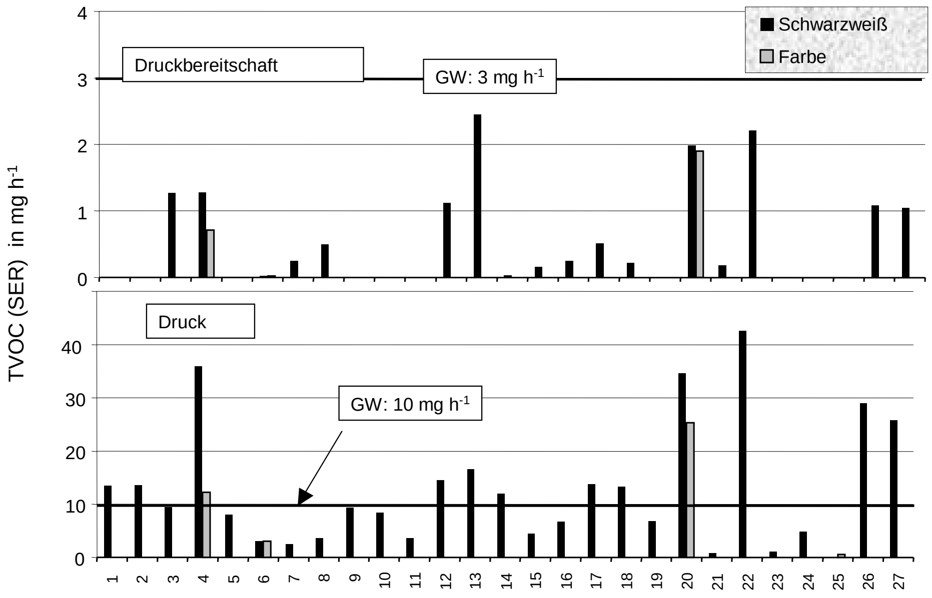


Figure 6: TVOC emission rates for 30 different freestanding devices,
top: device in pre-operating phase
bottom: device in printing phase

Druckbereitschaft	Pre-operating phase
GW	Limiting value
Schwarzweiß	Black-and-white
Farbe	Colour
Druck	Printing

The higher TVOC emissions from the freestanding devices in the pre-operating phase can be explained by the larger equipment mass and specific surface of the devices. It is nor surprising that the equipment's materials produce VOC emissions since the different materials and products which are used indoors, e.g. floor coverings, insulating materials, sealing compounds, paints, adhesives, lacquers, furniture, cleaning agents and also electronic devices nearly always exhibit VOC emissions.

It has to be considered for the TVOC emission rates during the printing process in freestanding devices that a calculation using formula 11 yields larger emission rates for devices with higher pre-operating emissions, than it is actually the case. This is caused by the relatively long follow-up phase for freestanding devices (4 hours, see test procedure). These circumstances are considered in a new calculation formula

(Equation 12, Section 2.5) in the assignment principles for the new environmental label RAL-UZ 122.

Since the TVOC value enables an interesting comparison of the devices regarding their summary VOC emissions, but only provides a very limited deduction for potential health effects, it is reasonable to have a closer look at the individual VOCs which are released by the devices. 59 different volatile organic compounds were clearly identified and quantified individually in the investigations presented. Some of them e.g. isopropanol can be attributed to the VVOC (Very Volatile Organic Compounds).

The most frequent VOCs found at higher concentrations are shown in Figure 7 for the pre-operating phase and in Figure 8 for the printing process. The emission rates for the individual VOCs (in mg h^{-1}) are indicated on the left ordinate, the resulting average air concentrations of the room calculated for a model room are shown on the right ordinate. For the model room based on ISO 16000-9 a volume of 17.4 m³ and an air exchange rate of 0.5 h^{-1} was specified.

The conversion of emission rates to room air concentrations was performed using Equation 13, whereby different utilization factors were assumed for the pre-operating process (100 %: F=1) and the printing process (10 %: F = 0.1).

$$C_R = SER * n_R^{-1} * V_R^{-1} * F * 1000\ \mu g/mg \qquad \text{Formula 13}$$

C_R: concentration in the model room [µg/m³]

SER: specific emission rate

N_R: air exchange rate in the model room [h^{-1}]

V_R: volume of the model room [m³]

F: utilization factor

$F=1$ for pre-operating (assumed pre-operating over the whole day)

$F=0.1$ for printing process (assuming that the printer is used for a maximum of 10 % of the working day)

Each substance column shows the results for desktop devices tested in the 1-m³ chamber on the left and those for freestanding devices, measured in the 20-m³ chamber, on the right.

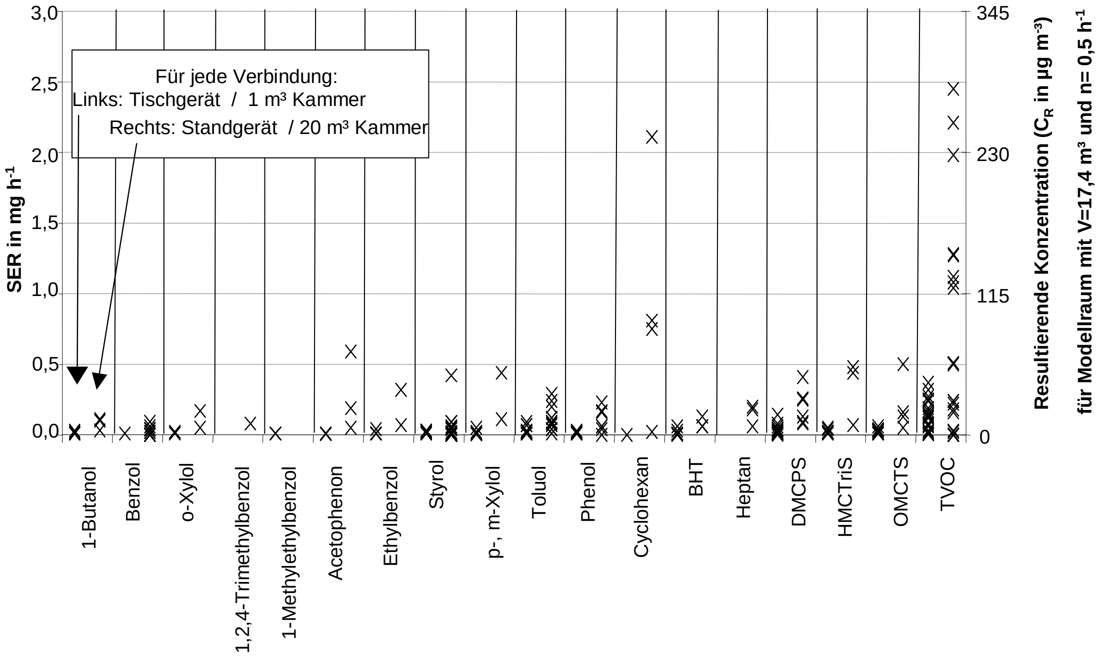


Figure 7: Frequent VOCs in pre-operating phase
(BHT: butylhydroxy toluene, DMCPS: decamethyl cyclopentasiloxane (D5),
HMCTriS: hexamethyl cylotrisiloxane (D3),
OMCTS: octamethyl cyclotetrasiloxane (D4))

Für jede Verbindung	For each compound
Links: Tischgerät / 1 m³ Kammer	Left: desktop device, 1-m³ chamber
Rechts: Standgerät / 20 m³ Kammer	Right: freestanding device, 20-m³ chamber
Benzol	Benzene
o-Xylol	o-xylene
1,2,4-Trimethylbenzol	1,2,4-trimethyl benzene
1-Methylethylbenzol	1-methylethyl benzene
Acetophenon	Acetophenone
Ethylbenzol	Ethylbenzene
Styrol	Styrene
p-, m-Xylol	p-, m-xylene
Toluol	Toluene
Cyclohexan	Cyclohexane
Heptan	Heptane
Resultierende Konzentration (C_R in µg m^{-3}) für Modellraum mit V=17,4 m^3 und n=0,5 h^{-1}	Resulting concentration (C_R in µg m^{-3}) for a model room with V=17.4 m^3 and n=0.5 h^{-1}

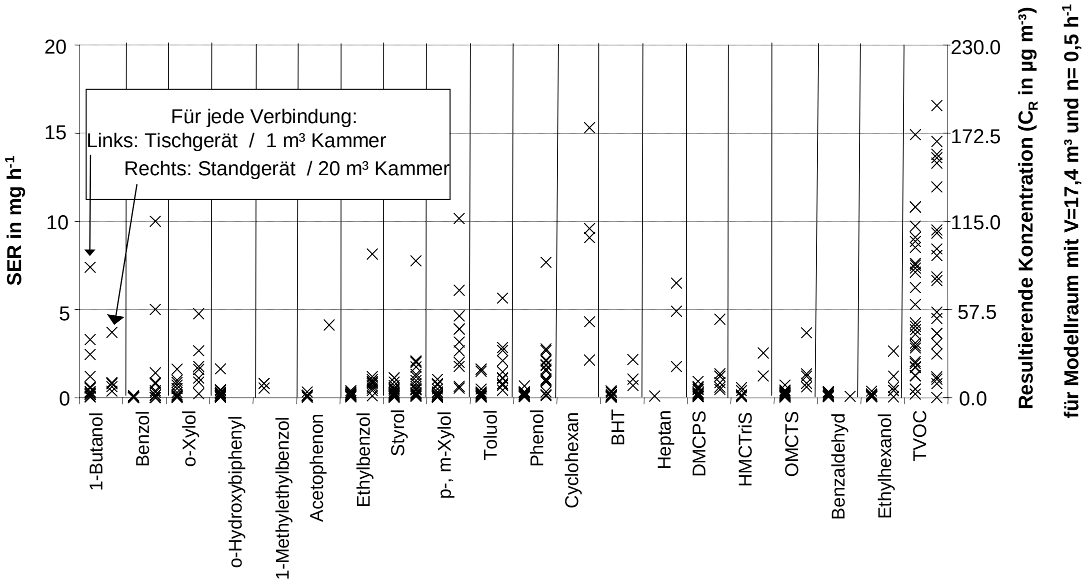


Figure 8: Frequent VOCs from the printing phase
(BHT: butylhydroxy toluene, DMCPS: decamethyl cyclopentasiloxane (D5),
HMCTriS: hexamethyl cyclotrisiloxane (D3),
OMCTS: octamethyl cyclotetrasiloxane (D4))

Für jede Verbindung:	For each compound:
Links: Tischgerät / 1 m³ Kammer	Left: desktop device, 1-m³ chamber
Rechts: Standgerät / 20 m³ Kammer	Right: freestanding device, 20-m³ chamber
Benzol	Benzene
o-Xylol	o-xylene
1,2,4-Trimethylbenzol	1,2,4-trimethyl benzene
1-Methylethylbenzol	1-methylethyl benzene
Acetophenon	Acetophenone
Ethylbenzol	Ethylbenzene
Styrol	Styrene
p-, m-Xylol	p-, m-xylene
Toluol	Toluene
Cyclohexan	Cyclohexane
Heptan	Heptane
Resultierende Konzentration (C_R in µg m^{-3}) für Modellraum mit V=17,4 m^3 und n=0,5 h^{-1}	Resulting concentration (C_R in µg m^{-3}) for a model room with V=17.4 m^3 and n=0.5 h^{-1}

It is conspicuous that there are only relatively small qualitative differences between the VOC emission in the pre-operating phase (Figure 7) and the printing process (Figure 8). The VOCs found in the printing process are nearly always detected (in smaller quantities) in the pre-operating phase. This indicates that VOC emissions come from the toner and the paper, but to a more substantial part, originate from the device materials which may also exhibit high temperatures (locally max. 180 °C in the fixing area). Additional VOCs emitted in the printing process in considerable concentrations are o-hydroxybiphenyl (main source paper), as well as benzaldehyde and ethylhexanol.

Regarding the concentrations resulting for the room air (right ordinate) it can be noted that only small concentrations (< 50 µg/m³) can be expected in the pre-operating phase for most VOC in most devices (Figure 7). Concentrations of up to some 100 µg/m³ of TVOC and cyclohexane were only detected in a few cases, in particular for larger devices. However, it has to be considered that these large devices are either used mainly in larger rooms or in rooms in which people do not usually stay over longer periods of time.

Similar deductions can be drawn for the printing process. The expected room air concentrations are predominantly markedly below 100 µg/m³, higher values were only detected for some larger devices, in particular for cyclohexane and TVOC.

In addition to the well-known VOCs such as styrene, xylenes, ethylbenzene and C3 benzenes, which are well known and regarded as "typical" for printers and copiers, the frequently occurring siloxanes (HMCTriS (D3), OMCTS (D4), DMCPS (D5)) are conspicuous.

In a few cases significant benzene emissions detected are particularly critical concerning health aspects.

In addition to the compounds mentioned so far, a few more should be mentioned which arise less frequently and/or only at low concentrations:

1,2-propanediol, hexanal, isopropyl alcohol, 1-propanol 2,2-dimethyl, nonanal, tri- and tetradecane, isothiocyano cyclohexane and pentamethyl heptane.

Formaldehyde and acetaldehyde has to be mentioned as frequently occurring aldehydes which were determined by means of the HPLC/DNPH method per ISO 16000 3 (ISO 2001). In this case the paper used also might have had a substantial contribution.

4.2.2 Ozone

Most desktop devices failed to produce ozone emissions (Figure 9, top). However, substantial ozone emissions were detected in some of the freestanding devices (Figure 9, bottom).

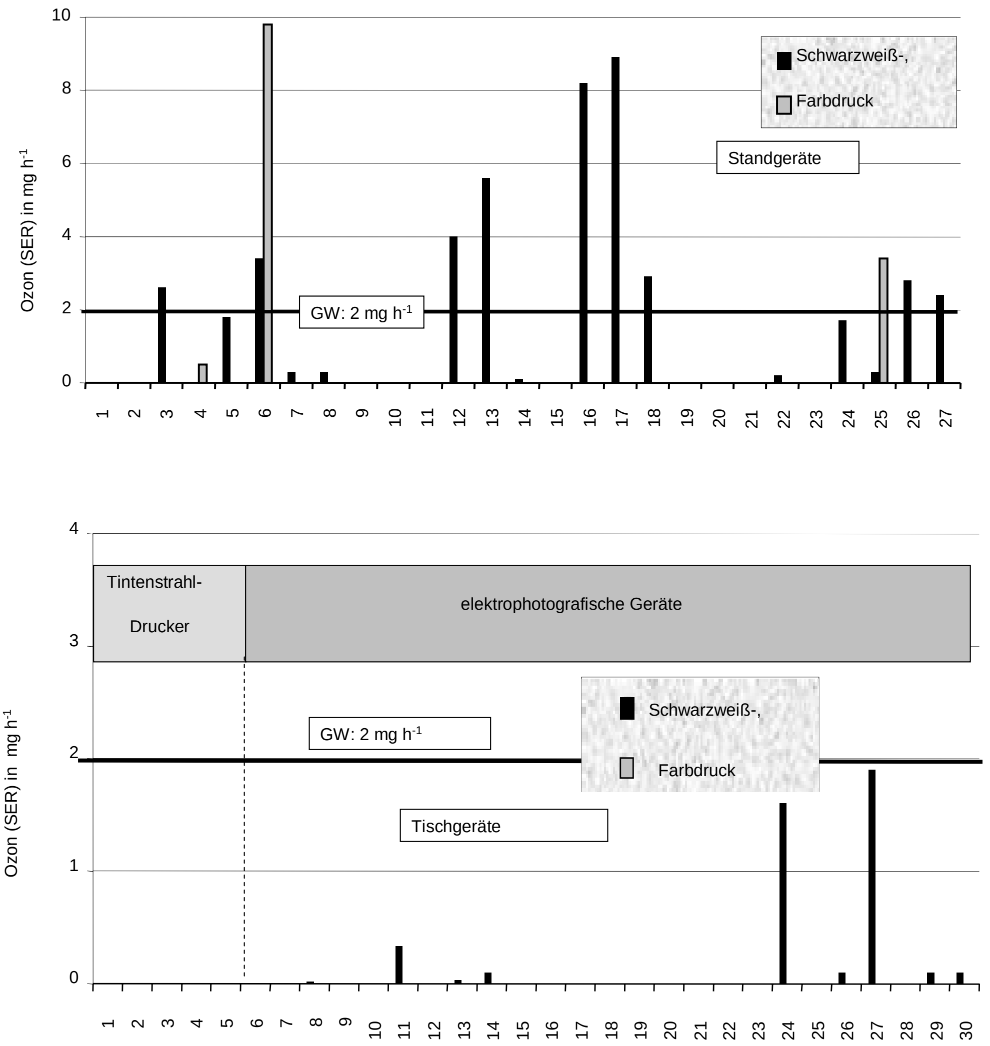
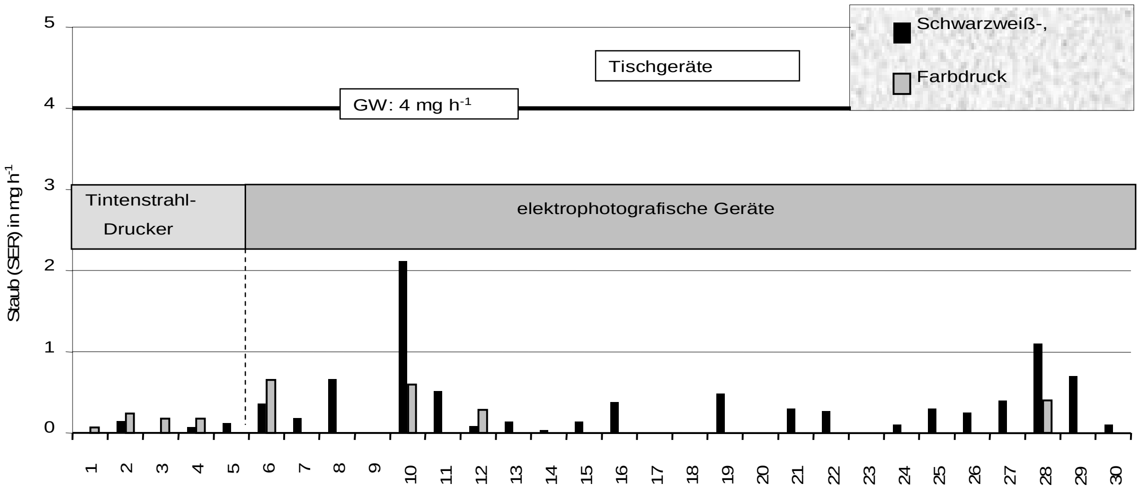


Figure 9: Ozone emission rates
top: for 30 different **desktop devices**
bottom: for 27 different **freestanding devices**

Ozon	Ozone
Tintenstrahldrucker	Ink jet printer
elektrophotographische Gerät	Electrophotographic devices
GW	Limiting value
Schwarzweiß-	Black-and-white
Farbdruck	Colour print
Tischgeräte	Desktop devices
Standgeräte	Freestanding devices

3.3 Dust

The dust emissions determined by means of a gravimetric method were usually very low, both for desktop devices (Figure 10, top) and for freestanding devices (Figure 10, bottom).



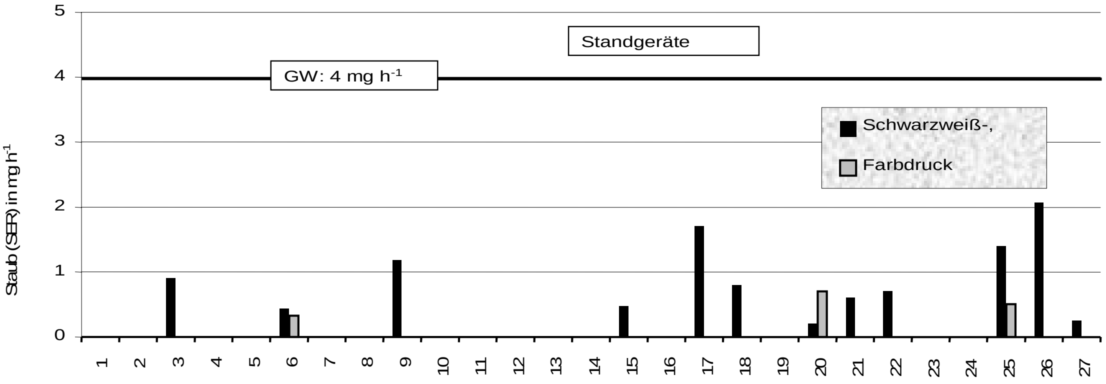


Figure 10: Dust emission rates
top: for 30 different **desktop devices**
bottom: for 27 different **freestanding devices**

Staub	Dust
Tintenstrahldrucker	Ink jet printer
elektrophotographische Gerät	Electrophotographic devices
GW	Limiting value
Schwarzweiß-	Black-and-white
Farbdruck	Colour print
Tischgeräte	Desktop devices
Standgeräte	Freestanding devices

4.3 Main investigations

4.3.1 Investigations into emissions of colour printing

To obtain an overview of the type and the quantity of the emissions from the colour printer, a set of devices from different manufacturers were tested in monochromatic and colour print phase. The emission measurements were performed according to RAL-UZ 114. A printer pattern with 5% coverage was used for the toner colours black, magenta, yellow and cyan (see Appendix).

The results for the TVOC emissions are illustrated in Figure 11. It was shown that there are very different TVOC emission rates for colour printing compared to monochromatic printing. The range spread from a fivefold increase of the emission rate to a decrease in the emission rate.

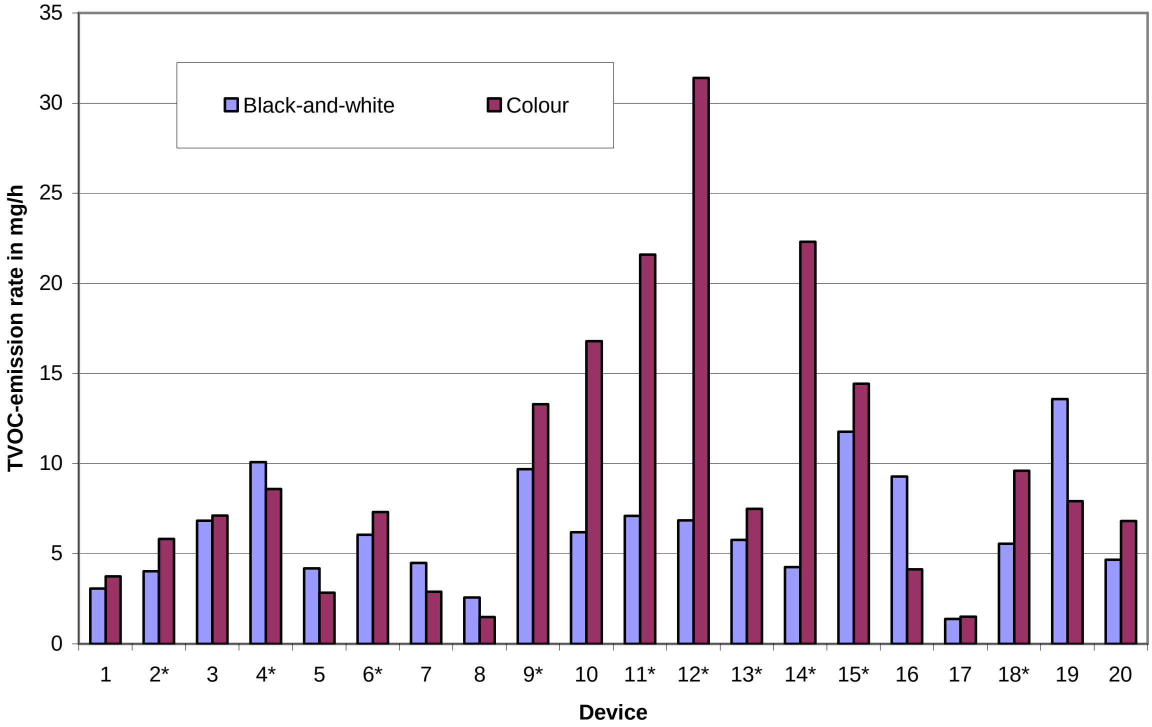
Since the contribution of the black toner should actually be the same for both printing modes, a decrease can only be explained by the machine creating black by mixing the three primary colours. This was confirmed by optical tests and toner consumption measurements.

Although the 20% coverage is four times higher in the colour print, only small differences in the TVOC emission rates could be detected which indicates a very low VOC input from some colour toners.

However, there are also devices which show a proportional increase with the degree of coverage for colour printing.

Figure 12 shows the ozone emission rates of the tested devices. In four of the 20 devices an ozone emission rate of 0.5 mg/h or above was detected. The highest emissions were observed during colour printing.

Figure 13 shows the dust emission rates. The values are all markedly below the limiting value for Blue Angel which is 4 mg/h. Nine of the 20 devices exhibited a dust emission of 0.4 mg/h or less, in some cases no dust at all was detected.



* same printing rate for colour and monochromatic printing

Figure 11: Emission rates of colour printers (TVOC)

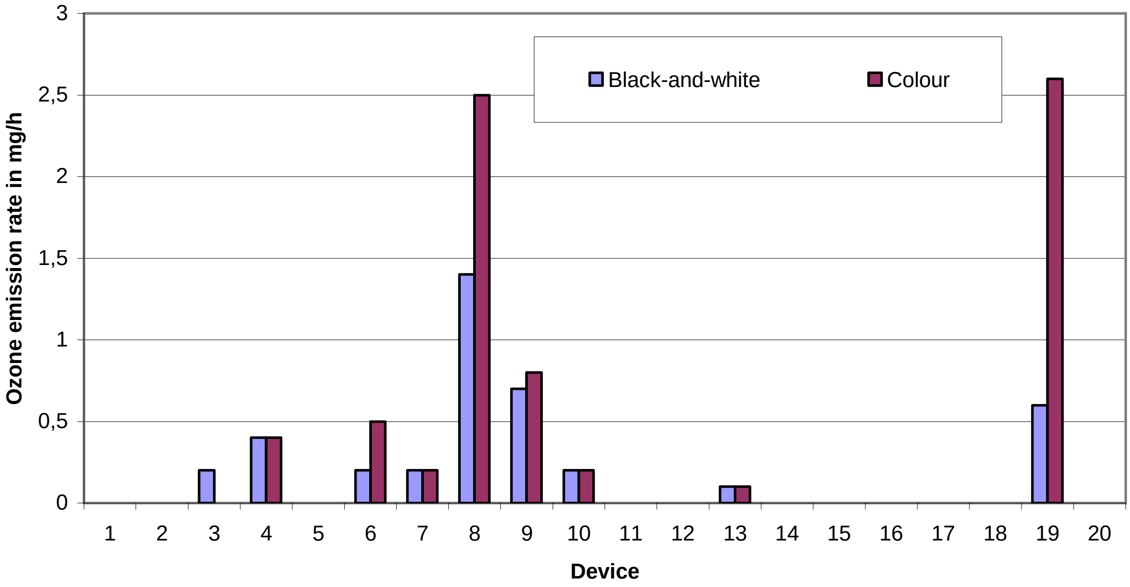


Figure 12: Ozone emission rates of colour printers

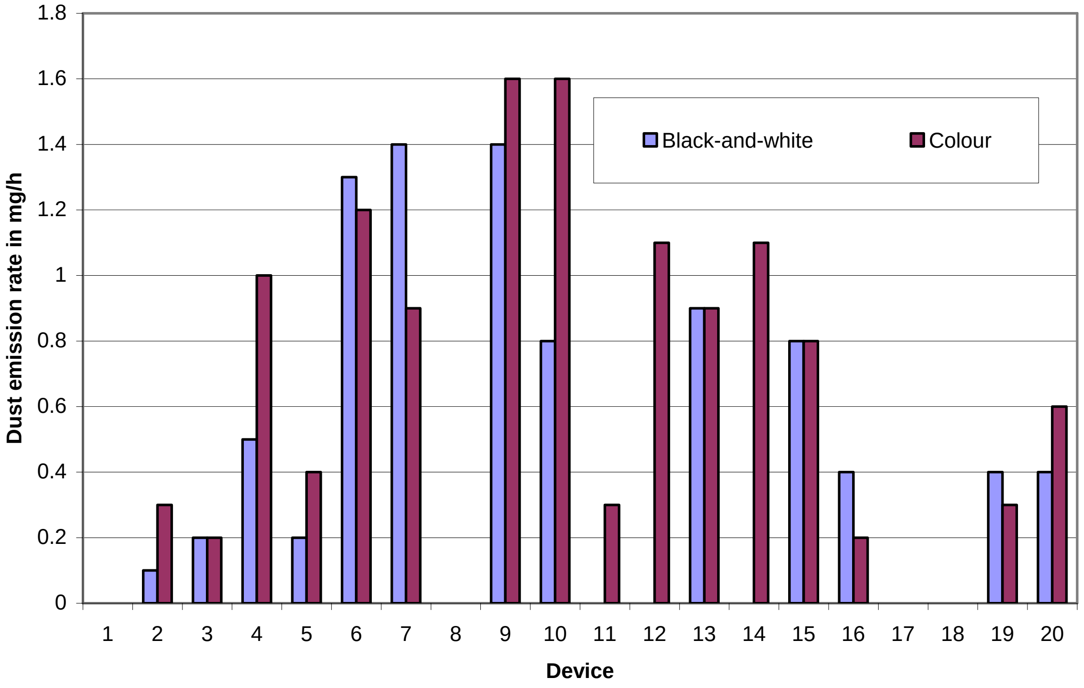


Figure 13: Dust emission rates of colour printers

4.3.2 Ageing tests of the specimens

Ageing tests were carried out on a device that was replaced in its original packaging after each test and on two devices that were used daily after the first test.

Figure 14 additionally shows a comparison between the TVOC emission rate according to UZ 114 (old) and UZ 122 (new). The calculation according to UZ 114 yields a much greater reduction for the emission rate in the printing phase than the calculation as per UZ 122. This is caused by a reduction of the emission rate in the pre-operating phase. Since the emission rate of the pre-operating phase is deducted in the calculation of the TVOC emission rate per UZ 122 (see formula 12), the emission rate of the printing phase clearly shows a more stable level. The reduction is approx. 25 % over 13 months, while the TVOC emission rate calculated as per UZ 114 decreases in the same period by more than 50%.

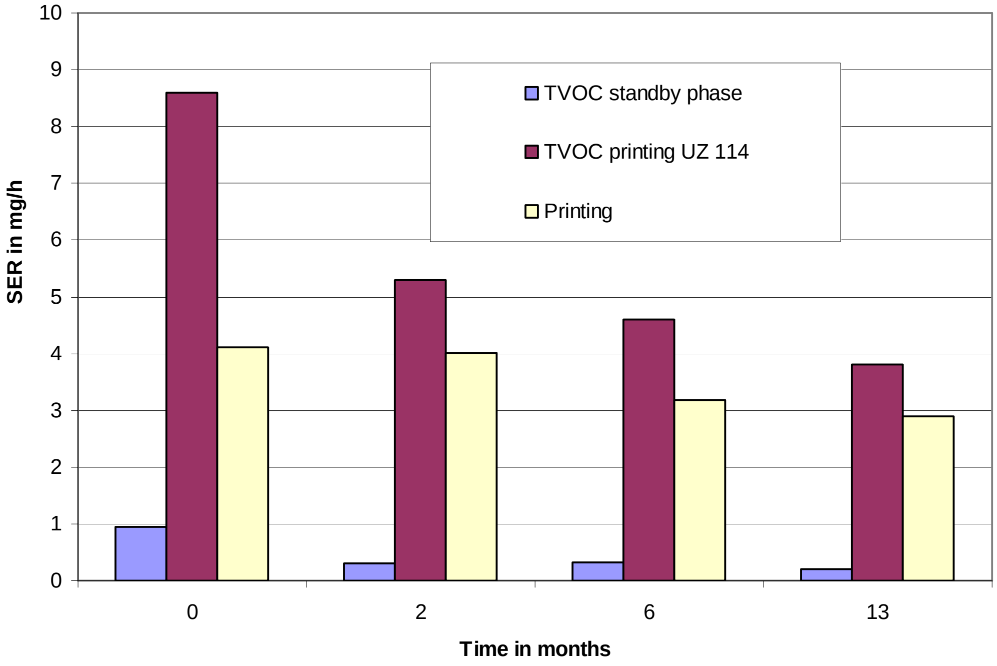


Figure 14: Ageing of a printer

While the stored device shows little ageing within 2 months (Figure 14, TVOC printing UZ 122), the VOC emissions clearly decreased in the devices used daily over 2 months. This ageing is shown in Figure 15 and Figure 16 .

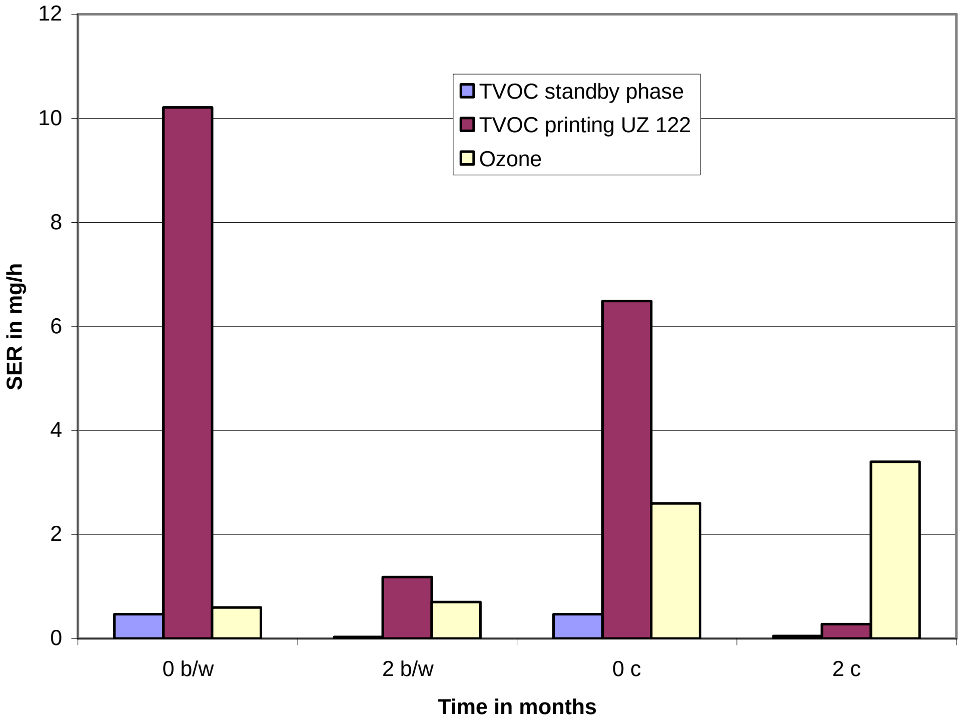


Figure 15: Ageing of a printer in daily use for monochromatic (b/w) and colour printing (c)

Although the TVOC emission rate in Figure 15 has been calculated as per RAL-UZ 122, i.e. the influence of the pre-operating phase is minimized, both monochromatic printing (b/w) and colour printing (c) exhibits almost a 90% reduction of VOC emission, however, aging of the device hardly affects ozone emission.

Figure 16 shows a reduction of VOC emissions by approx. 50% for another device used daily.

A stronger reduction of VOC emissions by daily use is in particular due to ageing of the components which are heated up in the printing process, since the toner cartridges were not replaced and the reduction of the TVOC values were already accounted for in the pre-operating phase.
The TVOC emission profiles in the pre-operating phase are displayed in Figure 27.

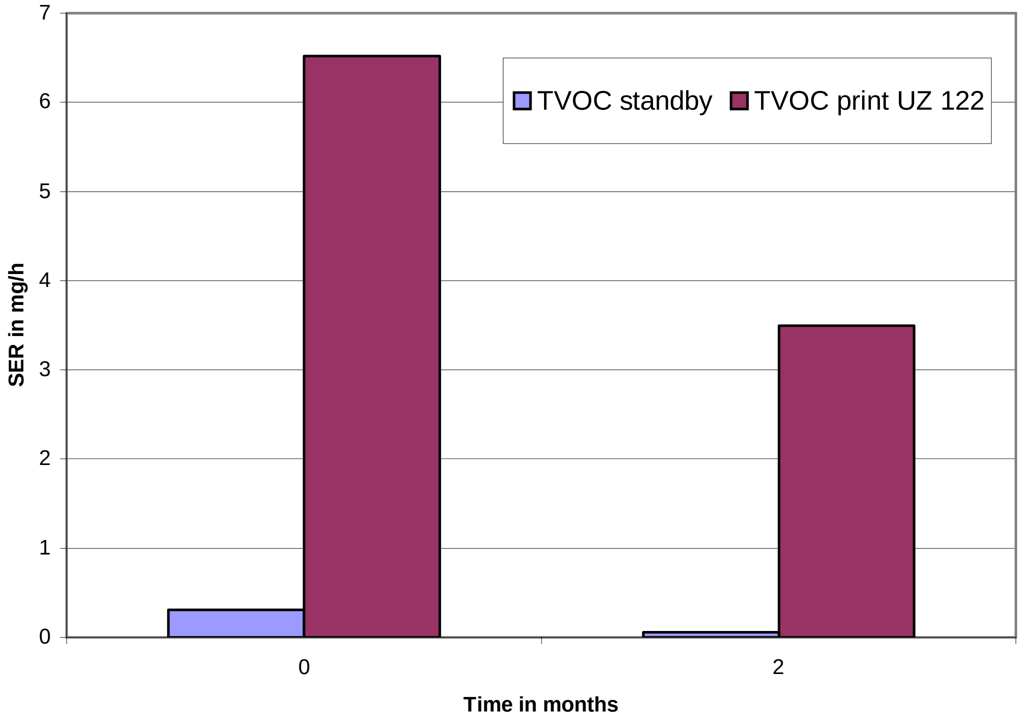


Figure 16: Ageing of a printer in daily use (2)

4.3.3 Reproducibility tests

The objective of this part of the investigation was to see to what extent the test results for devices of the same design agreed. For this purpose three test series on each of three devices from two manufacturers were performed.

The results of the first test series (Figure 17) showed a standard deviation of 14 % for TVOC and 16 % for ozone.

The results of the second test series (Figure 18) provided a standard deviation of 39 % of TVOC for monochromatic printing and 44 % of TVOC for colour printing.

The results of the third test series (Figure 19) showed a standard deviation of 7 % for TVOC and 9 % for ozone. In contrast to the first and second test series, toner cartridges from the same batch were used here.

In Figure 20 the test results of the third series for benzene, styrene and dust are represented. While a good agreement was found for benzene and styrene, the standard deviation for dust was about 45 %.

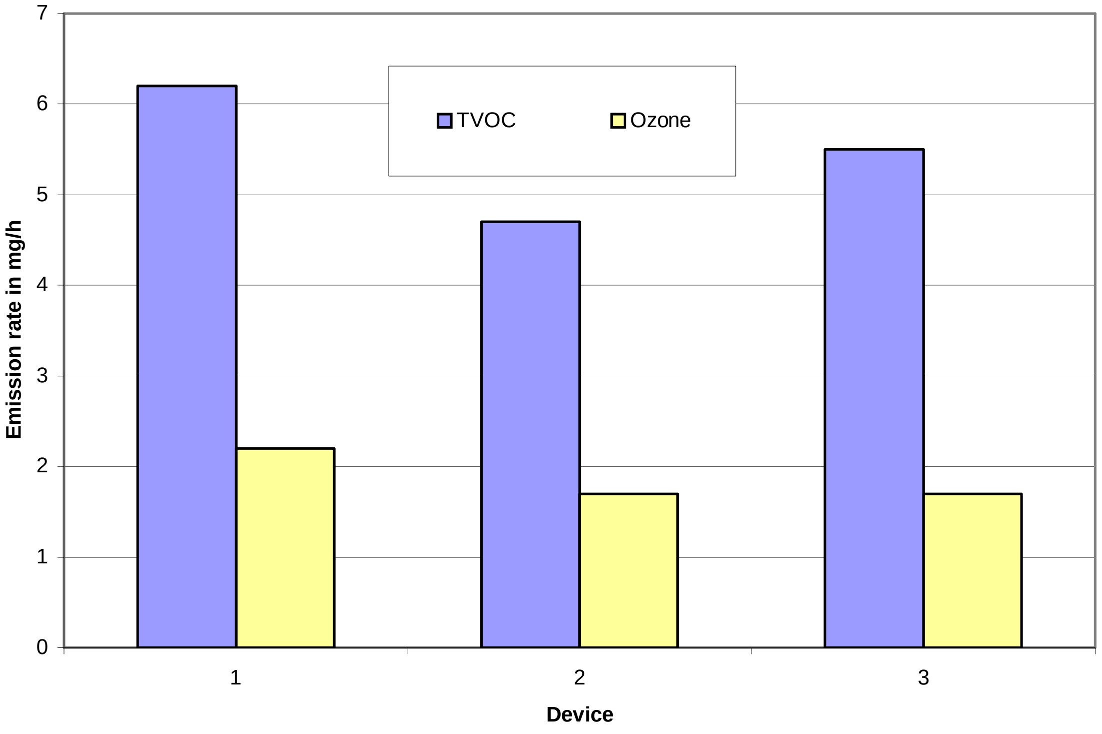


Figure 17: Test results for devices of the same design (new devices, toners from different batches)

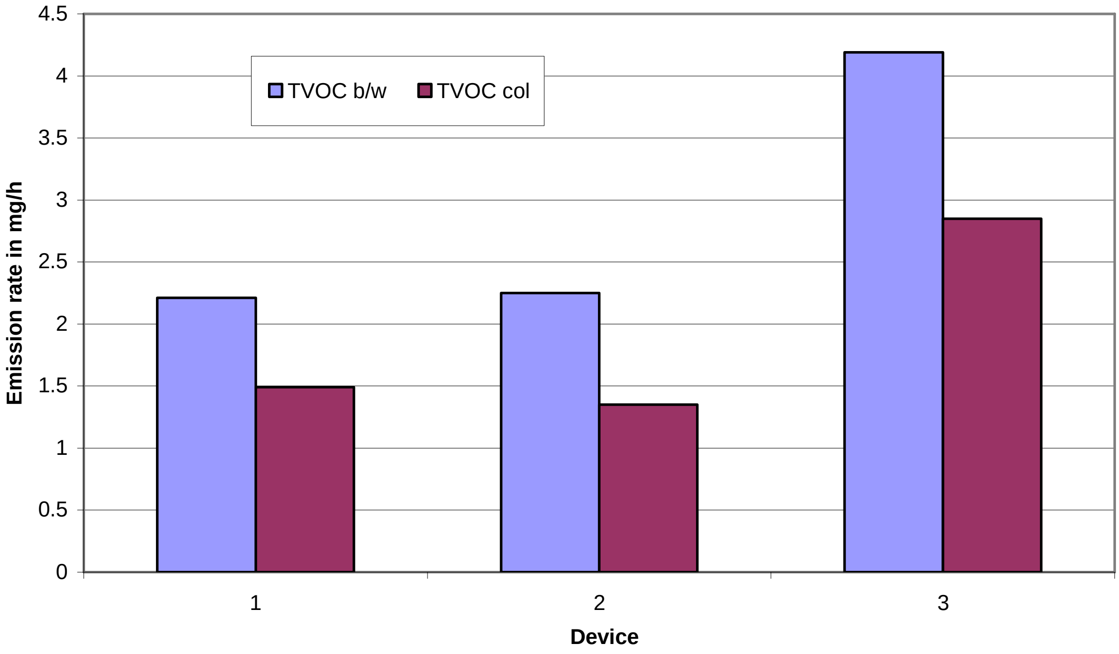


Figure 18: Test results for devices of the same design (new devices, toners from different batches)

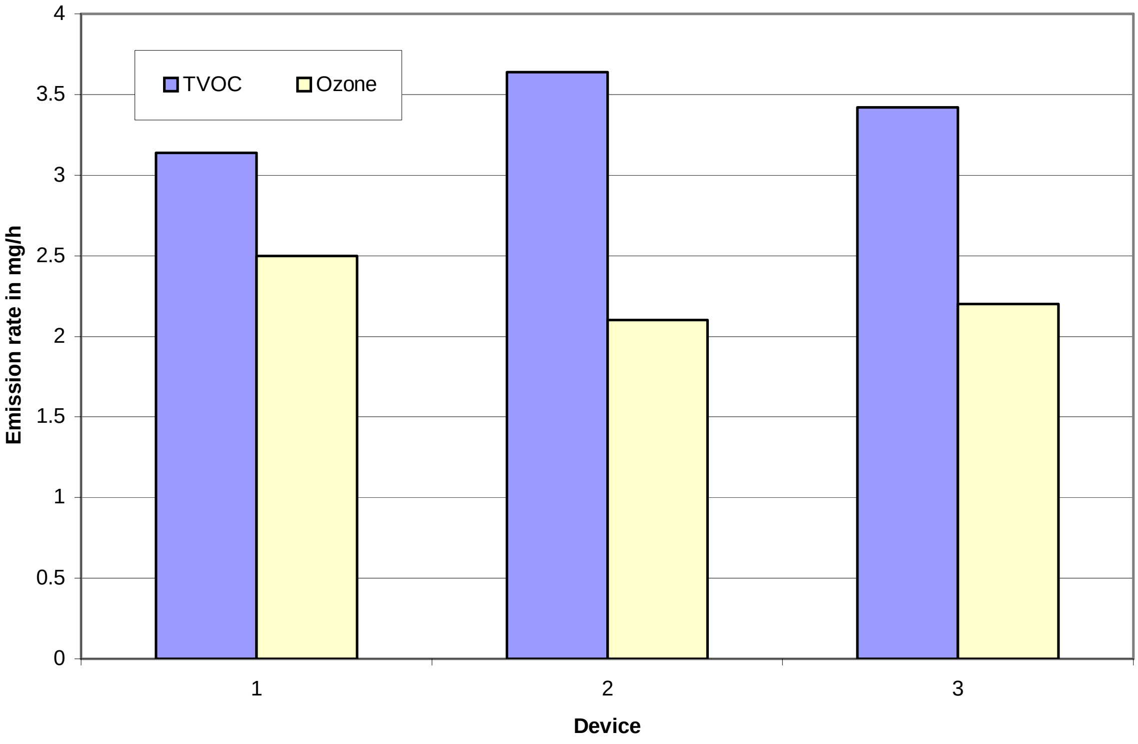


Figure 19: Test results for devices of the same design (about 2-year-old devices, toners from the same batch)

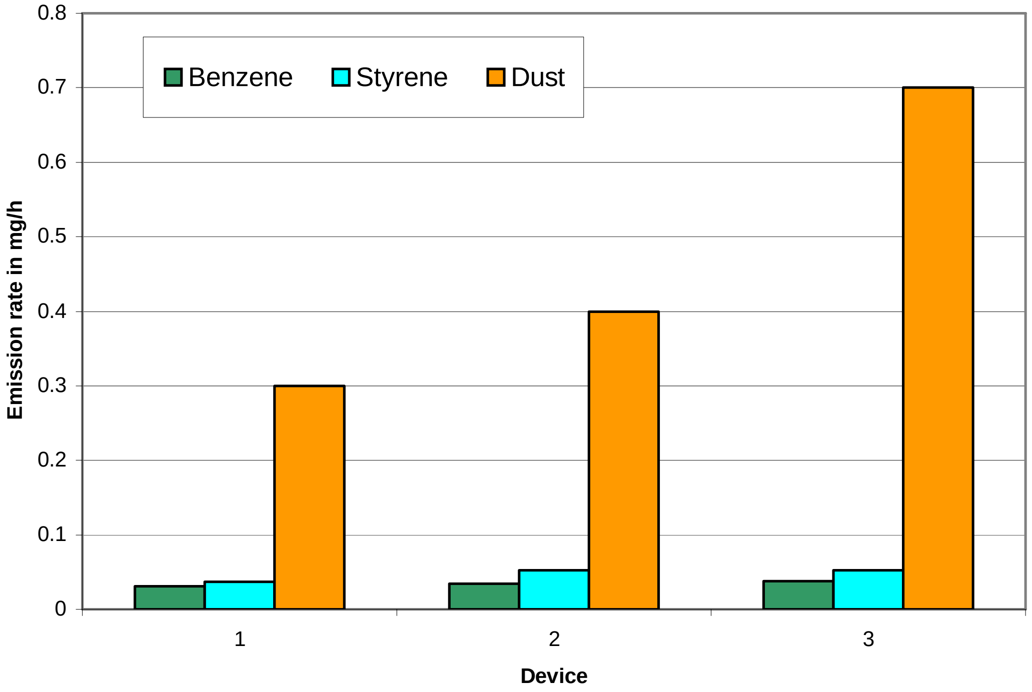


Figure 20: Test results for devices of the same design (about 2-year-old devices, toners from the same batch)

4.3.4 Investigations into the influence of different toner batches

Tests on a laser printer with toner cartridges from different batches were performed for this purpose. The test results are illustrated in Figure 21 and Figure 22.

It can be seen that toner cartridge 1 produced markedly higher TVOC, benzene and styrene emission values than other cartridges. In the tests with toner cartridge 2 no benzene emission was detected.

The toner cartridges failed to show any effect on ozone and dust emissions.

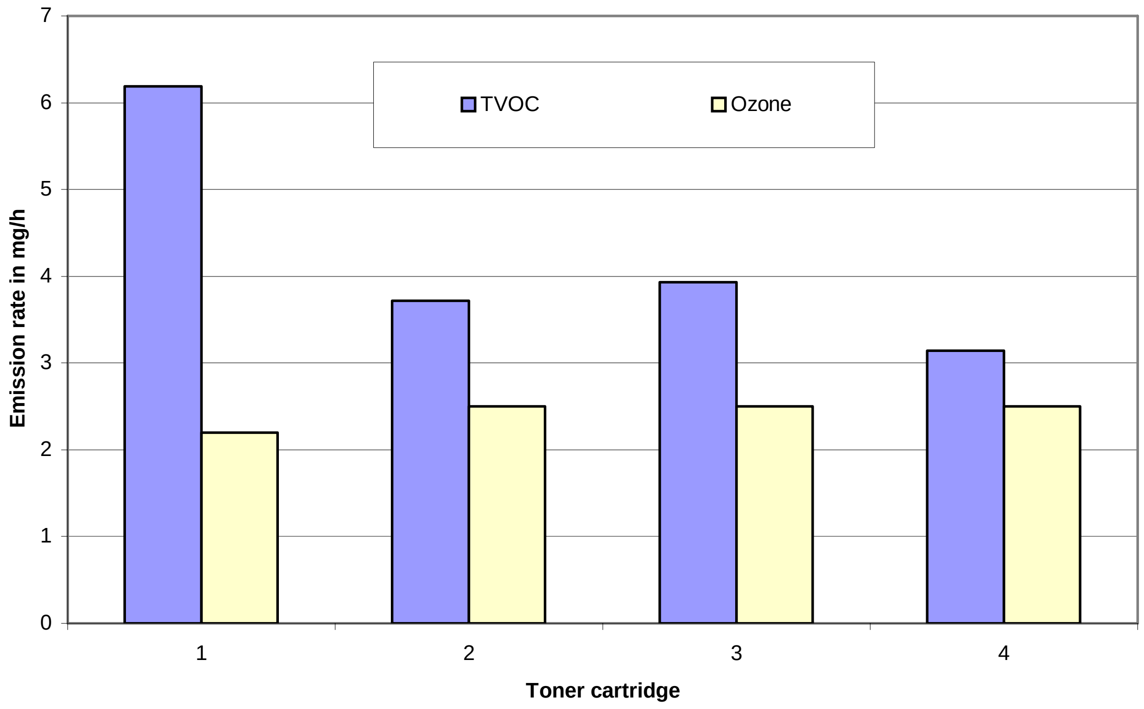


Figure 21: Influence of different toner cartridges on the emissions

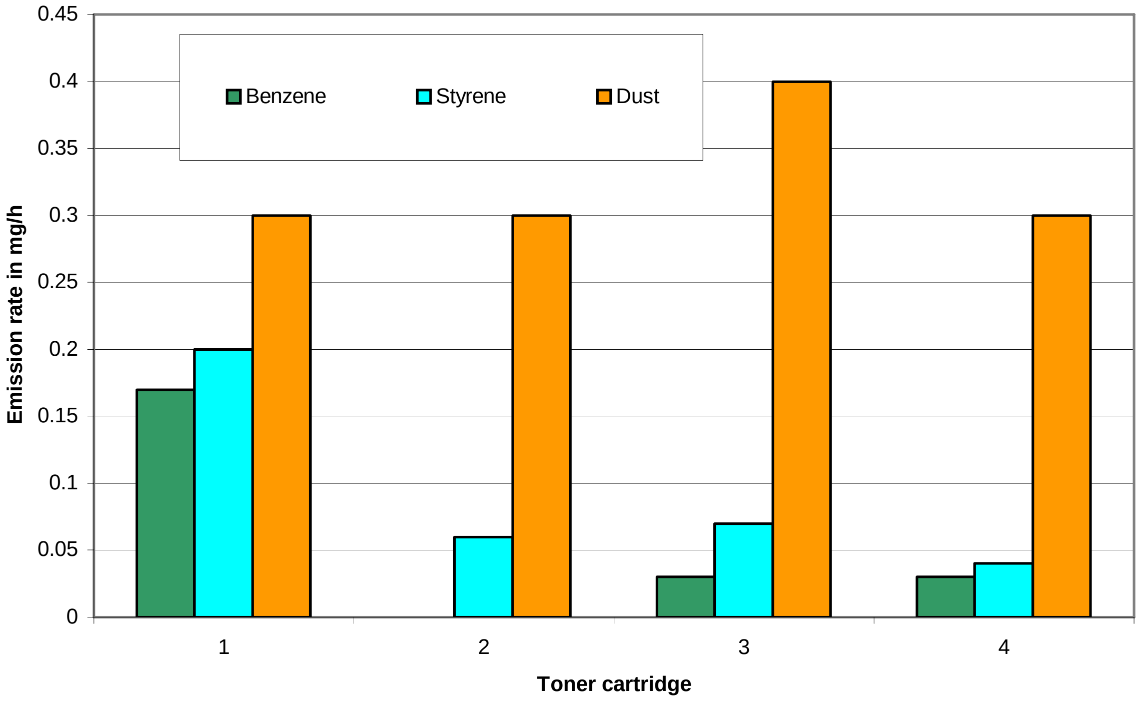


Figure 22: Influence of different toner cartridges on the emissions

4.3.5 Correlation of the TVOC value with the printing rate

In Figure 23, Figure 24, Figure 25 and Figure 26 the TVOC values determined as per RAL-UZ 114 are plotted against the relevant printing rate (page per minute). Figure 23 and Figure 24 display the results for the devices in the preliminary tests (Chapter 4.2), for Figure 25 and Figure 26 the devices from Chapter 4.3.1 were used.

Figure 24 and Figure 26 do not show any increase in the TVOC values with increasing printing rate. Though a certain trend toward higher TVOC values can be recognized in Figure 23 and Figure 25 for faster devices, there are also slower devices with similar TVOC values as those of faster devices and vice versa.

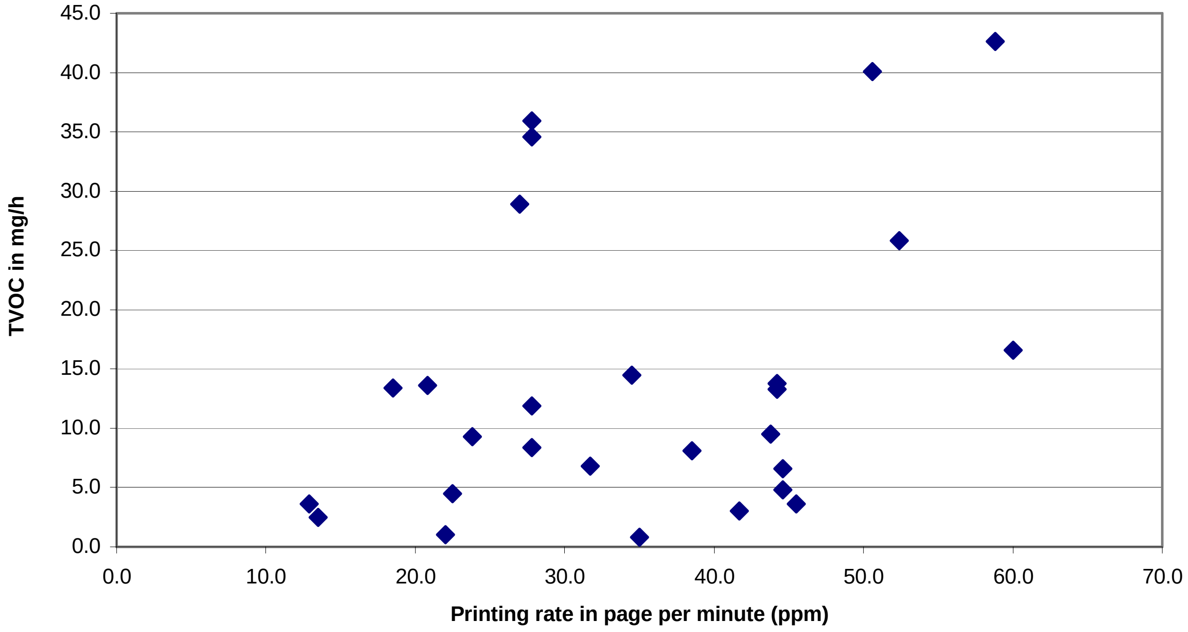


Figure 23: Correlation of TVOC value and printing rate for freestanding devices from the preliminary tests in black-and-white printing phase

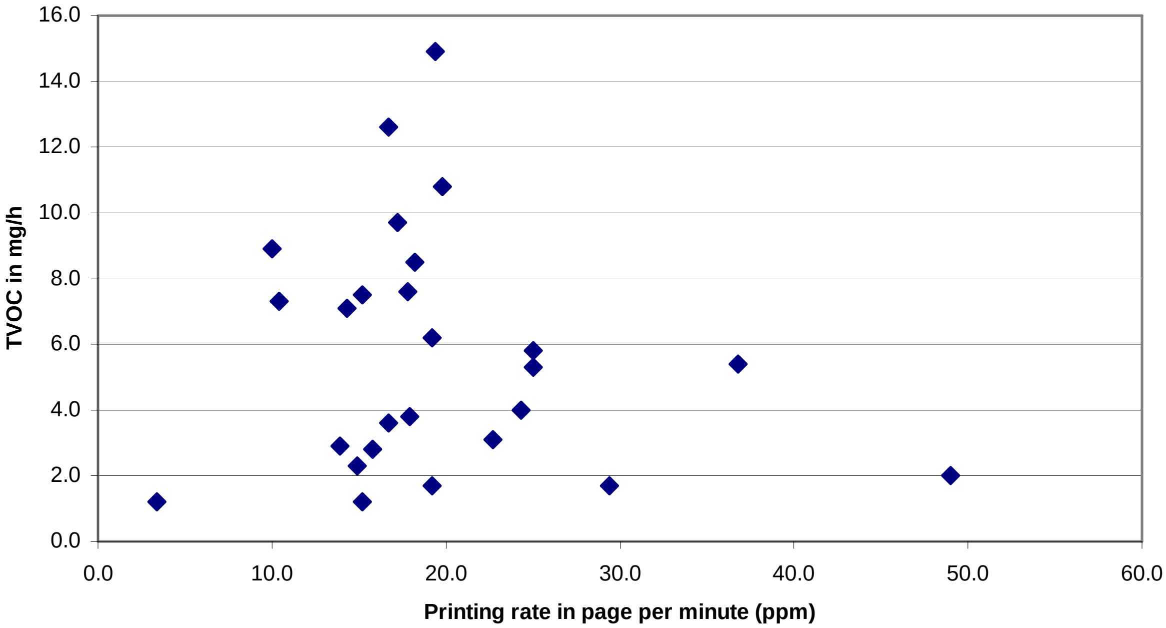


Figure 24: Correlation of TVOC value and printing rate for desktop devices in the preliminary tests in black-and-white printing phase

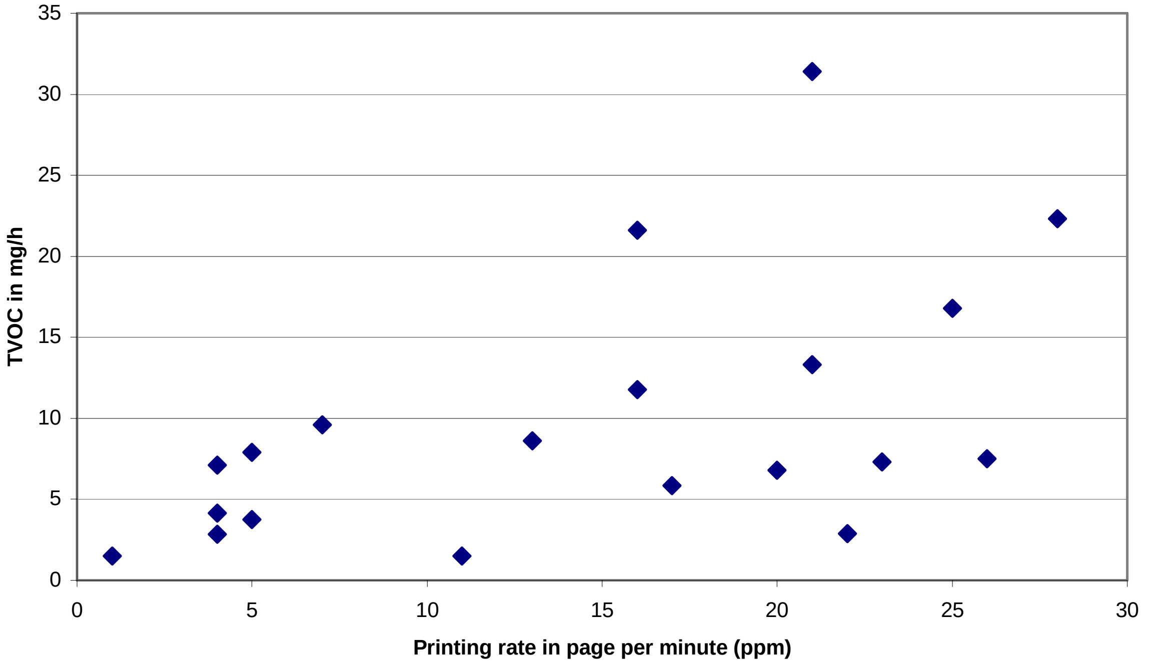


Figure 25: Correlation of TVOC value and printing rate for devices in the main tests in colour printing phase

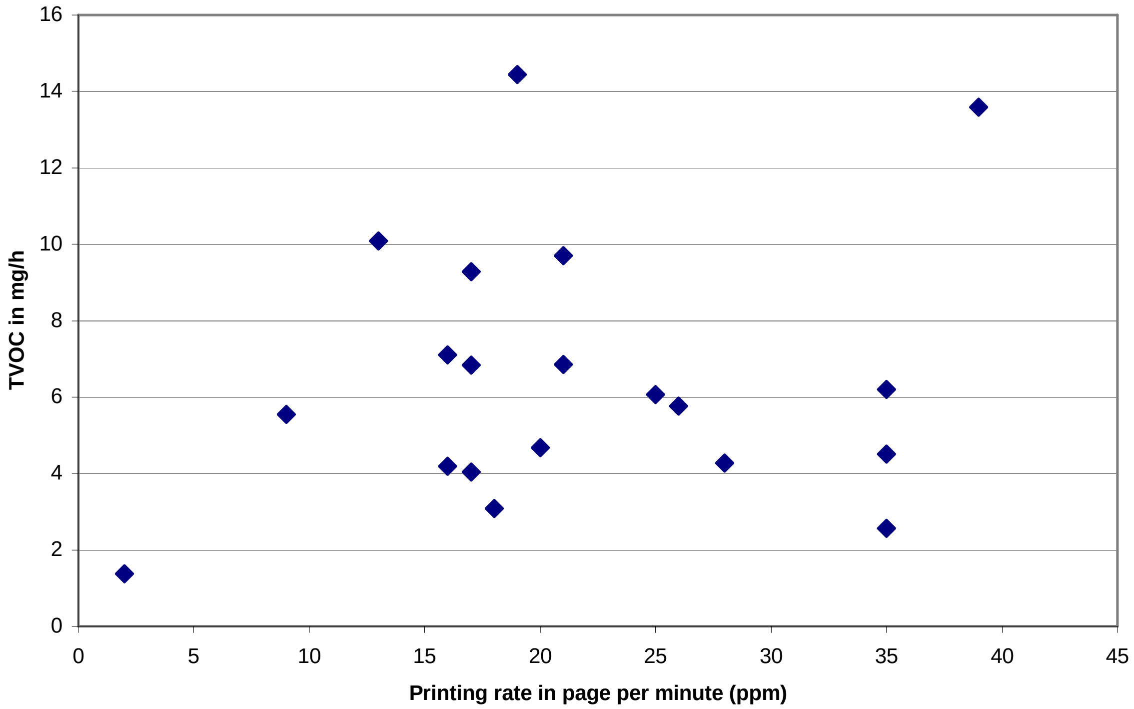


Figure 26: Correlation of TVOC value and printing rate for devices in the main tests in black-and-white printing phase

4.3.6 Testing of TVOC emission in the pre-operating phase

Figure 27 shows the results of a long-term test which was performed analogous to a building product test. For this purpose a printer remained in the test chamber during the whole test period. The device was switched on one hour before the sampling (pre-operating phase similar to the test per RAL-UZ 122). The air exchange rate was 1/h during the entire 21 days.

As in building product tests, a decay curve for the TVOC value has resulted: the TVOC value decreases within 21 days to about a third of the value measured on the first day.

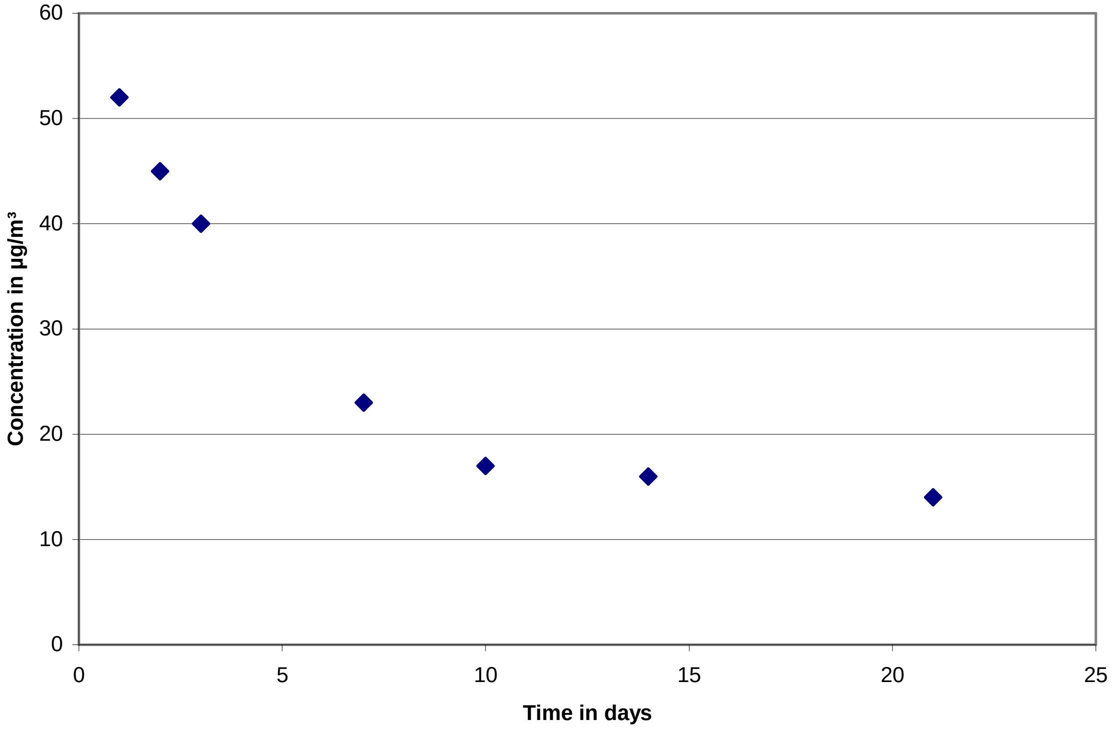


Figure 27: Concentration in the pre-operating phase over 21 days

4.3.7 Toner consumption tests

Table 6 displays the TVOC emission rates and toner consumption for two devices determined over several tests. Colour printing exhibited a much higher total toner consumption (as expected due to the higher degree of coverage), while the TVOC values were similar or even lower.

The abbreviation “col-mod” stands for a colour printing where the printer pattern for monochromatic print was used, therefore black was mixed from 3 colours.

Table 6: Comparison of TVOC value and toner consumption

Job No.	TVOC [mg/h]	Printed pages	Print time [min]	Consumption (g)			
				black	**cyan**	**magenta**	**yellow**
G1_b/w	10.09	200	15.9	4.75			
G1_col	8.60	200	15.3	5.04	4.56	4.17	3.18
G1_b/w(2)	4.26	200	15.9	3.43			
G1_f(2)	5.28	200	14.9	5.24	5.35	3.46	3.31
G1_col-mod	3.83	200	15.5	4.41	1.97	2.25	0.66
G1_b/w(3)		132	12.8	4.52			
G1_col(3)	4.57	200	14.9	4.62	5.09	5.15	3.24
G1_col(4)		198	14.6	4.03	5.26	4.12	2.26
G2_b/w	11.78	292	15.0	6.94			
G2_col	14.44	250	16.0	4.76	5.98	8.68	12.01
G2_b/w(duplex)	6.58	300 on 150 sh.	15.5	7.11			
G2_col(duplex)	7.10	250 on 125 sh.	20.3	5.60	5.20	6.67	7.83
G2_col-mod	6.65	250	12.8	6.25	0.22	0.21	0.16

4.3.8 Investigations into lightness L* [CIE]

For the tests as per RAL-UZ 114 a linearization of the grey tones was required. This "calibration" was to achieve comparable luminosity and to make the tests of different hardcopy devices more comparable. However, it has been found that this linearization hardly changed the lightness of the different devices.

Since according to manufacturers’ statements some devices carry out an additional "self calibration" during printing which waives the linearization, it was decided to consider the determination of lightness L* and the variegation a* and b* as sufficient in the standard setting of the respective device for RAL-UZ 122. The measurement then takes place using a colour spectrometer. L*, a* and b* can be calculated from the intensity of the light reflected from the printed-on paper per CIE.

Figure 28 shows a correlation of printing rate and lightness.

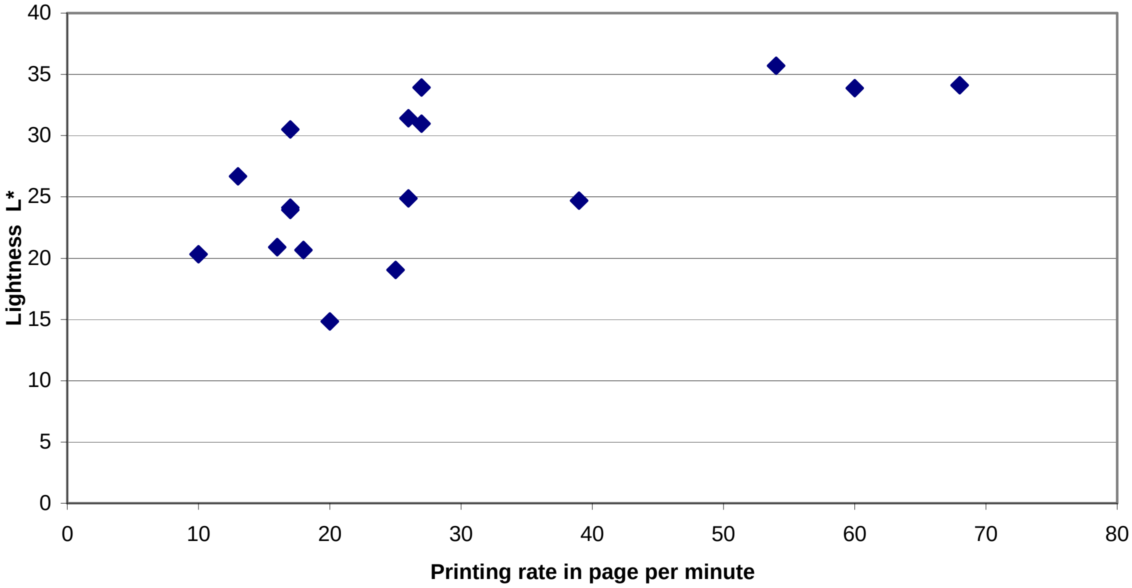


Figure 28: Correlation of printing rate and lightness

It can be seen that the fastest devices provide the highest luminosity, i.e. the least blackening due to printing. This would explain relatively small TVOC emission rates despite high printing rates. This view is supported by Figure 29 which shows a correlation of luminosity and TVOC values. It can be seen that most devices with higher luminosity exhibit relatively small TVOC emission rates.

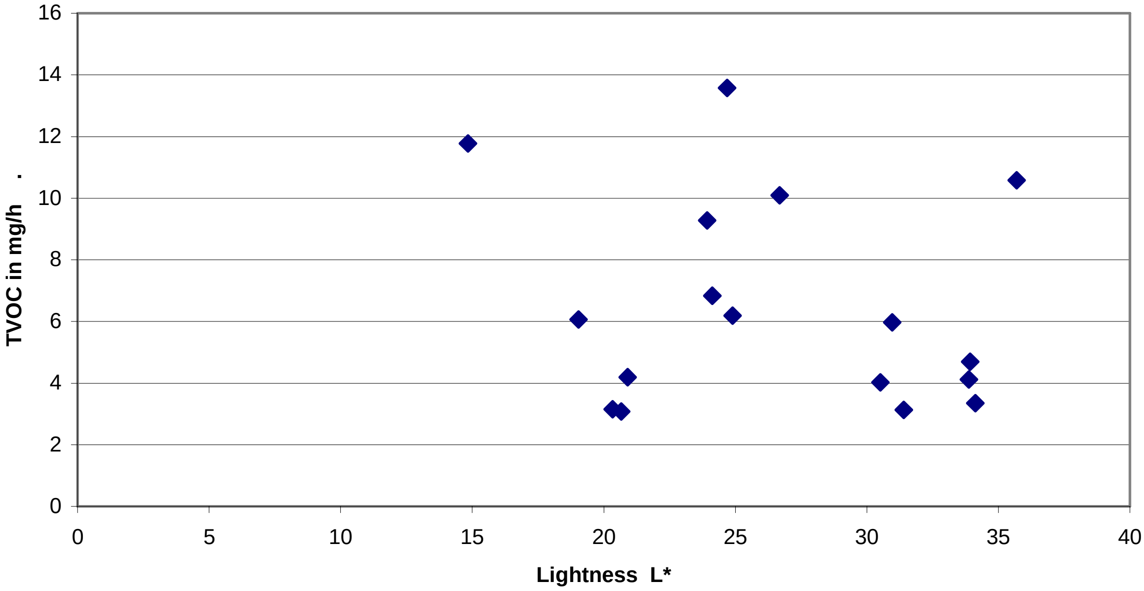


Figure 29: Correlation of luminosity and TVOC emission rate

4.3.9 Dust characterisation

The investigations performed were aimed to characterise dust in order to ascertain the composition of the dust retained by the glass-fibre filter. Electron micrograph images of the filters were prepared with the help of an Environmental Scanning Electron Microscope (ESEM) and an elemental analysis of the dust particles was carried out. The scanning electron microscopic investigations by ESEM in combination with energy dispersive X-ray analysis (EDX) enable a morphological and chemical characterisation of materials and substances. No pre-treatment (e.g. vaporizing) of the samples was necessary.

Comparative ESEM tests have also been made on toner materials from toner cartridges.

Further images were taken of printed paper.

Toner particles were identified on the glass-fibre filters used for sampling. The following images show some variations of size and form of these toner particles.

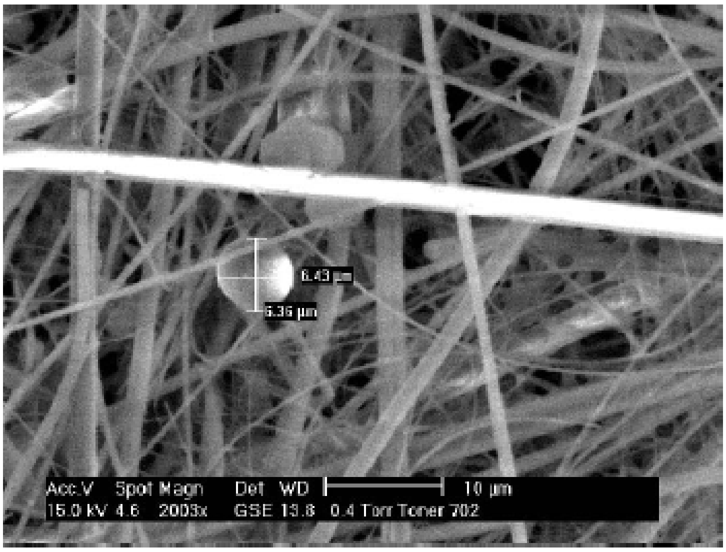


Figure 30: Glass-fibre filter, emission chamber test

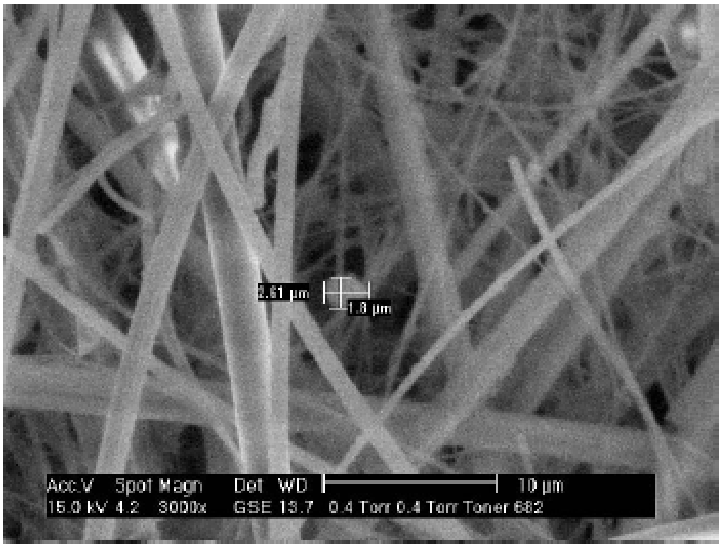


Figure 31: Glass-fibre filter, emission chamber test

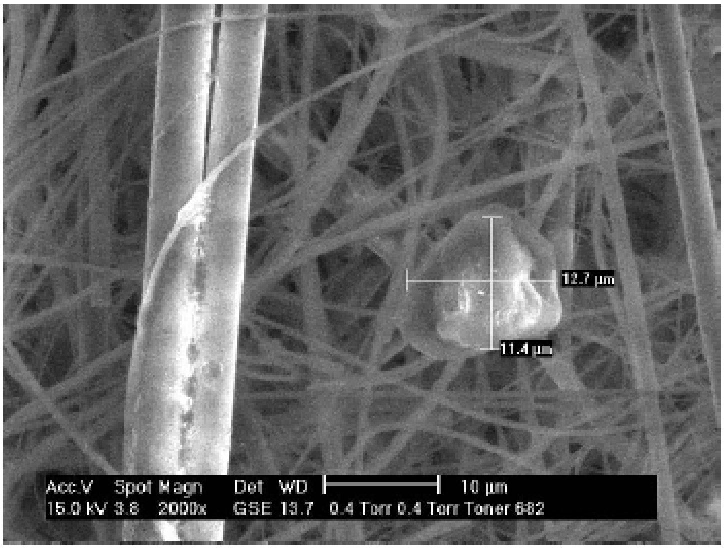


Figure 32: Glass-fibre filter, emission chamber test

Figure 33 and Figure 34 show toner structures after printing. Microscopic structures in the range of approx. 70 nm to 150 nm show up in the selected enlargement.

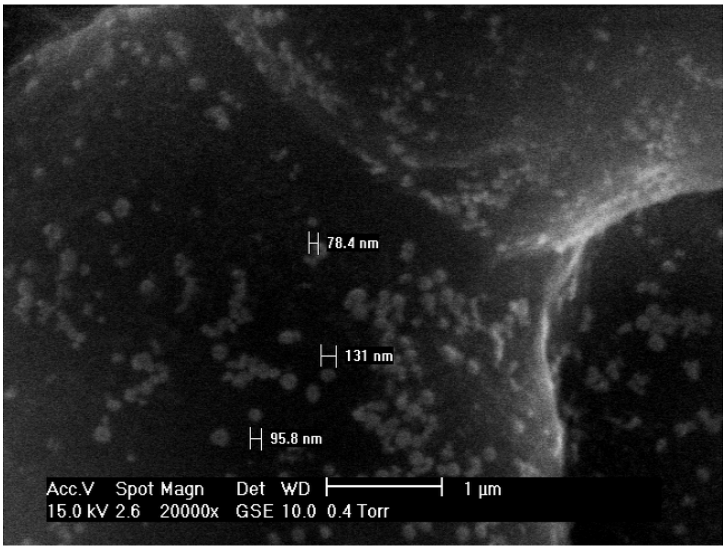


Figure 33: Toner after printing on paper

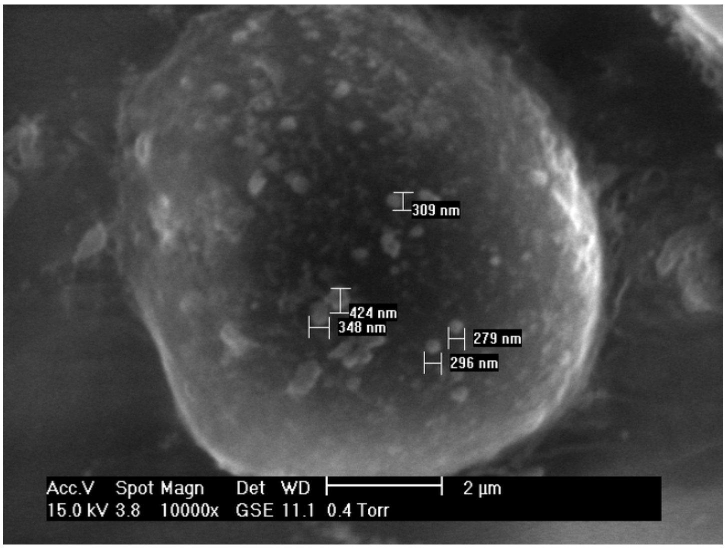


Figure 34: Toner after printing on paper

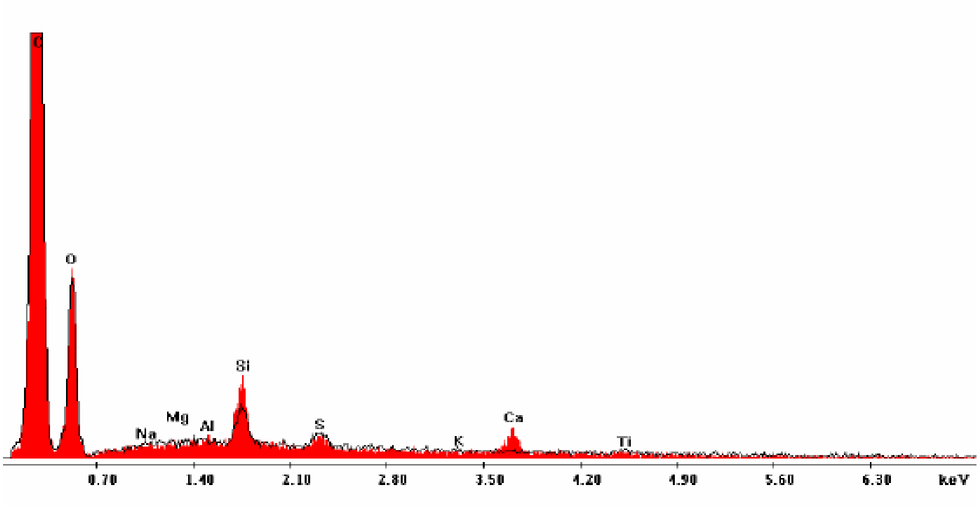


Figure 35: EDX comparison of toner on paper (red) and pure toner (black line)

Figure 36 shows an ESEM image of a toner which was scattered directly on a glass-fibre filter with size data of some toner particles.

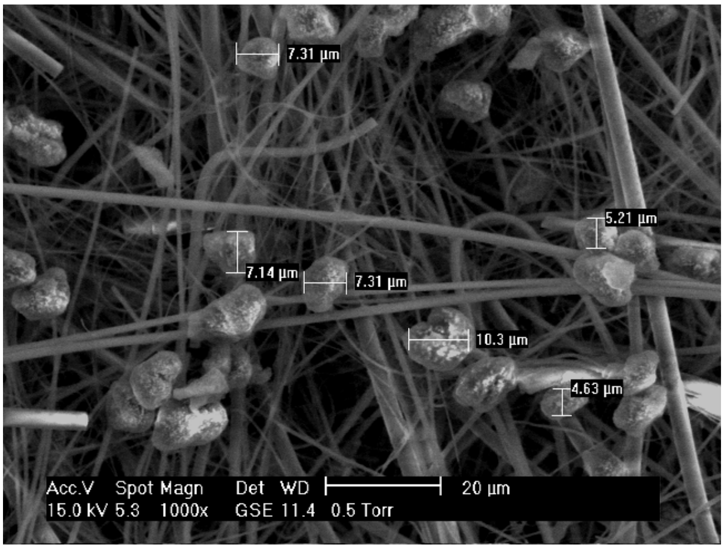


Figure 36: Toner scattered on a filter

Scanning electronic investigation coupled with EDX analysis (see Figure 35) is a suitable method to allocate the particles emitted during printing.

Thus certain substances can be assigned directly to the original material, for example calcium to the paper or iron (Fe) as a "finger print" to some toners.

Figure 37 shows a blank paper and Figure 38 the relevant EDX spot measurement with a high calcium content mainly within the bright parts of the paper.

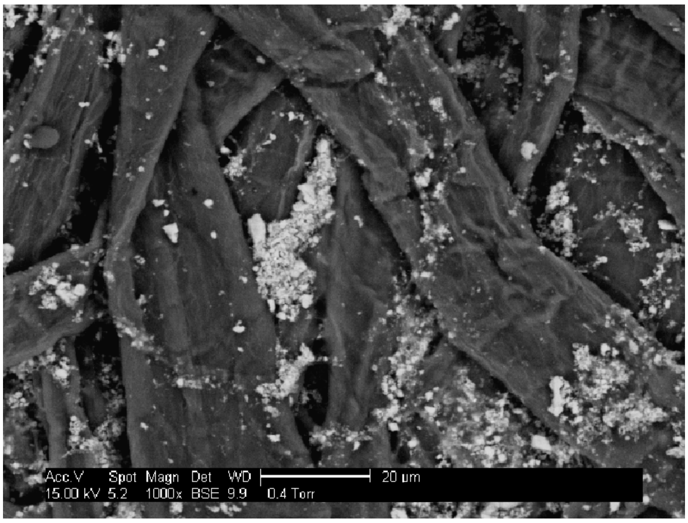


Figure 37: ESEM image, blank paper

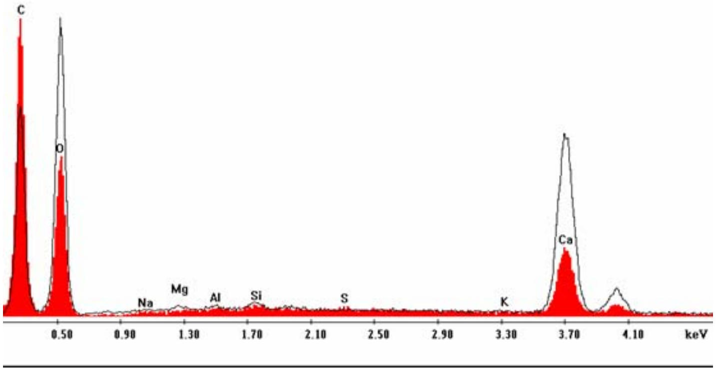


Figure 38: EDX spectrum of paper fibre (red), crystalline bright areas (black)

Figure 39 and Figure 40 illustrate the pure ESEM image for the same toner particle and the EDX line scan by the particle in Figure 40. The increase of Fe concentration in the area of the particle (yellow line) is clearly visible.

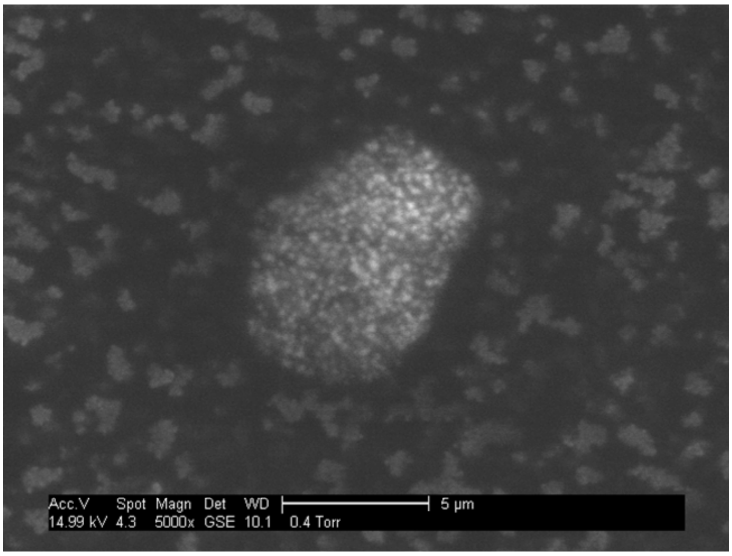


Figure 39: Surface illustration of a toner particle

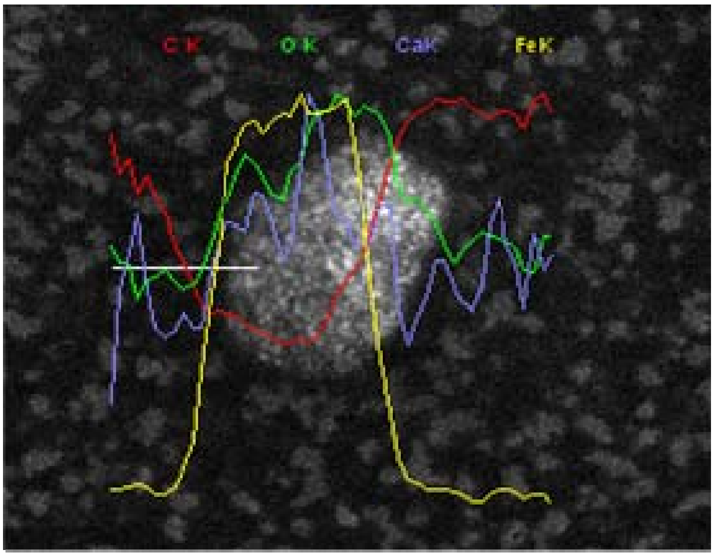


Figure 40: EDX line scan Fe (yellow)

Looking for ultra fine particles (smaller than 100 nm) images were also made with the help of a transmission electron microscope (TEM). Figure 41 shows a TEM image of a toner particle and Figure 42 the relevant EDX analysis in the range of smaller particles. A clear-cut iron peak can also be seen here as a characteristic feature for the toner.

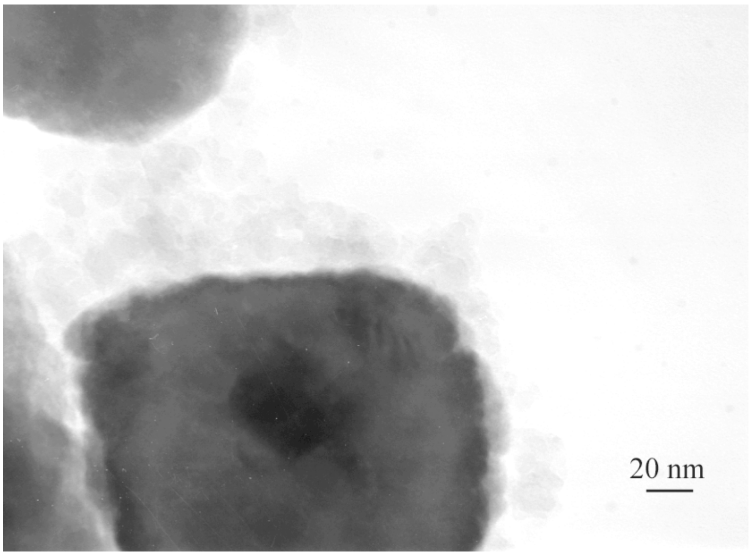


Figure 41: TEM image of a toner

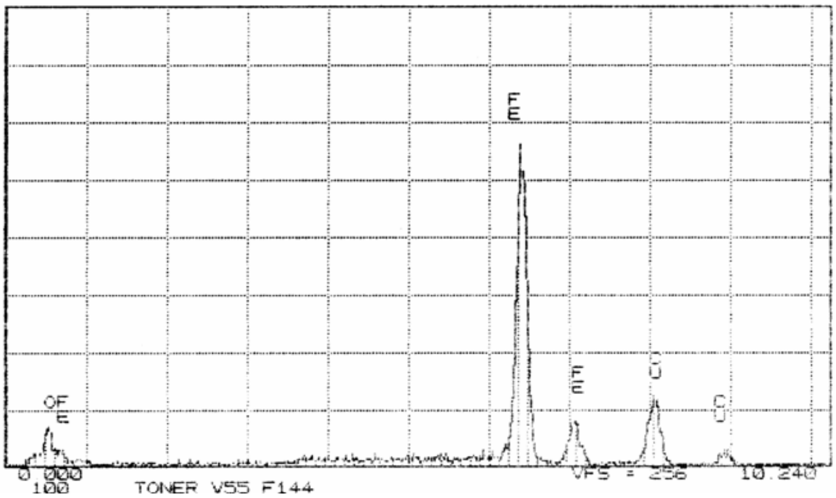


Figure 42: EDX analysis in the range of small particles from Figure 41

5 Investigations to improve the test procedure

5.1 Considerations about the influence of pre-operating emission on the emission rate in the printing phase

The results of the emission tests (preliminary tests, Section 4.2) indicated that considerably more freestanding devices than desktop devices failed to meet the "Blue Angel" criteria. It was conspicuous that the emissions of freestanding devices were markedly stronger in the pre-operating phase than those of desktop devices. This can be explained by a larger surface and more intensive use of material. Calculations using the test chamber pre-operating phase concentration for calculating the emission rate during printing showed that the emission during the pre-operating phase alone resulted in the limiting values being exceeded for the printing phase.

Figure 43 schematically illustrates the concentration during an emission test. The areas B1 and/or B2 represent the fraction of pre-operating emission during the printing and follow-up phases. When the follow-up time is longer, the percentage of B2 becomes greater. Thus, the influence of the pre-operating emission is particularly large in large test chambers since they are operated with a smaller air exchange rate and sampling takes longer when air exchange rates are small.

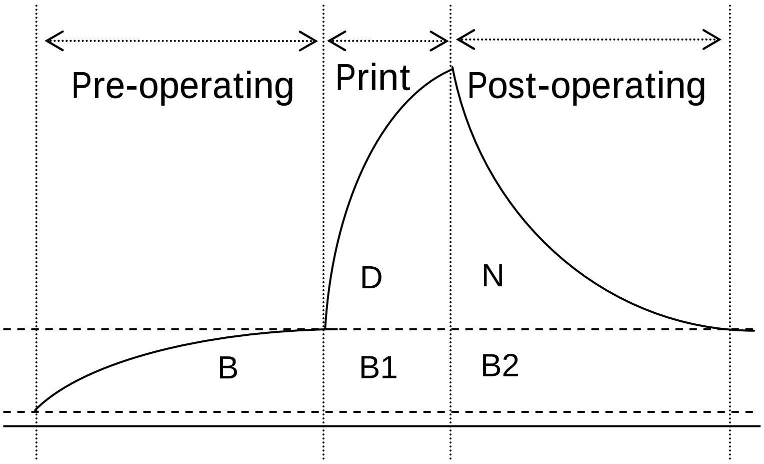


Figure 43: Schematic concentration profile of a printer test

In order to minimize the influence of pre-operating emission, it was agreed as a first step that the devices to be tested must not be kept in a state from which printing can immediately be started over the whole pre-operating phase, but depending upon the factory setting, the device may be allowed to drop into an energy saving mode after a certain period of time.

Theoretical considerations [Ito, 2005] indicate that tests in various sized test chambers on a device yield large differences in the emission rate during printing when the emissions are high in the pre-operating phase (1 mg/h).

Therefore, in order to reduce the influence of pre-operating emission it was discussed whether the VOC sampling time during the follow-up phase should be reduced. The available possibility of sampling at the end of the printing process (Equation 5 of the test procedure of June 2003) could only be used in small test chambers due to a small sample volume.

Theoretical considerations [Yazaki, 2005] clarified the influence of sampling time on the average concentration achieved during sampling.

It was found that sampling from the beginning of printing up to one air exchange after the end of printing provided the greatest average concentration. The average concentration is approximately a factor 2 higher compared to sampling over the entire follow-up phase. Coupled with an increase in the sample flow rate from 100 ml/min to 200 ml/min, the same amount of analyte can thus be collected within a substantially shorter time than if sampling is done over the entire follow-up phase. Thus the influence of pre-operating emission is minimized.

5.1.1 Use of a new calculation formula for the VOC emission rate

Table 7 and Table 8 show the results of TVOC emission rates as per RAL-UZ 114 and RAL-UZ 122 obtained by tests in a 1-m^3 and a 20-m^3 chamber. For these measurements the TVOC emission rates were calculated both as per UZ 114 and UZ 122. The calculation according to RAL-UZ 122 provided smaller emission rates. The change (reduction) depends on the emission rate in the pre-operating phase. The tests on desktop devices yielded on average somewhat smaller deviations compared to UZ 114 than on freestanding devices. In the 1-m^3 emission test chamber about 32 % smaller emission rates were obtained on average. The tests in the 20-m^3 emission test chamber yielded on average up to 45 % lower emission rates.

Table 7: Comparison of emission rates per UZ 114 and 122 for desktop devices

Test	TVOC Pre-operating	TVOC RAL-UZ 114	TVOC RAL-UZ 122	Change in %
1	0.28	9.28	7.05	24
2	0.31	4.13	2.40	42
3	1.21	11.78	6.12	48
4	1.08	14.44	9.24	36
5	0.26	4.19	2.68	36
8	0.07	6.19	5.76	7
9	1.21	10.09	6.56	35
10	0.32	4.26	2.73	36
11	0.94	8.60	3.87	55
12	0.31	5.28	3.75	29
15	0.18	5.88	4.76	19
16	0.14	6.91	6.08	12
			Average	**32**

Table 8: Comparison of emission rates per UZ 114 and 122 for freestanding devices

Test	TVOC Pre-operating	TVOC RAL-UZ 114	TVOC RAL-UZ 122	Change in %
1	1.98	34.60	6.57	81
2	0.03	11.94	11.58	3
3	0.53	10.26	1.23	88
4	0.22	13.30	8.51	36
5	0.51	13.80	2.48	82
6	1.08	28.90	14.45	50
7	1.04	25.80	11.87	54
8	0.17	4.12	3.16	23
9	0.07	3.35	2.81	16
10	0.47	10.21	6.86	28
11	0.47	6.49	3.58	38
			Average	**45**

5.2 Investigations into benzene generation by reaction of Tenax with ozone

To check certain assumptions which state that benzene might be generated from the reaction of ozone with Tenax used for VOC sampling, a sampling series on an emission test chamber filled with ozone was performed using Tenax tubes. The profile of ozone concentration is illustrated in Figure 44 and the determined benzene concentrations are also plotted for comparison. Indeed, a relationship between ozone and benzene concentration can be recognized.

Since the resulting benzene concentrations may be sufficient to exceed the specified benzene emission rate, it was decided to carry out an additional sampling for the measurement of benzene using Carbosieve or Carbotrap as an adsorbent material.

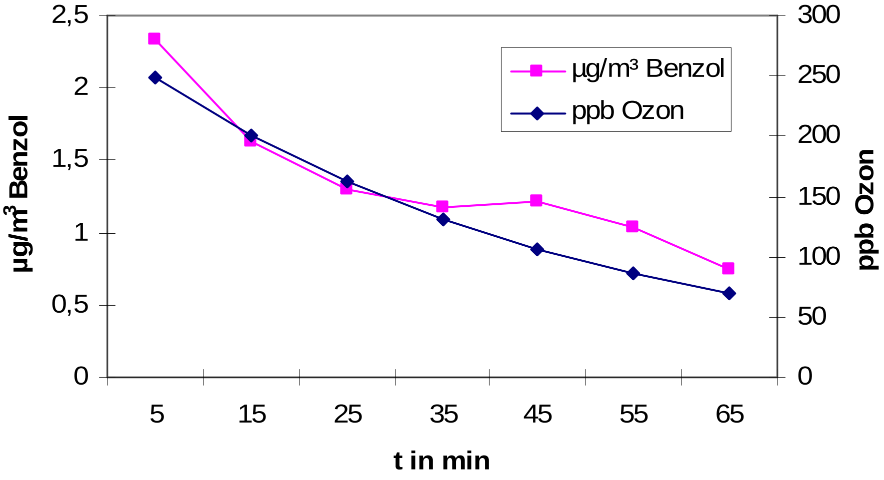


Figure 44: Effect of ozone emission on benzene determination

5.3 Tests using particle spectrometers (size resolving particle counters)

In addition to gravimetric dust measurements, particle counters were used in order to make statements on size distribution and concomitantly determine ultra fine particles of dust (nanoparticles). Table 9 gives an overview of the tests performed using particle counting. In particular, the influence of the degree of coverage (amount of toner) and the medium (various types of paper) was examined. Humidity, air exchange rate and the use of different, sometimes re-filled toner cartridges were other parameters considered.

Table 9: Overview of tests using particle spectrometers

No.	Test #	Printer type	Comments (Medium, coverage, printing mode, others) (*)
1	6	A	Paper, 0.3 % coverage, colour
2	2	A	Paper, 20 % coverage, colour
3	3	A	Paper, 20 % coverage, colour
4	10	A	Paper, 20 % coverage, colour, air exch 1 h^{-1}
5	21	A	Paper, 20 % coverage, colour, air exch 1 h^{-1}
6	44	A	Paper, 5 % coverage, b/w
7	20	A	Paper, pre-dried, 20 % coverage, colour
8	7	A	Environmental paper, 20 % coverage, colour
9	15	B	Paper, 5 % coverage, b/w
10	15a	B	Paper, 5 % coverage, b/w, air exch 1
11	14	B	Paper, 20 % coverage, colour
12	DW10	B	Paper, 20 % coverage, colour
13	16	C1	Paper, 5 % coverage, b/w
14	31	C2	Paper, 5 % coverage, b/w, external cartridge
15	32	C2	Paper, 5 % coverage, b/w
16	33	C2	Paper, 5 % coverage, b/w
17	35	C3	Paper, 5 % coverage, b/w
18	37	C3	Paper, 5 % coverage, b/w
19	52	C5	Manufacturer’s paper, 5 % coverage, b/w
20	53	C5	Manufacturer’s paper, 20 % coverage, colour
21	17	D1	Paper, 5 % coverage, b/w
22	18	D1	Paper, 20 % coverage, colour
23	DW4	D1	Paper, 20 % coverage, colour
24	19	D2	Paper, 5 % coverage, b/w
25	38	D2	Paper, 5 % coverage, b/w
26	39	D2	Paper, 5 % coverage, b/w
27	40	D2	Paper, 5 % coverage, b/w
28	23	E1	Paper, 20 % coverage, colour
29	DW7	E2	Paper, 5 % coverage, b/w
30	25	F	Paper, 5 % coverage, b/w
31	26	F	Paper, 5 % coverage, b/w, air exch 1.6 h^{-1}
32	27	F	Paper, 20 % coverage, colour, air exch 1.6 h^{-1}
33	29	G	Paper, 5 % coverage, b/w, external cartridge
34	30	G	Paper, 5 % coverage, b/w

(*) If not indicated otherwise: standard conditions, i.e. standard paper, air exch ~ 4 h^{-1}.

The analysis series of the measured data described in Chapter 2.3.2 will be demonstrated in the following based on two examples.

Based on the recorded raw data, i.e. measured particle number concentration in the chamber, Figure 45 illustrates the change in particle size and intensity of particle emission during the printing process (marked by blue lines) and the follow-up phase by the example of tests # 18 and # 2 (both colour printing).

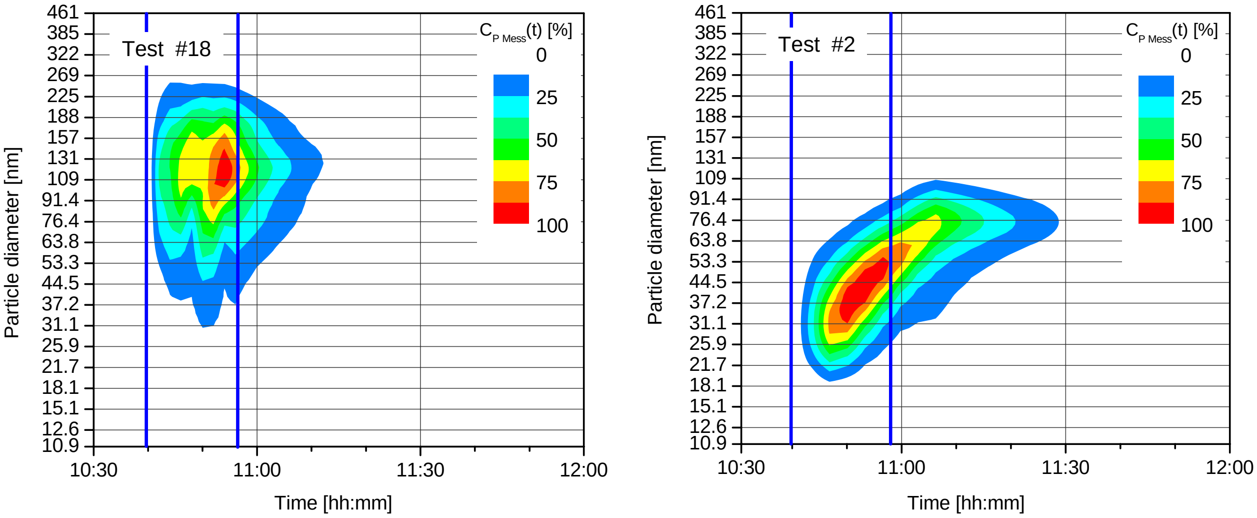


Figure 45: Change in particle size and intensity of particle emission during printing process (marked by blue lines) and the follow-up phase. Concentration data $C_{P\ test}$ (t) are normalized to the maximum emission.

Figure 46 shows particle emission rates $SEP_{\Delta D}(t)$ calculated for four size ranges in tests # 18 and # 2 shown in Figure 42 as examples and total emission rates SEP(t), both during printing phase.

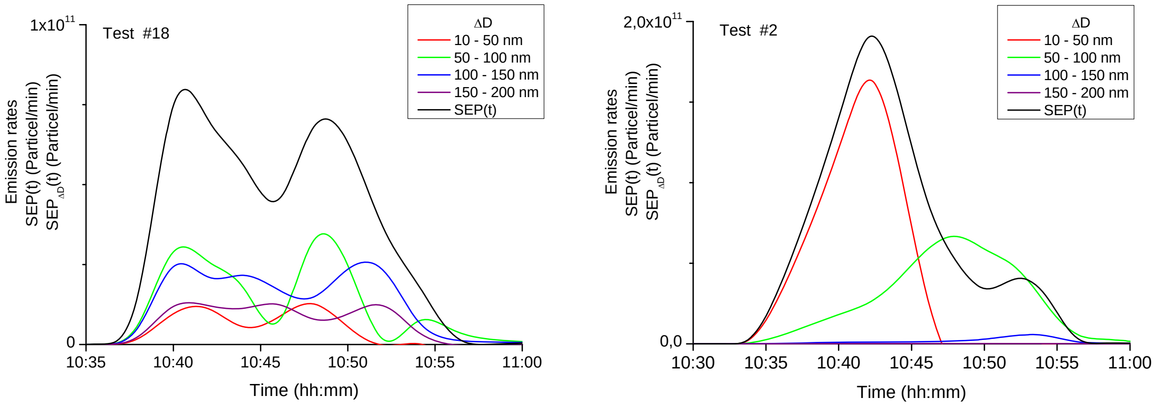


Figure 46: Calculated particle emission rates $SEP_{\Delta D}(t)$ for four size ranges and total emission rates SEP(t) during printing phase

In addition to Figure 43, Figure 47 shows the records of the chamber parameters for humidity, ozone concentration and printer current consumption during printing for tests # 18 and # 2 shown in Figure 42.

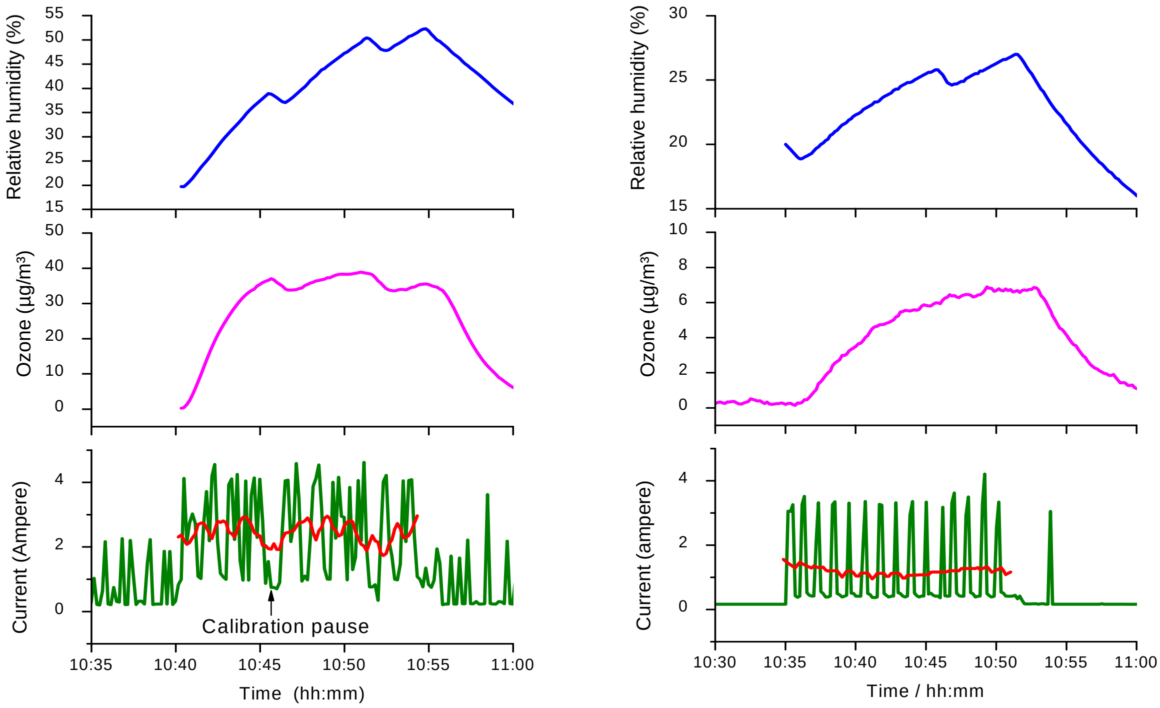


Figure 47: Chamber parameters moisture, ozone concentration and current consumption of the printer during printing

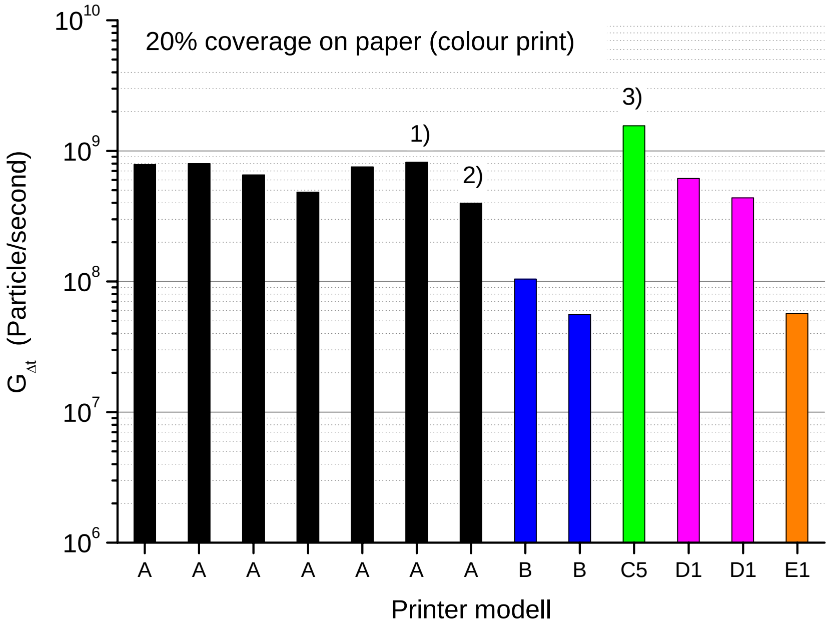
It can be recognized from the current consumption curve of the printer in the example on the left (green curve) that the printer inserts a small calibration break during printing at 10:45. At the same time a significant short-term decrease can be recognized in the emission rates. Furthermore, the emission rates also indicate that particles of different sizes are emitted from the beginning almost simultaneously.

No calibration break arose on the right in the example and the emission rates run markedly differently: primarily small particles < 50 nm were emitted while larger particles were only detected in the second half of the printing process.

The examples shown indicate that:

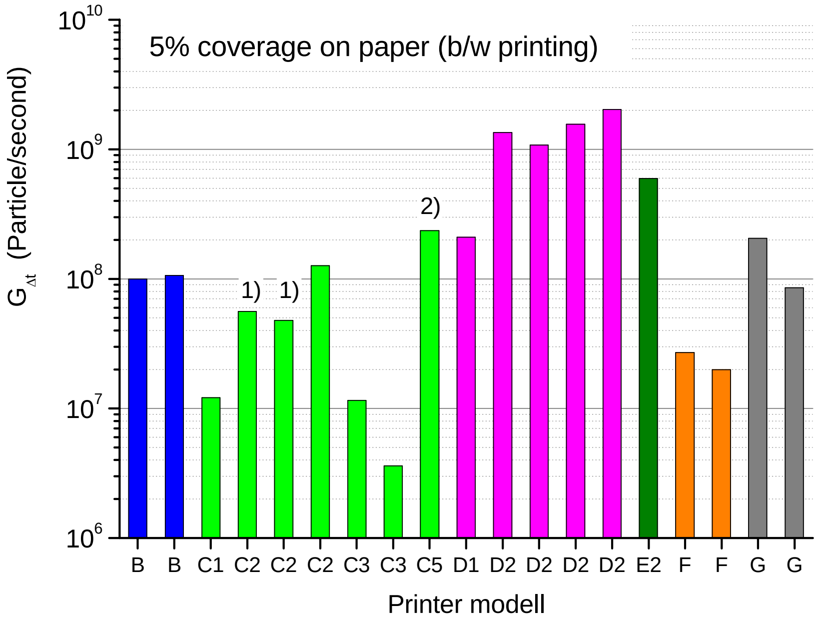
- printing events of different printer makes can have very different printing processes in terms of particle emission as a function of time,
- the measurement technique used enables a very good determination of these time characteristics, and
- coincidences between particle emissions, gaseous emissions and climatic development in the test chamber can be identified in this way, which makes a more exact analysis in the details of printer emissions possible in the future.

The most important results from the particle emission measurements on printers are presented in the following:



1) pre-dried paper; 2) environmental paper; 3) manufacturer's paper

Figure 48: Total particle emission $G_{\Delta t}$ normalized to printing time for colour printing on paper (20 % coverage)



1) external cartridge, 2) manufacturer's paper

Figure 49: Total particle emission $G_{\Delta t}$ normalized to printing time for b/w printing on paper (5 % coverage)

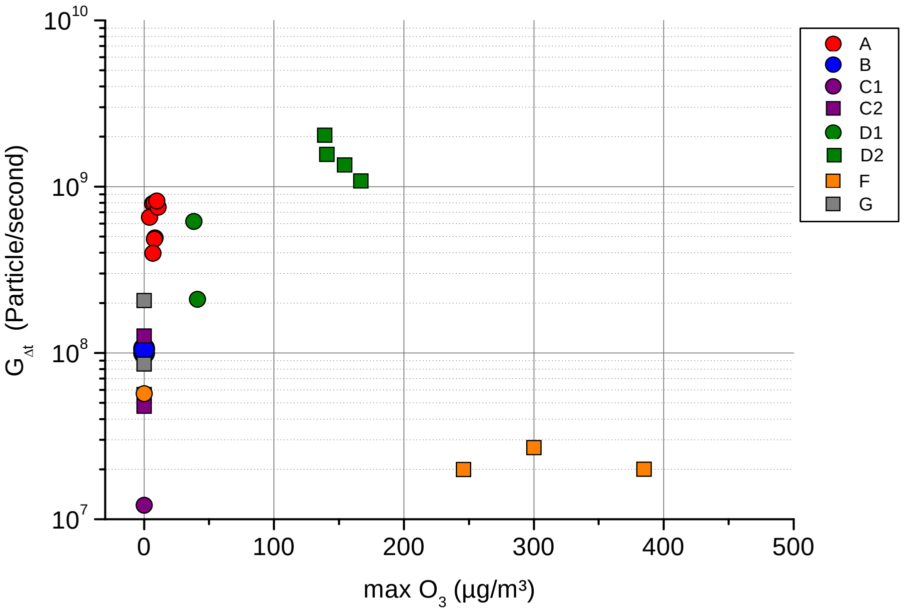
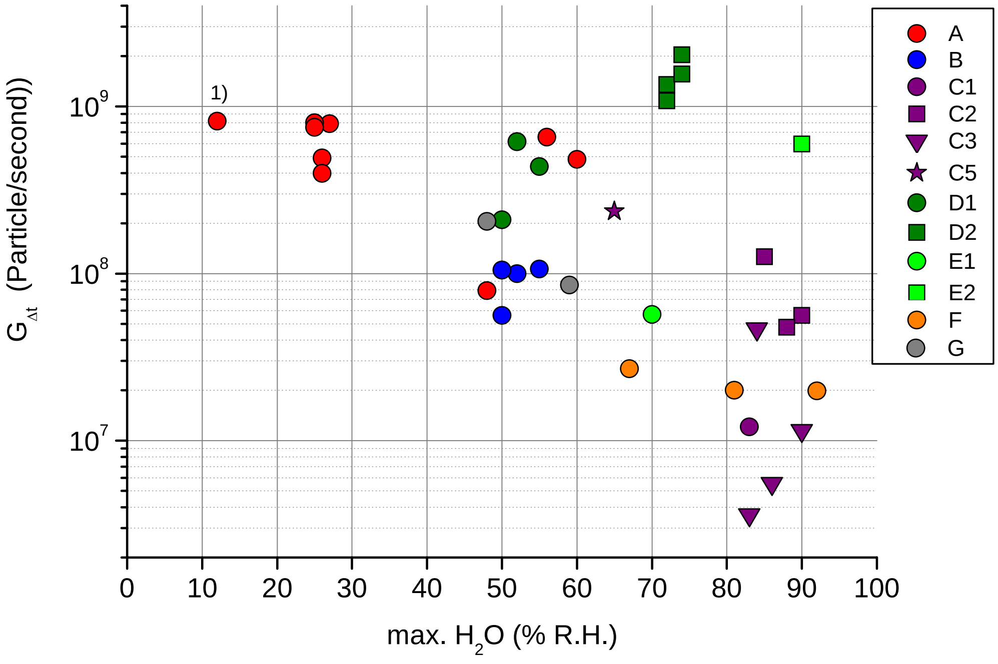


Figure 50: Relationship between ozone emission and total particle emission normalized to printing time

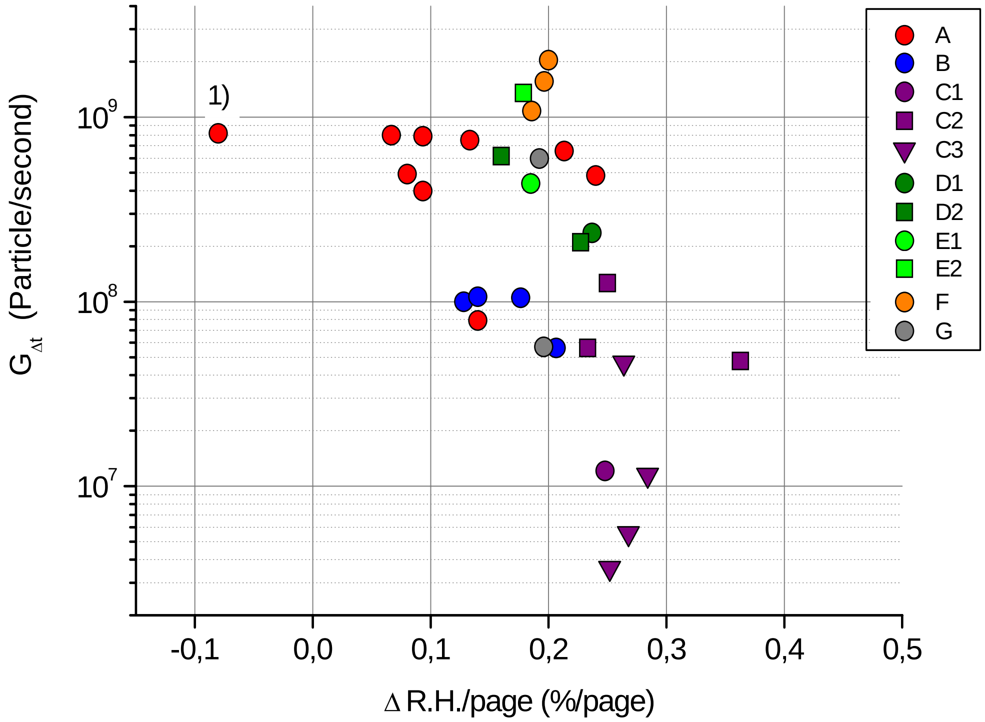
Only the printers D2 and F exhibited an increased ozone emission. No clear relationship between high ozone concentrations in the test chamber and high total particle emissions can be established because high particle emissions also occur at very low ozone concentrations.



1) pre-dried paper

Figure 51: Relationship between moisture content in the chamber and total particle emission normalized to printing time

During printing the paper heated up by the printer release moisture. At the same chamber humidity the total particle emission of the printers varies by up to nearly 2 orders of magnitude. However, high humidity in the test chamber does not inevitably cause high particle emission: the data indicate a trend toward smaller particle output at higher humidity.



1) pre-dried paper

Figure 52: Relationship between moisture emission and total particle emission $G_{\Delta t}$ normalized to printing time

Humidity increase per page can be interpreted as an approximate measure for the thermal energy spent on fixing the toner to the paper, and, in addition, simultaneously drying the paper. It can be assumed that the paper exhibits the same moisture content at the beginning of the printing process in each case. In general terms the measurement data suggest that the printers using a small amount of energy for fixing (e.g. printer A) exhibit higher particle emissions than those printers using more energy for fixing (e.g. C2, C3). The use of pre-dried paper (see 1 on the left in Figure 52) leads however, to a drying of the chamber atmosphere during printing, not to a reduction of particle emission.

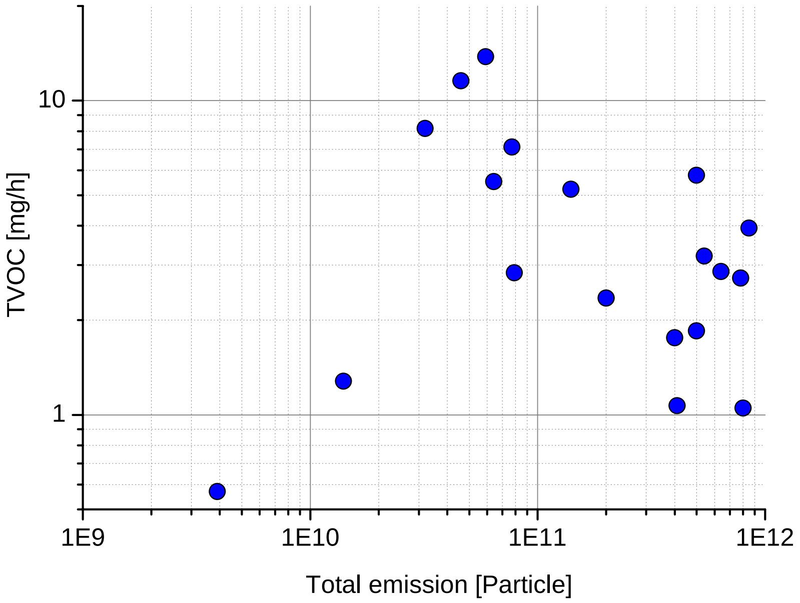


Figure 53: Relationship between particle and TVOC emission

TVOC emission and particle emission of the printers tested cannot be correlated. High TVOC emission does not inevitably cause high particle emission.

The emission measurements of ultra fine particles from laser printers can be very well reproduced in an emission test chamber, as well as measured both quantitatively and in a time-resolved fashion. The differences of up to two orders of magnitude detected between the different makes and types primarily depend on the actual device and design. A targeted influencing of moisture conditions in the chamber (e.g. by using pre-dried paper) did not have any significant influence on the particle emission behaviour. TVOC emission and ozone emission also correlated poorly with particle emission. Therefore, VOCs, SVOCs, ozone and water vapour should be regarded rather as accompanying phenomena and not as key factors or causes of ultra fine particle emission from laser printers.

6 Interlaboratory comparison

6.1 VOC, dust and ozone emission measurements

All certified testing institutes had to participate in an interlaboratory comparison which was aimed at enhancing quality assurance. For this purpose three devices of the same design were sent to the USA, Japan/South Korea and within Germany. The devices were about 2 years old at the time of the interlaboratory comparison and had been tested in BAM several times during this time. All participants carried out a test as per RAL-UZ 122, Appendix 4. The measurements took a period of up to three months (Japan/South Korea) successively among the participants.

Emission rates measured by BAM before the dispatch are shown in Figure 19 and Figure 20.

Table 10 displayed the results of all participants.

Table 10: Results of the interlaboratory comparison for printer test per RAL-UZ 122

Printing phase	Emission rate in mg/h				
	TVOC	**Benzene**	**Styrene**	**Ozone**	**Dust**
Laboratory 1	3.42	0.038	0.052	2.20	0.70
Laboratory 2	4.70	0.010	0.032	2.00	0.56
Laboratory 3	3.90	0.010	0.100	1.43	1.10
Laboratory 4	1.94	<0.05	0.040	1.70	0.69
Laboratory 5	2.79	0.012	0.058	1.55	0.50
Laboratory 6	3.20	0.005	0.060	1.90	2.30
Laboratory 7	1.72	0.005	0.080	2.08	<0.45
Laboratory 8	7.00	0.009	0.090	1.60	<0.30
Laboratory 9	5.40	0.010	0.060	1.68	0.90
Laboratory 10	7.16	<0.05	0.057	1.19	0.43
Laboratory 11	2.70	0.006	0.036	1.36	1.30
Laboratory 12	3.27	0.017	0.129	0.84	1.38
Average	**3.93**	**0.012**	**0.07**	**1.63**	**0.99**
Standard deviation	1.80	0.010	0.03	0.39	0.57
STAB in %	46	80	43	24	58

The standard deviations for TVOC and styrene were in the same range as determined by interlaboratory comparisons on building products for VOC. The higher standard deviation for benzene can be explained by the very low chamber concentration.

The standard deviation for ozone is markedly better; however changes in the ozone half-life determination were necessary by some of participants to achieve this result.

The relatively high deviations for dust required more clarification by discussion with the participants about sampling and weighing. A potential explanation is certainly the low total dust emission.

7 Summary

The investigations performed on laser printers essentially served as a revision of the test method for the determination of emissions from hardcopy devices for the environmental award "Blue Angel" for office devices according to RAL-UZ 62, 85 and 114 of June 2003. The resulting test procedure according to RAL-UZ 122 was previously published in June 2006.
The changes in relation to the test method of June 2003 are listed in the following:

Procedure according to RAL-UZ 122:

- Loading of the chamber on the day preceding the test
- Measurement of L*, a*, b* values without linearization of the grey tones
- Calculation of the emission rate for ozone takes place at the maximum concentration during the first 10 minutes of printing
- Sampling for VOC in the follow-up phase only for the period of one air exchange
- Sampling flow rate for VOC up to 200 ml/min
- Quantification of unknown substances using the response factor of toluene (previously: deuterated toluene)
- New calculation formula for the VOC emission rate of the printing phase
- VOC limit no longer considered as a concentration, but emission rate as a function of chamber size
- Additional data in the test report, in particular a new form
- New colour template (www.ps.bam.de/RALUZ122)
- Manufacturer’s adjustment instead of maintaining of the pre-operating phase beyond 60 min,
- Approval of UV devices for ozone determination
- Determination of ozone half-life at low ozone emissions is void
- Additional sampling using Carbosieve or Carbotrap for benzene determination

In addition to amending the test method, new maximum emission values were specified for the assignment of the environmental label RAL-UZ 122 of the Federal Environment Agency in co-operation with BAM based on the measurement results on colour laser printers. These new maximum values can be found in Table 11.

Table 11: Permitted maximum emission rates per RAL-UZ 122

Substance	***Emission rate*** ***Printing phase (mg/h)***		***Emission rate*** ***Pre-operating phase (mg/h).***	
	Colour print ***Sum*** ***Pre-operating*** ***+ printing phase***	***Monochromatic print*** ***Sum*** ***Pre-operating*** ***+ printing phase***	***Desktop devices***	***Freestanding devices*** *(Device volume >250 litres)*
TVOC	**18**	**10**	**1**	**2**
Benzene	**< 0.05**	**< 0.05**		
Styrene	**1.8**	**1.0**		
Ozone	**3.0**	**1.5**		
Dust	**4.0**	**4.0**		

The report presents the emission test results of VOC, ozone and dust on more than 70 different printers and copiers. The preliminary investigations deal with the tests from the years 2003 to 2004, and the main investigations describe the tests performed in 2005 and 2006, in particular those on colour laser printers.

The maximum value specified by the Blue Angel for the dust emission rate of 4 mg/h, was not exceeded in any of the cases.

While the maximum value for ozone emission (2 mg/h as per RAL-UZ 114 and 1.5 mg/h as per RAL-UZ 122) was not exceeded by desktop devices, it was exceeded by some of the freestanding devices.

VOC emissions are also higher on average from freestanding devices than from desktop devices. This can be explained by a larger equipment mass and surface of freestanding devices. The calculation of TVOC emission rates according to RAL-UZ

114 at higher pre-operating emissions in the printing phase yielded higher emission rates than is the actual case in the printing process. Therefore a new calculation formula was established for RAL-UZ 122. The application of this new formula leads to markedly lower VOC emission rates in the printing phase of devices which exhibit a relatively high pre-operating emission in comparison to RAL-UZ 114.

It is noticeable that some of the colour printers exhibited similar TVOC emission rates in the colour printing phase as in monochromatic printing, although the paper coverage of 20 % is four times as high and thus toner consumption is also considerably higher. Apparently, some coloured toners contain much less VOC than black toners.

When comparing test devices which were used frequently, or on a daily basis, to those which were only used in the tests, a markedly stronger decrease in the TVOC emission rate was found over a 2-month period, while the ozone emission rate hardly changed.

A good reproducibility of ozone emission was found when the agreement of measurement results from identically designed devices was investigated. However, the TVOC emission rate could vary sharply due to the use of toner cartridges from different production batches. This also applied to individual VOCs.

A proportional relationship between printing rate and TVOC emission rate has not been found. On the average a higher lightness L* may be the explanation, i.e. a more moderate blackening in the case of faster printers. Faster printers thus use less toner per page, whereby a potential VOC emission is reduced.

The investigations performed for dust characterisation unfortunately furnished no explicit results. Although toner particles could be detected on the glass-fibre filters, dust sampling has so far not been able to detect paper dust on the glass-fibre filters. Thus no conclusions have been possible as to the fraction of paper dust in total dust emission.

The use of particle spectrometers for particle counting confirmed that ultra fine dust emerged in the laser printing phase. Very different particle spectra with changing particle size as a function of time were found in the tested laser printers. A chemical characterisation of the ultra fine dust has so far not been possible. The toner, the paper or VOC/SVOC emissions may be potential sources of nanoparticles. Further tests are necessary for a more exact characterisation of the fine and ultra fine dust particles.

For this purpose methods are needed to size-classify and separate the ultra fine particles and enable an access to further physical and chemical analyses.

All in all, emission measurements of ultra fine particles from laser printers are clearly reproducible in an emission test chamber both quantitatively and as a function of time.

However, further research is needed for the integration of particle counting into the emission test method according to RAL-UZ 122 and for the specification of limiting values for particle emissions addressing the following issues:

- Comparability of measurements using different particle counters (measurement principles, sample flow rates, measurement ranges)
- Measurements in different emission test chambers (chamber volume, air exchange rate, air flow, background concentration, climate)
- different methods for the evaluation of assumed data (determination of emission rates, particle number concentrations, particle mass concentrations, total particle emissions)

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9 List of abbreviations

a*	Variegation according to CIE
b*	Variegation according to CIE
BITKOM	Federal Association for Information Industry, Telecommunication and New Media (Bundesverband Informationswirtschaft, Telekommunikation und neue Medien e.V.)
CIE	International Lighting Commission (Commission internationale de l'eclairage)
DIN	German Institute for Standardization (Deutsches Institut für Normung)
DKD	German Calibration Services (Deutscher Kalibrierdienst)
ECA	European Collaborative Action
ECMA	European Computer Manufacturer Association
EDX	Energy Dispersive X-ray Analysis
ESEM	Environmental Scanning Electron Microscope
FID	Flame Ionisation Detector
GC	Gaschromatography
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
JBMIA	Japan Business Machine and Information System Industries Association
L*	Luminosity according to CIE
LGA	State Trade Institute (Landesgewerbeanstalt, Nürnberg)
LOD	Limit of Detection (Nachweisgrenze)
LOQ	Limit of quantification (Bestimmungsgrenze)
MS	Mass Spectrometer
RAL	German Institute for Quality Assurance and Labelling (Deutsches Institut für Gütesicherung und Kennzeichnung e.V.)
SVOC	Semi Volatile Organic Compound
TEM	Transmission Electron Microscopy
TDS	Thermodesorption
TVOC	Total Volatile Organic Compounds
UBA	Federal Environment Agency (Umweltbundesamt)
UZ	Environmental Label (Umweltzeichen)
VOC	Volatile Organic Compound
VVOC	Very Volatile Organic Compound

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12 Appendix

12.1 Compilation of test results for VOCs

Pre-operating phase Device A monochromatic

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Butanol	71-36-3	13	0.01
Benzene	71-43-2	<LOD*	<LOD
Toluene	108-88-3	6	0.01
n-butyl acetate	141-32-2	4	0.00
Ethylbenzene	100-41-4	6	0.01
m,p-xylene	108-38-3/106-42-3	4	0.00
Styrene	100-42-5	21	0.02
o-xylene	95-47-6	2	0.00
Benzaldehyde	100-52-7	3	0.00
Phenol	108-95-2	22	0.02
Ethylhexanol	104-76-7	4	0.00
Acetophenone	98-86-2	6	0.01
Nonanal	124-19-6	5	0.0
Decamethylpentacyclosiloxane	541-02-6	7	0.01
Isothiocyanocyclohexane [toluene equivalent]	1122-82-3	7	0.01
Dodecane	112-40-3	3	0.00
Tridecane [dodecane equivalent]	629-50-5	3	0.00
Tetradecane	629-59-4	3	0.00
TVOC (calculated, exclusively identified substances)		119	0.11
Sum of unidentified VOC		13	0.01
TVOC (calculated, incl. unidentified substances)		**130**	**0.12**

Printing phase Device A monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emissionsrate** [mg/h]
Butanol	71-36-3	18	0.21
Benzene	71-43-2	<LOD	<LOD
Toluene	108-88-3	3	0.03
Hexanal	66-25-1	5	0.06
Ethylbenzene	100-41-4	4	0.05
m,p-xylene	108-38-3 106-42-3	2	0.02
Styrene	100-42-5	42	0.50
Benzaldehyde	100-52-7	3	0.04
Phenol	108-95-2	10	0.12
Ethylhexanol	104-76-7	3	0.03
Decamethylpentacyclosiloxane	541-02-6	5	0.05
Isothiocyanocyclohexane [toluene equivalent]	1122-82-3	4	0.05
Decanal	112-31-2	3	0.04
Tetradecane	629-59-4	2	0.02
o-hydroxybiphenyl [toluene equivalent]	90-43-7	5	0.06
BHT	128-37-0	3	0.03
TVOC (calculated, exclusively identified substances)		112	1.31
Sum of unidentified VOC		495	5.80
TVOC (calculated, incl. unidentified substances)		**607**	**7.11**

Summary Device A monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	7.11	0.12
Benzene	0.05	–	<LOD	<LOD
Styrene	1.0	–	0.50	0.02
Ozone	2	–	<LOD	<LOD
Dust	4	–	0.085	–

Pre-operating phase Device A colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Butanol	71-36-3	9	0.01
Benzene	71-43-2	<LOD	<LOD
Toluene	108-88-3	7	0.01
n-butyl acetate	141-32-2	4	0.00
Ethylbenzene	100-41-4	5	0.00
m,p-xylene	108-38-3 106-42-3	4	0.00
Styrene	100-42-5	17	0.02
o-xylene	95-47-6	2	0.00
Benzaldehyde	100-52-7	3	0.00
Phenol	108-95-2	19	0.02
Ethylhexanol	104-76-7	3	0.00
Acetophenone	98-86-2	5	0.00
Decamethylpentacyclosiloxane	541-02-6	6	0.01
Isothiocyanocyclohexane [toluene equivalent]	1122-82-3	6	0.01
TVOC (calculated, exclusively identified substances)		90	0.09
Sum of unidentified VOC		19	0.02
TVOC (calculated, incl. unidentified substances)		**108**	**0.11**

Printing phase Device A colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Butanol	71-36-3	15	0.17
Benzene	71-43-2	<LOD	<LOD
Toluene	108-88-3	4	0.04
Hexanal	66-25-1	5	0.06
n-butyl acetate	141-32-2	3	0.03
Ethylbenzene	100-41-4	8	0.09
m,p-xylene	108-38-3 106-42-3	2	0.03
Styrene	100-42-5	94	1.09
Benzaldehyde	100-52-7	7	0.08
Phenol	108-95-2	9	0.11
Octamethyltetracyclosiloxane l	556-67-2	5	0.06
Ethylhexanol	104-76-7	3	0.04
Nonanal	124-19-6	4	0.05
Decamethylpentacyclosiloxane	541-02-6	7	0.08
Isothiocyanocyclohexane [toluene equivalent]	1122-82-3	4	0.05
Tetradecane	629-59-4	2	0.02
o-hydroxybiphenyl [toluene equivalent]	90-43-7	6	0.08
BHT	128-37-0	3	0.03
TVOC (calculated, exclusively identified substances)		181	2.11
Sum of unidentified VOC		1669	19.5
TVOC (calculated, incl. unidentified substances)		**1850**	**21.6**

Summary Device A colour

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	21.6	0.11
Benzene	0.05	–	<LOD	<LOD
Styrene	1.0	–	1.09	0.02
Ozone	2	–	<LOD	<LOD
Dust	4	–	0.280	–

Pre-operating phase Device B monochromatic

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	5	0.01
Toluene	108-88-3	21	0.02
Ethylbenzene	100-41-4	6	0.01
m,p-xylene	108-38-3/106-42-3	2	0.00
Styrene	100-42-5	5	0.01
Benzaldehyde	100-52-7	3	0.00
Phenol	108-95-2	6	0.01
Ethylhexanol	104-76-7	2	0.00
TVOC (calculated, exclusively identified substances)		50	0.06
Sum of unidentified VOC		7	0.01
TVOC (calculated, incl. unidentified substances)		**57**	**0.07**

Printing phase Device B monochromatic

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	6	0.17
Toluene	108-88-3	24	0.69
Hexanal	66-25-1	5	0.14
n-butyl acetate	123-86-11	4	0.11
Ethylbenzene	100-41-4	13	0.37
m,p-xylene	108-38-3/106-42-3	3	0.07
Styrene	100-42-5	7	0.20
o-xylene	95-47-6	4	0.12
Benzaldehyde	100-52-7	12	0.34
Phenol	108-95-2	7	0.21
Ethylhexanol	104-76-7	6	0.16
Nonanal	124-19-6	6	0.18
Decamethylcyclopentasiloxane	541-02-6	3	0.10
Tetradecane	629-59-4	2	0.07
Pentadecane	629-62-9	2	0.06
Hydroxybiphenyl	90-43-7	3	0.10
BHT	128-37-0	6	0.18
TVOC (calculated, exclusively identified substances)		113	3.27
Sum of unidentified VOC		101	2.92
TVOC (calculated, incl. unidentified substances)		**214**	**6.19**

Summary Device B monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	6.19	0.07
Benzene	0.05	-	0.17	0.01
Styrene	1.0	-	0.20	0.01
Ozone	2	-	2.2	< LOD
Dust	4	-	0.3	-

Pre-operating phase Device C monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Butanol	71-36-3	64	0.07
Benzene	71-43-2	<LOD	<LOD
Toluene	108-88-3	7	0.01
Hexanal	66-25-1	2	0.00
Hexamethylcyclotrisiloxane	541-05-09	7	0.01
Styrene	100-42-5	19	0.02
Benzaldehyde	100-52-7	3	0.00
Phenol	108-95-2	9	0.01
Octamethylcyclotetrasiloxane	556-67-2	9	0.01
Ethylhexanol	104-76-7	6	0.01
Acetophenone	98-86-2	2	0.00
Nonanal	124-19-6	6	0.01
Decamethylcyclopentasiloxane	541-02-6	7	0.01
Dodecane	112-40-3	2	0.00
Tetradecane	629-59-4	2	0.00
TVOC (calculated, exclusively identified substances)		145	0.16
Sum of unidentified VOC		59	0.06
TVOC (calculated, incl. unidentified substances)		**204**	**0.22**

Printing phase Device C monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Butanol	71-36-3	81	2.21
Benzene	71-43-2	1	0.02
Propanediol	57-55-6	5	0.13
Toluene	108-88-3	7	0.20
Hexanal	66-25-1	4	0.10
Hexamethylcyclotrisiloxane	541-05-09	3	0.08
Styrene	100-42-5	11	0.29
Benzaldehyde	100-52-7	4	0.10
Phenol	108-95-2	5	0.14
Octamethylcyclotetrasiloxane	556-67-2	4	0.10
Ethylhexanol	104-76-7	7	0.18
Acetophenone	98-86-2	2	0.06
Nonanal	124-19-6	4	0.12
Decamethylcyclopentasiloxane	541-02-6	3	0.07
Tetradecane	629-59-4	2	0.07
Hydroxybiphenyl	90-43-7	6	0.17
TVOC (calculated, exclusively identified substances)		148	4.02
Sum of unidentified VOC		65	1.75
TVOC (calculated, incl. unidentified substances)		**213**	**5.77**

Summary Device C monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	5.77	0.22
Benzene	0.05	-	0.02	<LOD
Styrene	1.0	-	0.29	0.02
Ozone	2	-	<0.1	ND*
Dust	4	-	0.94	-

* non determined

Pre-operating phase Device D colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Butanol	71-36-3	63	0.06
Benzene	71-43-2	<LOD	<LOD
Toluene	108-88-3	6	0.01
Hexamethylcyclotrisiloxane	541-05-09	6	0.01
Styrene	100-42-5	14	0.01
Benzaldehyde	100-52-7	3	0.00
Phenol	108-95-2	7	0.01
Octamethylcyclotetrasiloxane	556-67-2	8	0.01
Ethylhexanol	104-76-7	5	0.01
Nonanal	124-19-6	3	0.00
Decamethylcyclopentasiloxane	541-02-6	6	0.01
TVOC (calculated, exclusively identified substances)		121	0.13
Sum of unidentified VOC		47	0.05
TVOC (calculated, incl. unidentified substances)		**168**	**0.18**

Printing phase Device D colour

Substance	CAS No	Concentration [µg/m³]	Emissionsrate [mg/h]
Butanol	71-36-3	86	2.16
Benzene	71-43-2	1	0.03
Propanediol	57-55-6	4	0.10
Toluene	108-88-3	6	0.16
Hexanal	66-25-1	2	0.06
Hexamethylcyclotrisiloxane	541-05-09	2	0.06
Ethylbenzene	100-41-4	2	0.06
Styrene	100-42-5	19	0.48
Benzaldehyde	100-52-7	5	0.14
Phenol	108-95-2	5	0.13
Octamethylcyclotetrasiloxane	556-67-2	3	0.09
Ethylhexanol	104-76-7	7	0.17
Acetophenone	98-86-2	4	0.09
Nonanal	124-19-6	4	0.09
Decamethylcyclopentasiloxane	541-02-6	2	0.06
Tetradecane	629-59-4	2	0.06
Hydroxybiphenyl	90-43-7	6	0.16
TVOC (calculated, exclusively identified substances)		159	4.07
Sum of unidentified VOC		136	3.43
TVOC (calculated, incl. unidentified substances)		**295**	**7.50**

Summary Device D colour

	Requirements for granting the environmental award		Measured emission rates	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	7.50	0.18
Benzene	0.05		0.03	<LOD
Styrene	1.0		0.48	0.01
Ozone	2		0.1	ND
Dust	4		0.9	-

Pre-operating phase Device F colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	1	0.00
Toluene	108-88-3	3	0.00
Hexamethylcyclotrisiloxane	541-05-09	5	0.01
Styrene	100-42-5	3	0.00
Benzaldehyde	100-52-7	3	0.00
Octamethylcyclotetrasiloxane	556-67-2	4	0.00
Ethylhexanol	104-76-7	3	0.00
1-octanol	111-87-5	4	0.00
Nonanal	124-19-6	5	0.01
Decamethylcyclopentasiloxane	541-02-6	6	0.01
Decanal	112-31-2	6	0.01
TVOC (calculated, exclusively identified substances)		43	0.04
Sum of unidentified VOC		36	0.04
TVOC (calculated, incl. unidentified substances)		**79**	**0.08**

Printing phase Device F colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Butanol	71-36-3	10	0.22
Benzene	71-43-2	<LOD	<LOD
Hexamethylcyclotrisiloxane	541-05-09	3	0.06
Styrene	100-42-5	3	0.06
Benzaldehyde	100-52-7	4	0.07
Phenol	108-95-2	5	0.10
Octamethylcyclotetrasiloxane	556-67-2	2	0.05
Ethylhexanol	104-76-7	2	0.05
1-octanol	111-87-5	40	0.85
Nonanal	124-19-6	5	0.10
Decamethylcyclopentasiloxane	541-02-6	2	0.05
Decanal	112-31-2	7	0.14
o-hydroxybiphenyl	90-43-7	8	0.17
TVOC (calculated, exclusively identified substances)		91	1.92
Sum of unidentified VOC		88	1.83
TVOC (calculated, incl. unidentified substances)		**179**	**3.75**

Summary Device F colour

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	3.75	0.08
Benzene	0.05	-	<LOD	<LOD
Styrene	1.0	-	0.06	<LOD
Ozone	2	-	<LOD	<LOD
Dust	4	-	<0.1	-

Pre-operating phase Device F monochromatic

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	<LOD	<LOD
Toluene	108-88-3	3	0.00
Hexamethylcyclotrisiloxane	541-05-09	4	0.00
Styrene	100-42-5	2	0.00
Benzaldehyde	100-52-7	2	0.00
Phenol	108-95-2	6	0.01
Octamethylcyclotetrasiloxane	556-67-2	3	0.00
1-octanol	111-87-5	2	0.00
Nonanal	124-19-6	3	0.00
Decamethylcyclopentasiloxane	541-02-6	6	0.01
Decanal	112-31-2	3	0.00
TVOC (calculated, exclusively identified substances)		35	0.02
Sum of unidentified VOC		34	0.03
TVOC (calculated, incl. unidentified substances)		**69**	**0.05**

Printing phase Device F monochromatic

Substance	CAS No	Concentration [µg/m³]	Emissionsrate [mg/h]
Butanol	71-36-3	19	0.50
Benzene	71-43-2	<LOD	<LOD
Propanediol	57-55-6	4	0.11
Hexanal	66-25-1	4	0.09
Styrene	100-42-5	2	0.06
Benzaldehyde	100-52-7	3	0.08
Phenol	108-95-2	4	0.10
Ethylhexanol	104-76-7	3	0.08
1-octanol	111-87-5	21	0.54
Nonanal	124-19-6	3	0.08
Decanal	112-31-2	2	0.06
o-hydroxybiphenyl	90-43-7	9	0.24
TVOC (calculated, exclusively identified substances)		74	1.94
Sum of unidentified VOC		44	1.14
TVOC (calculated, incl. unidentified substances)		**118**	**3.08**

Summary Device F monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	3.08	0.05
Benzene	0.05	-	<LOD	<LOD
Styrene	1.0	-	0.06	<LOD
Ozone	2	-	<LOD	<LOD
Dust	4	-	<0.1	-

Pre-operating phase Device G colour

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Butanol	71-36-3	16	0.02
Benzene	71-43-2	<LOD	<LOD
Propanediol	57-55-6	5	0.01
Toluene	108-88-3	7	0.01
Hexanal	66-25-1	3	0.00
n-butyl acetate	123-86-11	36	0.04
Hexamethylcyclotrisiloxane	541-05-09	7	0.01
Ethylbenzene	100-41-4	10	0.01
m,p-xylene	108-38-3/106-42-3	3	0.00
Styrene	100-42-5	15	0.02
Benzaldehyde	100-52-7	6	0.01
Phenol	108-95-2	4	0.00
Decane	124-18-5	7	0.01
Octamethylcyclotetrasiloxane	556-67-2	30	0.03
Ethylhexanol	104-76-7	5	0.01
Acetophenone	98-86-2	2	0.00
Nonanal	124-19-6	4	0.00
Undecane	1120-21-4	5	0.01
Decamethylcyclopentasiloxane	541-02-6	40	0.04
Dodecane	112-40-3	3	0.00
Tetradecane	629-59-4	2	0.00
Longifolene	475-20-7	3	0.00
BHT	128-37-0	5	0.01
TVOC (calculated, exclusively identified substances)		218	0.24
Sum of unidentified VOC		71	0.07
TVOC (calculated, incl. unidentified substances)		**289**	**0.31**

Printing phase Device G colour

Substance	CAS No	Concentration [µg/m^3]	Emission rate [mg/h]
Butanol	71-36-3	40	0.54
Benzene	71-43-2	<LOD	<LOD
Propanediol	57-55-6	7	0.10
Toluene	108-88-3	8	0.11
Hexanal	66-25-1	6	0.08
n-butyl acetate	123-86-11	23	0.31
Hexamethylcyclotrisiloxane	541-05-09	8	0.11
Ethylbenzene	100-41-4	28	0.38
Styrene	100-42-5	22	0.30
n-butyl ether	142-96-1	13	0.18
Benzaldehyde	100-52-7	20	0.27
Propylbenzene	103-65-1	8	0.11
Phenol	108-95-2	4	0.05
Decane	124-18-5	7	0.10
Octamethylcyclotetrasiloxane	556-67-2	15	0.20
Ethylhexanol	104-76-7	8	0.11
Acetophenone	98-86-2	3	0.04
1-octanol	111-87-5	2	0.03
Nonanal	124-19-6	6	0.08
Undecane	1120-21-4	3	0.04
Decamethylcyclopentasiloxane	541-02-6	20	0.27
Decanal	112-31-2	3	0.04
Dodecane	112-40-3	4	0.05
Tetradecane	629-59-4	4	0.05
Longifolene	475-20-7	3	0.04
o-hydroxybiphenyl	90-43-7	10	0.14
BHT	128-37-0	7	0.09
TVOC (calculated, exclusively identified substances)		283	3.84
Sum of unidentified VOC		147	1.99
TVOC (calculated, incl. unidentified substances)		**430**	**5.83**

Summary Device G colour

	Requirements for granting the environmental award		Measured emission rates	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	5.83	0.31
Benzene	0.05		< LOD	< LOD
Styrene	1.0		0.30	0.02
Ozone	2		< LOD	< LOD
Dust	4		0.3	-

Pre-operating phase Device G monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Butanol	71-36-3	16	0.02
Benzene	71-43-2	<LOD	<LOD
Propanediol	57-55-6	4	0.00
Toluene	108-88-3	8	0.01
Hexanal	66-25-1	4	0.00
n-butyl acetate	123-86-11	42	0.04
Hexamethylcyclotrisiloxane	541-05-09	7	0.01
Ethylbenzene	100-41-4	11	0.01
m,p-xylene	108-38-3/106-42-3	2	0.00
Styrene	100-42-5	18	0.02
Benzaldehyde	100-52-7	6	0.01
Phenol	108-95-2	4	0.00
Decane	124-18-5	4	0.00
Octamethylcyclotetrasiloxane	556-67-2	34	0.03
Ethylhexanol	104-76-7	6	0.01
Acetophenone	98-86-2	3	0.00
Nonanal	124-19-6	5	0.01
Undecane	1120-21-4	2	0.00
Decamethylcyclopentasiloxane	541-02-6	46	0.05
Decanal	112-31-2	3	0.00
Dodecane	112-40-3	3	0.00
Acryl-(2-ethylhexyl ester)	103-11-7	3	0.00
Tetradecane	629-59-4	3	0.00
Longifolene	475-20-7	4	0.00
BHT	128-37-0	6	0.01
TVOC (calculated, exclusively identified substances)		243	0.24
Sum of unidentified VOC		91	0.09
TVOC (calculated, incl. unidentified substances)		**334**	**0.33**

Printing phase Device G monochromatic

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Butanol	71-36-3	30	0.41
Benzene	71-43-2	<LOD	<LOD
Propanediol	57-55-6	6	0.08
Toluene	108-88-3	7	0.10
Hexanal	66-25-1	5	0.07
n-butyl acetate	123-86-11	19	0.26
Hexamethylcyclotrisiloxane	541-05-09	6	0.08
Ethylbenzene	100-41-4	16	0.22
m,p-xylene	108-38-3/106-42-3	2	0.03
Styrene	100-42-5	13	0.18
Benzaldehyde	100-52-7	10	0.14
Propylbenzene	103-65-1	4	0.05
Phenol	108-95-2	3	0.04
Decane	124-18-5	6	0.08
Octamethylcyclotetrasiloxane	556-67-2	13	0.18
Ethylhexanol	104-76-7	7	0.10
Acetophenone	98-86-2	2	0.03
Nonanal	124-19-6	5	0.07
Undecane	1120-21-4	2	0.03
Decamethylcyclopentasiloxane	541-02-6	18	0.24
Decanal	112-31-2	2	0.03
Dodecane	112-40-3	3	0.04
Acryl-(2-ethylhexyl ester)	103-11-7	2	0.03
Tetradecane	629-59-4	3	0.04
Longifolene	475-20-7	3	0.04
o-hydroxybiphenyl	90-43-7	8	0.11
BHT	128-37-0	6	0.08
TVOC (calculated, exclusively identified substances)		202	2.74
Sum of unidentified VOC		95	1.29
TVOC (calculated, incl. unidentified substances)		**297**	**4.03**

Summary Device G monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	4.03	0.33
Benzene	0.05	-	< LOD	< LOD
Styrene	1.0	-	0.18	0.02
Ozone	2	-	< LOD	< LOD
Dust	4	-	0.14	-

Pre-operating phase Device H colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	< LOD	< LOD
Acetic acid	64-19-7	4	0.00
Toluene	108-88-3	2	0.00
Styrene	100-42-5	6	0.01
Benzaldehyde	100-52-7	3	0.00
Phenol	108-95-2	7	0.01
Acetophenone	98-86-2	2	0.00
Nonanal	124-19-6	4	0.00
Decamethylcyclopentasiloxane	541-02-6	3	0.00
Decanal	112-31-2	3	0.00
TVOC (calculated, exclusively identified substances)		34	0.02
Sum of unidentified VOC		8	0.01
TVOC (calculated, incl. unidentified substances)		**42**	**0.03**

Printing phase Device H colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	1	0.01
Acetic acid	64-19-7	6	0.09
Toluene	108-88-3	2	0.03
Hexanal	66-25-1	3	0.04
Hexamethylcyclotrisiloxane	541-05-09	4	0.07
Ethylbenzene	100-41-4	2	0.03
Styrene	100-42-5	37	0.55
Benzaldehyde	100-52-7	6	0.08
Propylbenzene	103-65-1	4	0.06
Phenol	108-95-2	14	0.22
Octamethylcyclotetrasiloxane	556-67-2	7	0.11
Ethylhexanol	104-76-7	2	0.03
Acetophenone	98-86-2	3	0.04
Nonanal	124-19-6	6	0.09
Decamethylcyclopentasiloxane	541-02-6	10	0.15
Decanal	112-31-2	4	0.07
o-hydroxybiphenyl	90-43-7	10	0.00
TVOC (calculated, exclusively identified substances)		121	182
Sum of unidentified VOC		350	5.30
TVOC (calculated, incl. unidentified substances)		**471**	**7.12**

Summary Device H colour

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	7.12	0.03
Benzene	0.05		0.01	< LOD
Styrene	1.0		0.55	0.01
Ozone	2.0		< 0.1	< LOD
Dust	4.0		0.2	-

Pre-operating phase Device H monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Acetic acid	64-19-7	4	0.0
Benzene	71-43-2	<LOD	<LOD
Toluene	108-88-3	6	0.01
n-butyl acetate	123-86-11	3	0.00
Hexamethylcyclotrisiloxane	541-05-09	2	0.00
m,p-xylene	108-38-3/106-42-3	2	0.00
Styrene	100-42-5	9	0.01
Benzaldehyde	100-52-7	4	0.00
Phenol	108-95-2	15	0.02
Octamethylcyclotetrasiloxane	556-67-2	4	0.00
Ethylhexanol	104-76-7	2	0.00
Acetophenone	98-86-2	4	0.00
Nonanal	124-19-6	3	0.00
Decamethylcyclopentasiloxane	541-02-6	6	0.01
Decanal	112-31-2	2	0.00
TVOC (calculated, exclusively identified substances)		66	0.05
Sum of unidentified VOC		31	0.03
TVOC (calculated, incl. unidentified substances)		**97**	**0.08**

Printing phase Device H monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Butanol	71-36-3	17	0.47
Benzene	71-43-2	<LOD	<LOD
Acetic acid	64-19-7	5	0.14
Benzene	71-43-2	1	0.02
Propanediol	57-55-6	3	0.08
Toluene	108-88-3	2	0.04
Hexanal	66-25-1	7	0.19
Hexamethylcyclotrisiloxane	541-05-09	3	0.07
Styrene	100-42-5	11	0.30
Propylbenzene	103-65-1	2	0.06
Phenol	108-95-2	13	0.36
Octamethylcyclotetrasiloxane	556-67-2	4	0.11
Ethylhexanol	104-76-7	4	0.11
Acetophenone	98-86-2	3	0.07
Nonanal	124-19-6	7	0.18
Decamethylcyclopentasiloxane	541-02-6	7	0.18
Decanal	112-31-2	2	0.05
o-hydroxybiphenyl	90-43-7	14	0.37
TVOC (calculated, exclusively identified substances)		105	2.80
Sum of unidentified VOC		150	4.03
TVOC (calculated, incl. unidentified substances)		**255**	**6.83**

Summary Device H monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	6.83	0.08
Benzene	0.05	-	0.02	<LOD
Styrene	1.0	-	0.3	0.01
Ozone	2.0	-	0.2	<LOD
Dust	4.0	-	0.2	-

Pre-operating phase Device I colour

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	5	0.01
Acetic acid	64-19-7	652	0.65
Toluene	108-88-3	37	0.04
Hexamethylcyclotrisiloxane	541-05-09	5	0.01
Ethylbenzene	100-41-4	2	0.00
m,p-xylene	108-38-3/106-42-3	2	0.00
Styrene	100-42-5	4	0.00
Benzaldehyde	100-52-7	3	0.00
Phenol	108-95-2	7	0.01
Octamethylcyclotetrasiloxane	556-67-2	36	0.04
Acetophenone	98-86-2	2	0.00
Nonanal	124-19-6	4	0.00
Decamethylcyclopentasiloxane	541-02-6	35	0.03
Decanal	112-31-2	8	0.01
BHT	128-37-0	32	0.03
TVOC (calculated, exclusively identified substances)		834	0.83
Sum of unidentified VOC		106	0.11
TVOC (calculated, incl. unidentified substances)		**940**	**0.94**

Printing phase Device I colour

Substance	**CAS No**	**Concentration** [µg/m³]	**Emissionsrate** [mg/h]
Benzene	71-43-2	2	0.05
Acetic acid	64-19-7	180	3.95
Propanediol	57-55-6	3	0.08
Toluene	108-88-3	19	0.41
Hexamethylcyclotrisiloxane	541-05-09	3	0.07
Styrene	100-42-5	4	0.08
Benzaldehyde	100-52-7	2	0.05
Phenol	108-95-2	8	0.17
Octamethylcyclotetrasiloxane	556-67-2	18	0.40
Ethylhexanol	104-76-7	2	0.05
Nonanal	124-19-6	5	0.11
Decamethylcyclopentasiloxane	541-02-6	19	0.41
Decanal	112-31-2	8	0.17
o-hydroxybiphenyl	90-43-7	11	0.25
BHT	128-37-0	22	0.49
TVOC (calculated, exclusively identified substances)		306	6.74
Sum of unidentified VOC		84	1.86
TVOC (calculated, incl. unidentified substances)		**390**	**8.60**

Summary Device I colour

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	8.60	0.94
Benzene	0.05		0.05	0.01
Styrene	1.0		0.08	0.00
Ozone	2		0.4	< LOD
Dust	4		1	-

Pre-operating phase Device I monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	6	0.01
Acetic acid	64-19-7	868	0.86
Toluene	108-88-3	42	0.04
Hexamethylcyclotrisiloxane	541-05-09	6	0.01
Ethylbenzene	100-41-4	3	0.00
m,p-xylene	108-38-3/106-42-3	2	0.00
Styrene	100-42-5	5	0.01
Benzaldehyde	100-52-7	4	0.00
Phenol	108-95-2	7	0.01
Octamethylcyclotetrasiloxane	556-67-2	41	0.04
Acetophenone	98-86-2	3	0.00
Nonanal	124-19-6	5	0.01
Decamethylcyclopentasiloxane	541-02-6	40	0.04
Decanal	112-31-2	9	0.01
BHT	128-37-0	41	0.04
TVOC (calculated, exclusively identified substances)		1082	1.08
Sum of unidentified VOC		127	0.13
TVOC (calculated, incl. unidentified substances)		**1209**	**1.21**

Printing phase Device I monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	3	0.05
Acetic acid	64-19-7	250	5.15
Propanediol	57-55-6	4	0.08
Toluene	108-88-3	21	0.44
Hexanal	66-25-1	2	0.04
Hexamethylcyclotrisiloxane	541-05-09	3	0.06
Styrene	100-42-5	4	0.08
Benzaldehyde	100-52-7	2	0.05
Phenol	108-95-2	7	0.14
Octamethylcyclotetrasiloxane	556-67-2	23	0.48
Ethylhexanol	104-76-7	2	0.05
Nonanal	124-19-6	5	0.10
Decamethylcyclopentasiloxane	541-02-6	22	0.46
Decanal	112-31-2	7	0.14
o-hydroxybiphenyl	90-43-7	14	0.30
BHT	128-37-0	28	0.60
TVOC (calculated, exclusively identified substances)		390	8.22
Sum of unidentified VOC		88	1.87
TVOC (calculated, incl. unidentified substances)		**478**	**10.09**

Summary Device I monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	10.09	1.21
Benzene	0.05	-	0.05	0.01
Styrene	1.0	-	0.08	0.01
Ozone	2	-	0.4	< LOD
Dust	4	-	0.5	-

Pre-operating phase Device J colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	< LOD	0.00
Propanediol	57-55-6	9	0.01
Toluene	108-88-3	49	0.05
n-butyl acetate	123-86-11	3	0.00
Ethylbenzene	100-41-4	5.5	0.01
m/p-xylene	108-38-3/106-42-3	44	0.00
Styrene	100-42-5	10.5	0.01
1,3,5-trimethylbenzene	108-67-8	3	0.00
Phenol	108-95-2	3	0.00
1,2,4-trimethylbenzene	95-63-6	3	0.00
Octamethylcyclotetrasiloxane	556-67-2	16.5	0.02
Ethylhexanol	104-76-7	3.5	0.00
Acetophenone	98-86-2	2.5	0.00
1-octanol	111-87-5	2	0.00
Undecane	120-21-4	3	0.00
Decamethylcyclopentasiloxane	541-02-6	12	0.01
Longifolene	475-20-7	2.5	0.00
Cumene	98-82-8	2	0.00
alpha-pinene	80-56-8	7.5	0.01
3-carene	498-15-7	4.5	0.00
Dipropylene glycol methyl ether	34590-94-8	5	0.01
TVOC (calculated, exclusively identified substances)		151	0.15
Sum of unidentified VOC		25	0.02
TVOC (calculated, incl. unidentified substances)		**176**	**0.17**

Printing phase Device J colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	< LOD	0.00
Butanol	71-36-3	6	0.12
Propanediol	57-55-6	4	0.08
Toluene	108-88-3	32	0.63
Hexamethylcyclotrisiloxane	541-05-09	4	0.08
Ethylbenzene	100-41-4	7	0.14
m,p-xylene	108-38-3/106-42-3	4	0.08
Styrene	100-42-5	8	0.16
Benzaldehyde	100-52-7	4	0.08
Phenol	108-95-2	3	0.06
Octamethylcyclotetrasiloxane	556-67-2	18	0.36
Ethylhexanol	104-76-7	3	0.06
Decamethylcyclopentasiloxane	541-02-6	13	0.26
TVOC (calculated, exclusively identified substances)		106	2.11
Sum of unidentified VOC		38	0.75
TVOC (calculated, incl. unidentified substances)		**144**	**2.86**

Summary Device J colour

	Requirements for granting the environmental award		Measured emission rates	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	2.86	0.15
Benzene	0.05		< LOD	< LOD
Styrene	1.0		0.16	0.01
Ozone	2		< 0.1	< LOD
Dust	4		0.4	-

Pre-operating phase Device J monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	1	0.00
Propanediol	57-55-6	12	0.01
Toluene	108-88-3	76	0.07
n-butyl acetate	123-86-11	4	0.00
Hexamethylcyclotrisiloxane	541-05-09	4	0.00
Ethylbenzene	100-41-4	8	0.01
m,p-xylene	108-38-3/106-42-3	6	0.01
Styrene	100-42-5	18	0.02
Benzaldehyde	100-52-7	8	0.01
Phenol	108-95-2	5	0.01
Decane	124-18-5	5	0.00
Octamethylcyclotetrasiloxane	556-67-2	18	0.02
Ethylhexanol	104-76-7	12	0.01
Acetophenone	98-86-2	6	0.01
Nonanal	124-19-6	4	0.00
Dodecane	112-40-3	3	0.00
Decamethylcyclopentasiloxane	541-02-6	12	0.01
Decanal	112-31-2	2	0.00
Tetradecane	629-59-4	3	0.00
Pentadecane	629-62-9	3	0.00
TVOC (calculated, exclusively identified substances)		210	0.19
Sum of unidentified VOC		69	0.07
TVOC (calculated, incl. unidentified substances)		**279**	**0.26**

Printing phase Device J monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	0	0.01
Propanediol	57-55-6	8	0.21
Toluene	108-88-3	32	0.82
Hexamethylcyclotrisiloxane	541-05-09	3	0.07
Ethylbenzene	100-41-4	5	0.12
m,p-xylene	108-38-3/106-42-3	3	0.07
Styrene	100-42-5	10	0.25
Benzaldehyde	100-52-7	5	0.13
Phenol	108-95-2	4	0.10
Decane	124-18-5	2	0.05
Octamethylcyclotetrasiloxane	556-67-2	5	0.14
Ethylhexanol	104-76-7	5	0.12
Acetophenone	98-86-2	3	0.08
Nonanal	124-19-6	5	0.12
Decamethylcyclopentasiloxane	541-02-6	4	0.10
Decanal	112-31-2	6	0.14
Tetradecane	629-59-4	3	0.07
Pentadecane	629-62-9	3	0.07
o-hydroxybiphenyl	90-43-7	3	0.06
BHT	128-37-0	2	0.05
TVOC (calculated, exclusively identified substances)		111	2.78
Sum of unidentified VOC		55	1.41
TVOC (calculated, incl. unidentified substances)		**166**	**4.19**

Summary Device J monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	4.19	0.26
Benzene	0.05	-	0.01	< LOD
Styrene	1.0	-	0.25	0.02
Ozone	2	-	< 0.1	< LOD
Dust	4	-	0.2	-

Pre-operating phase Device K colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	1	0.001
Butanol	71-36-3	19	0.02
Toluene	108-88-3	5	0.01
Hexanal	66-25-1	3	0.00
Hexamethylcyclotrisiloxane	541-05-09	268	0.26
Ethylbenzene	100-41-4	3	0.00
m,p-xylene	108-38-3/106-42-3	2	0.00
Styrene	100-42-5	68	0.07
Benzaldehyde	100-52-7	6	0.01
Phenol	108-95-2	17	0.02
Octamethylcyclotetrasiloxane	556-67-2	51	0.05
Ethylhexanol	104-76-7	5	0.01
Acetophenone	98-86-2	3	0.00
1-octanol	111-87-5	2	0.00
Nonanal	124-19-6	4	0.00
Decamethylcyclopentasiloxane	541-02-6	60	0.06
BHT	128-37-0	3	0.00
TVOC (calculated, exclusively identified substances)		520	0.51
Sum of unidentified VOC		589	0.57
TVOC (calculated, incl. unidentified substances)		**1109**	**1.08**

Printing phase Device K colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	0.2	0.004
Butanol	71-36-3	25	0.52
Toluene	108-88-3	3	0.06
Hexanal	66-25-1	3	0.07
Hexamethylcyclotrisiloxane	541-05-09	100	2.10
Ethylbenzene	100-41-4	3	0.05
Styrene	100-42-5	64	1.34
Benzaldehyde	100-52-7	6	0.13
Phenol	108-95-2	18	0.37
Octamethylcyclotetrasiloxane	556-67-2	23	0.47
Ethylhexanol	104-76-7	8	0.17
Acetophenone	98-86-2	3	0.06
1-octanol	111-87-5	14	0.29
Nonanal	124-19-6	4	0.08
Decamethylcyclopentasiloxane	541-02-6	37	0.78
Tetradecane	629-59-4	3	0.05
o-hydroxybiphenyl	90-43-7	6	0.12
BHT	128-37-0	2	0.05
TVOC (calculated, exclusively identified substances)		322	6.71
Sum of unidentified VOC		369	7.73
TVOC (calculated, incl. unidentified substances)		**691**	**14.44**

Summary Device K colour

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	14.44	1.08
Benzene	0.05		0.004	0.001
Styrene	1.0		1.34	0.07
Ozone	2		< LOD	< LOD
Dust	4		0.8	-

Pre-operating phase Device K monochromatic

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	<LOD	<LOD
Butanol	71-36-3	15	0.02
Toluene	108-88-3	5	0.01
Hexanal	66-25-1	2	0.00
Hexamethylcyclotrisiloxane	541-05-09	244	0.24
Ethylbenzene	100-41-4	4	0.00
m,p-xylene	108-38-3/106-42-3	3	0.00
Styrene	100-42-5	84	0.08
Benzaldehyde	100-52-7	6	0.01
Phenol	108-95-2	19	0.02
Octamethylcyclotetrasiloxane	556-67-2	51	0.05
Ethylhexanol	104-76-7	5	0.01
Acetophenone	98-86-2	3	0.00
1-octanol	111-87-5	2	0.00
Nonanal	124-19-6	4	0.00
Decamethylcyclopentasiloxane	541-02-6	69	0.07
BHT	128-37-0	3	0.00
TVOC (calculated, exclusively identified substances)		519	0.51
Sum of unidentified VOC		716	0.70
TVOC (calculated, incl. unidentified substances)		**1235**	**1.21**

Printing phase Device K monochromatic

Substance	CAS No	Concentration [µg/m³]	Emissionsrate [mg/h]
Benzene	71-43-2	<LOD	<LOD
Butanol	71-36-3	14	0.28
Hexanal	66-25-1	2	0.05
Hexamethylcyclotrisiloxane	541-05-09	81	1.67
Styrene	100-42-5	36	0.74
Benzaldehyde	100-52-7	4	0.08
Phenol	108-95-2	15	0.30
Octamethylcyclotetrasiloxane	556-67-2	19	0.40
Ethylhexanol	104-76-7	5	0.10
Acetophenone	98-86-2	2	0.04
1-octanol	111-87-5	4	0.08
Nonanal	124-19-6	3	0.07
Decamethylcyclopentasiloxane	541-02-6	32	0.66
o-hydroxybiphenyl	90-43-7	4	0.08
BHT	128-37-0	2	0.05
TVOC (calculated, exclusively identified substances)		223	4.60
Sum of unidentified VOC		347	7.18
TVOC (calculated, incl. unidentified substances)		**570**	**11.78**

Summary Device K monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	11.78	1.21
Benzene	0.05	-	< LOD	< LOD
Styrene	1.0	-	0.74	0.08
Ozone	2	-	< LOD	< LOD
Dust	4	-	0.8	-

Pre-operating phase Device L colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	1.5	0.00
Butanol	71-36-3	65	0.07
Toluene	108-88-3	11	0.01
Hexanal	66-25-1	4	0.00
Styrene	100-42-5	19	0.02
Benzaldehyde	100-52-7	3	0.00
Phenol	108-95-2	3	0.00
1,2,4-trimethylbenzene	95-63-6	7	0.01
Octamethylcyclotetrasiloxane	556-67-2	5	0.01
Ethylhexanol	104-76-7	4	0.00
Acetophenone	98-86-2	3	0.00
1-octanol	111-87-5	3	0.00
Nonanal	124-19-6	6	0.01
TVOC (calculated, exclusively identified substances)		133	0.13
Sum of unidentified VOC		9	0.01
TVOC (calculated, incl. unidentified substances)		**142**	**0.14**

Printing phase Device L colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	1.4	0.037
Butanol	71-36-3	71	1.873
Toluene	108-88-3	14	0.36
Hexanal	66-25-1	3	0.08
Ethylbenzene	100-41-4	4	0.11
Styrene	100-42-5	35	0.93
Benzaldehyde	100-52-7	8	0.21
1,2,4-trimethylbenzene	95-63-6	3	0.08
Ethylhexanol	104-76-7	4	0.11
1-octanol	111-87-5	50	1.33
Nonanal	124-19-6	4	0.11
Tetradecane	629-59-4	2	0.06
o-hydroxybiphenyl	90-43-7	7	0.18
TVOC (calculated, exclusively identified substances)		205	5.42
Sum of unidentified VOC		56	1.48
TVOC (calculated, incl. unidentified substances)		**261**	**6.91**

Summary Device L colour

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	6.91	0.14
Benzene	0.05	-	0.037	0.00
Styrene	1.0	-	0.93	0.02
Ozone	2.0	-	< 0.5	ND
Dust	4.0	-	1.2	-

Pre-operating phase Device L monochromatic

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	1.3	0.00
Butanol	71-36-3	79	0.08
Toluene	108-88-3	12	0.01
Hexanal	66-25-1	4	0.00
Hexamethylcyclotrisiloxane	541-05-09	4	0.00
Styrene	100-42-5	24	0.02
Benzaldehyde	100-52-7	3	0.00
1,3,5-trimethylbenzene	108-67-8	2	0.00
Phenol	108-95-2	4	0.00
1,2,4-trimethylbenzene	95-63-6	8	0.01
Octamethylcyclotetrasiloxane	556-67-2	5	0.01
1,2,3-trimethylbenzene	526-73-8	2	0.00
Ethylhexanol	104-76-7	4	0.00
Acetophenone	98-86-2	3	0.00
1-octanol	111-87-5	3	0.00
Nonanal	124-19-6	5	0.01
Decamethylcyclopentasiloxane	541-02-6	5	0.01
TVOC (calculated, exclusively identified substances)		167	0.17
Sum of unidentified VOC		10	0.01
TVOC (calculated, incl. unidentified substances)		**177**	**0.18**

Printing phase Device L monochromatic

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene ^{x}	71-43-2	1.7	0.045
Butanol	71-36-3	92	2.44
Toluene	108-88-3	25	0.67
Hexanal	66-25-1	4	0.10
Ethylbenzene	100-41-4	6	0.15
m,p-xylene	108-38-3/106-42-3	2	0.06
Styrene	100-42-5	14	0.37
Benzaldehyde	100-52-7	6	0.15
Phenol	108-95-2	3	0.07
1,2,4-trimethylbenzene	95-63-6	5	0.12
Ethylhexanol	104-76-7	5	0.14
1-octanol	111-87-5	21	0.57
Nonanal	124-19-6	3	0.09
o-hydroxybiphenyl	90-43-7	10	0.27
TVOC (calculated, exclusively identified substances)		196	5.24
Sum of unidentified VOC		24	0.64
TVOC (calculated, incl. unidentified substances)		**220**	**5.88**

Summary Device L monochromatic

	Requirements for granting the environmental award		Measured emission rates	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	5.88	0.18
Benzene	0.05	-	0.045	0.00
Styrene	1.0	-	0.37	0.02
Ozone	2.0	-	< 0.2	ND
Dust	4.0	-	1.3	-

Pre-operating phase Device M colour

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Hexane	110-54-3	5	0.01
Benzene	71-43-2	< LOD	< LOD
Toluene	108-88-3	8	0.01
Hexanal	66-25-1	3	0.00
n-butyl acetate	123-86-4	3	0.00
Hexamethylcyclotrisiloxane	541-05-9	6	0.01
Ethylbenzene	100-41-4	6	0.01
m,p-xylene	108-38-3/106-42-3	21	0.02
Styrene	100-42-5	<LOD	< LOD
Benzaldehyde	100-52-7	3	0.00
Phenol	108-95-2	19	0.02
Decane	124-18-5	4	0.00
Octamethylcyclotetrasiloxane	556-67-2	33	0.03
Ethylhexanol	104-76-7	11	0.01
Acetophenone	98-86-2	4	0.00
Decamethylcyclopentasiloxane	541-02-6	83	0.08
BHT	128-37-0	3	0.00
TVOC (calculated, exclusively identified substances)		218	0.21
Sum of unidentified VOC		97	0.10
TVOC (calculated, incl. unidentified substances)		**315**	**0.31**

Printing phase Device M colour

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	1.32	0.03
Butanol	71-36-3	3	0.07
Heptane	142-82-5	3	0.06
Toluene	108-88-3	3	0.09
Hexamethylcyclotrisiloxane	541-05-9	5	0.13
Ethylbenzene	100-41-4	3	0.08
Styrene	100-42-5	27	0.66
Benzaldehyde	100-52-7	4	0.09
Phenol	108-95-2	16	0.39
Octamethylcyclotetrasiloxane	556-67-2	14	0.35
Ethylhexanol	104-76-7	5	0.12
Acetophenone	98-86-2	5	0.13
Decamethylcyclopentasiloxane	541-02-6	40	0.97
o-hydroxybiphenyl	90-43-7	5	0.13
TVOC (calculated, exclusively identified substances)		133	3.26
Sum of unidentified VOC		201	4.91
TVOC (calculated, incl. unidentified substances)		**334**	**8.17**

Summary Device M colour

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	4.13	0.31
Benzene	0.05		0.03	<LOD
Styrene	1.0		0.66	<LOD
Ozone	2.0		< 0.1	-
Dust	4.0		0.2	-

Pre-operating phase Device M monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Hexane	110-54-3	2	0.00
Benzene	71-43-2	2	0.00
Butanol	71-36-3	5	0.01
Toluene	108-88-3	8	0.01
n-butylacetate	123-86-4	3	0.00
Hexamethylcyclotrisiloxane	541-05-9	7	0.1
Ethylbenzene	100-41-4	5	0.01
m,p–xylene	108-38-3/106-42-3	4	0.00
Styrene	100-42-5	20	0.02
Benzaldehyde	100-52-7	2	0.00
Phenol	108-95-2	19	0.02
Decane	124-18-5	3	0.00
Octamethylcyclotetrasiloxane	556-67-2	28	0.03
Ethylhexanol	104-76-7	11	0.01
Acetophenone	98-86-2	3	0.00
Decamethylcyclopentasiloxane	541-02-6	75	0.75
BHT	128-37-0	3	0.00
TVOC (calculated, exclusively identified substances)		200	0.20
Sum of unidentified VOC		84	0.08
TVOC (calculated, incl. unidentified substances)		**284**	**0.28**

Printing phase Device M monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	1.53	0.05
Butanol	71-36-3	4	0.14
Toluene	108-88-3	3	0.10
Hexanal	66-25-1	4	0.12
n-butyl acetate	123-86-4	2	0.07
Hexamethylcyclotrisiloxane	541-05-9	5	0.17
Ethylbenzene	100-41-4	2	0.08
Styrene	100-42-5	18	0.59
Benzaldehyde	100-52-7	3	0.11
Phenol	108-95-2	15	0.52
Octamethylcyclotetrasiloxane	556-67-2	12	0.39
Ethylhexanol	104-76-7	6	0.19
Acetophenone	98-86-2	4	0.13
Nonanal	124-19-6	4	0.14
Decamethylcyclopentasiloxane	541-02-6	37	1.24
o-hydroxybiphenyl	90-43-7	12	0.39
TVOC (calculated, exclusively identified substances)		131	4.37
Sum of unidentified VOC		148	4.91
TVOC (calculated, incl. unidentified substances)		**279**	**9.28**

Summary Device M monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	9.28	0.28
Benzene	0.05	-	0.05	0.00
Styrene	1.0	-	0.59	0.02
Ozone	2.0	-	< 0.2	-
Dust	4.0	-	0.4	-

Pre-operating phase Device N colour

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	< LOD	< LOD
Trichloroethylene	79-01-6	5	0.01
Butanol	71-36-3	8	0.01
Toluene	108-88-3	31	0.03
Hexanal	66-25-1	6	0.01
Hexamethylcyclotrisiloxane	541-05-9	2	0.00
Ethylbenzene	100-41-4	29	0.03
m,p–xylene	108-38-3/106-42-3	5	0.01
Styrene	100-42-5	42	0.04
o–xylene	95-47-6	2	0.00
Benzaldehyde	100-52-7	4	0.00
alpha-pinene	80-56-8	2	0.00
Propylbenzene	103-65-1	2	0.00
Phenol	108-95-2	3	0.00
1,2,4-trimethybenzene	95-63-6	6	0.01
Octamethylcyclotetrasiloxane	556-67-2	5	0.01
Ethylhexanol	104-76-7	8	0.01
Acetophenone	98-86-2	10	0.01
Nonanal	124-19-6	2	0.00
Decamethylcyclopentasiloxane	541-02-6	4	0.00
Tetradecane	629-59-4	4	0.00
BHT	128-37-0	21	0.02
Hexadecane	544-76-3	2	0.00
TVOC (calculated, exclusively identified substances)		205	0.21
Sum of unidentified VOC		51	0.05
TVOC (calculated, incl. unidentified substances)		**256**	**0.26**

Printing phase Device N colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	< LOD	< LOD
Trichloroethylene	79-01-6	9	0.04
Butanol	71-36-3	11	0.06
Toluene	108-88-3	33	0.16
Hexanal	66-25-1	6	0.03
Hexamethylcyclotrisiloxane	541-05-9	2	0.01
Ethylbenzene	100-41-4	26	0.13
m,p–xylene	108-38-3/106-42-3	5	0.02
Styrene	100-42-5	40	0.19
o–xylene	95-47-6	2	0.01
Benzaldehyde	100-52-7	4	0.02
alpha-pinene	80-56-8	2	0.01
Propylbenzene	108-95-2	2	0.01
Phenol	108-95-2	3	0.01
1,2,4-trimethybenzene	95-63-6	4	0.02
Octamethylcyclotetrasiloxane	556-67-2	6	0.03
Ethylhexanol	104-76-7	6	0.03
Acetophenone	98-86-2	11	0.06
Decamethylcyclopentasiloxane	541-02-6	4	0.02
Dodecane	112-40-3	2	0.01
Tetradecane	629-59-4	4	0.02
BHT	128-37-0	22	0.11
Hexadecane	544-76-3	2	0.01
TVOC (calculated, exclusively identified substances)		204	1.01
Sum of unidentified VOC		101	0.5
TVOC (calculated, incl. unidentified substances)		**305**	**1.51**

Summary Device N colour

	Requirements for granting the environmental award		Measured emission rates	
Emitter	Printing phase [mg/h]	Pre-operating phase [mg/h]	Printing phase [mg/h]	Pre-operating phase [mg/h]
TVOC	10	1	1.51	0.26
Benzene	0.05		< LOD	< LOD
Styrene	1.0		0.19	0.04
Ozone	2.0		< LOD	< LOD
Dust	4.0		< LOD	-

Pre-operating phase Device N monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	< LOD	< LOD
Butanol	71-36-3	5	0.01
Trichloroethylene	79-01-6	4	0.00
Toluene	108-88-3	38	0.04
Hexanal	66-25-1	3	0.00
Hexamethylcyclotrisiloxane	541-05-9	3	0.00
Ethylbenzene	100-41-4	19	0.02
m,p–xylene	108-38-3/106-42-3	5	0.01
Styrene	100-42-5	25	0.02
o–xylene	95-47-6	2	0.00
Benzaldehyde	100-52-7	3	0.00
alpha-pinene	80-56-8	4	0.00
Propylbenzene	103-65-1	2	0.00
Phenol	108-95-2	2	0.00
1,2,4-trimethylbenzene	95-63-6	7	0.01
Octamethylcyclotetrasiloxane	556-67-2	7	0.01
Ethylhexanol	104-76-7	6	0.01
Acetophenone	98-86-2	7	0.01
Decamethylcyclopentasiloxane	541-02-6	5	0.1
Dodecane	112-40-3	2	0.00
Tetradecane	629-59-4	4	0.00
BHT	128-37-0	22	0.02
Hexadecane	544-76-3	2	0.00
TVOC (calculated, exclusively identified substances)		177	0.17
Sum of unidentified VOC		51	0.05
TVOC (calculated, incl. unidentified substances)		**288**	**0.22**

Printing phase Device N monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	< LOD	< LOD
Butanol	71-36-3	7	0.04
Trichloroethylene	79-01-6	7	0.04
Toluene	108-88-3	39	0.22
Hexanal	66-25-1	4	0.02
Hexamethylcyclotrisiloxane	541-05-9	3	0.02
Ethylbenzene	100-41-4	18	0.10
m,p–xylene	108-38-3/106-42-3	4	0.02
Styrene	100-42-5	24	0.13
o–xylene	95-47-6	2	0.01
Benzaldehyde	100-52-7	3	0.02
alpha-pinene	80-56-8	3	0.02
Propylbenzene	103-65-1	2	0.01
1,2,4-trimethylbenzene	95-63-6	7	0.04
Octamethylcyclotetrasiloxane	556-67-2	7	0.04
Ethylhexanol	104-76-7	5	0.03
Acetophenone	98-86-2	8	0.04
Decamethylcyclopentasiloxane	541-02-6	5	0.03
Dodecane	112-40-3	2	0.01
Tetradecane	629-59-4	3	0.02
BHT	128-37-0	21	0.11
Hexadecane	544-76-3	2	0.01
TVOC (calculated, exclusively identified substances)		176	0.96
Sum of unidentified VOC		77	0.42
TVOC (calculated, incl. unidentified substances)		**253**	**1.38**

Summary Device N monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	1.38	0.22
Benzene	0.05	-	< LOD	< LOD
Styrene	1.0	-	0.13	0.02
Ozone	2.0	-	<LOD	<LOD
Dust	4.0	-	<0.1	-

Pre-operating phase Device O colour

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	< LOD	< LOD
Butanol	71-36-3	6	0.01
Toluene	108-88-3	2	0.00
1,3-butanediol	107-88-0	806	0.79
Styrene	100-42-5	4	0.00
Phenol	108-95-2	4	0.00
TVOC (calculated, exclusively identified substances)		822	0.80
Sum of unidentified VOC		3	0.00
TVOC (calculated, incl. unidentified substances)		**825**	**0.80**

Printing phase Device O colour

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	< LOD	< LOD
Butanol	71-36-3	26	0.08
Toluene	108-88-3	6	0.02
Hexanal	66-25-1	9	0.03
1,3-butanediol	107-88-0	3219	9.41
Styrene	100-42-5	6	0.02
Phenol	108-95-2	3	0.01
Ethylhexanol	104-76-7	3	0.01
Nonanal	124-19-6	2	0.01
TVOC (calculated, exclusively identified substances)		3274	9.57
Sum of unidentified VOC		13	0.04
TVOC (calculated, incl. unidentified substances)		**3287**	**9.61**

Summary Device O colour

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	9.61	0.80
Benzene	0.05		< LOD	< LOD
Styrene	1.0		0.02	0.00
Ozone	2.0		< LOD	< LOD
Dust	4.0		< 0.1	-

Pre-operating phase Device O monochromatic

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Hexane	110-54-3	< LOD	< LOD
Benzene	71-43-2	< LOD	< LOD
Butanol	71-36-3	11.8	0.01
Toluene	108-88-3	2	0.00
Hexanal	66-25-1	4	0.00
1,3-butanediol	107-88-0	970	0.95
Styrene	100-42-5	5	0.01
Phenol	108-95-2	5	0.01
Dodecane	112-40-3	2	0.00
TVOC (calculated, exclusively identified substances)		1000	0.97
Sum of unidentified VOC		4	0.00
TVOC (calculated, incl. unidentified substances)		**1004**	**0.97**

Printing phase Device O monochromatic

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Hexane	110-54-3	< LOD	< LOD
Benzene	71-43-2	< LOD	< LOD
Butanol	71-36-3	26	0.09
Toluene	108-88-3	4	0.02
Hexanal	66-25-1	11	0.04
1,3-butanediol	107-88-0	1502	5.33
Styrene	100-42-5	7	0.02
Phenol	108-95-2	4	0.02
Ethylhexanol	104-76-7	3	0.01
Tetradecane	629-59-4	2	0.01
TVOC (calculated, exclusively identified substances)		1559	5.53
Sum of unidentified VOC		5	0.02
TVOC (calculated, incl. unidentified substances)		**1564**	**5.55**

Summary Device O monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	5.55	0.97
Benzene	0.05	-	< LOD	< LOD
Styrene	1.0	-	0.02	0.01
Ozone	2.0	-	< LOD	< LOD
Dust	4.0	-	< LOD	-

Pre-operating phase Device P colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	1.4	0.03
Toluene	108-88-3	2	0.04
Styrene	100-42-5	3	0.05
Benzaldehyde	100-52-7	3	0.06
Decane	124-18-5	2	0.04
Acetophenone	98-86-2	5	0.10
BHT	128-37-0	5	0.09
TVOC (calculated, exclusively identified substances)		20	0.39
Sum of unidentified VOC		4	0.08
TVOC (calculated, incl. unidentified substances)		**24**	**0.47**

Printing phase Device P colour

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	< LOD	< LOD
Butanol	71-36-3	2	0.67
Toluene	108-88-3	2	0.56
Styrene	100-42-5	4	0.99
Phenol	108-95-2	3	0.69
Acetophenone	98-86-2	5	1.40
Decamethylcyclopentasiloxane	541-02-6	2	0.58
BHT	128-37-0	4	1.22
TVOC (calculated, exclusively identified substances)		22	6.09
Sum of unidentified VOC		7	1.83
TVOC (calculated, incl. unidentified substances)		**29**	**7.92**

Summary Device P colour

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	7.92	0.47
Benzene	0.05		< LOD	0.03
Styrene	1.0		0.99	0.05
Ozone	2.0		2.6	-
Dust	4.0		0.3	-

Pre-operating phase Device P monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	1	0.02
Toluene	108-88-3	2	0.04
Styrene	100-42-5	2	0.05
Benzaldehyde	100-52-7	3	0.06
Decane	124-18-5	2	0.05
Acetophenone	98-86-2	6	0.11
BHT	128-37-0	4	0.08
TVOC (calculated, exclusively identified substances)		19	0.39
Sum of unidentified VOC		4	0.08
TVOC (calculated, incl. unidentified substances)		**23**	**0.47**

Printing phase Device P monochromatic

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	< LOD	0.01
Butanol	71-36-3	4	1.49
Toluene	108-88-3	2	0.83
Styrene	100-42-5	4	1.42
Phenol	108-95-2	3	0.93
Decane	124-18-5	2	0.78
1-methyl-2-pyrrolidone	872-50-4	3	1.01
Acetophenone	98-86-2	6	2.12
Decamethylcyclopentasiloxane	541-02-6	2	0.79
BHT	128-37-0	5	1.70
TVOC (calculated, exclusively identified substances)		31	11.07
Sum of unidentified VOC		7	2.51
TVOC (calculated, incl. unidentified substances)		**38**	**13.58**

Summary Device P monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	13.58	0.47
Benzene	0.05	-	0.01	0.02
Styrene	1.0	-	1.42	0.05
Ozone	2.0	-	0.6	-
Dust	4.0	-	0.4	-

Pre-operating phase Device R colour

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	6.3	0.006
Butanol	71-36-3	11.7	0.012
n-propyl acetate	109-60-4	15.1	0.015
Hexamethylcyclotrisiloxane	541-05-9	55.8	0.056
Ethylbenzene	100-41-4	17.9	0.018
m,p–xylene	108-38-3/106-42-3	20.5	0.020
Styrene	100-42-5	4.4	0.004
o–xylene	95-47-6	10.9	0.011
Benzaldehyde	100-52-7	6.5	0.006
Phenol	108-95-2	31.3	0.031
Octamethylcyclotetrasiloxane	556-67-2	46.9	0.047
Ethylhexanol	104-76-7	7.0	0.007
Decamethylcyclopentasiloxane	541-02-6	72.2	0.072
TVOC (calculated, exclusively identified substances)		306	0.306
Sum of unidentified VOC		58	0.058
TVOC (calculated, incl. unidentified substances)		**364**	**0.364**

Printing phase Device R colour

Substance	**CAS No**	**Concentration** [µg/m³]	**Emission rate** [mg/h]
Benzene	71-43-2	5.3	0.051
Butanol	71-36-3	43.9	0.553
1,2-propanediol	57-55-6	12.5	0.166
n-propyl acetate	109-60-4	19.6	0.215
Hexamethylcyclotrisiloxane	541-05-9	31.5	0.246
Ethylbenzene	100-41-4	21.9	0.237
m,p–xylene	108-38-3/106-42-3	68.1	0.850
Styrene	100-42-5	28.3	0.366
o–xylene	95-47-6	41.9	0.528
Benzaldehyde	100-52-7	53.6	0.699
Propylbenzene	103-65-1	17.2	0.224
Phenol	108-95-2	17.7	0.139
Decane	124-18-5	3.9	0.050
Octamethylcyclotetrasiloxane	556-67-2	27.2	0.217
Ethylhexanol	104-76-7	8.5	0.092
Nonanal	124-19-6	7.2	0.087
Decamethylcyclopentasiloxane	541-02-6	48.1	0.417
Dodecane	112-40-3	5.4	0.069
Dipropylene glycol-mono-n-butyl ether1	29911-28-2	16.3	0.217
Dipropylene glycol-mono-n-butyl ether2	35884-42-5	19.1	0.254
o-hydroxybiphenyl	90-43-7	4.8	0.064
TVOC (calculated, exclusively identified substances)		502	5.743
Sum of unidentified VOC		96	1.069
TVOC (calculated, incl. unidentified substances)		**598**	**6.813**

Summary Device R colour

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	6.813	0.364
Benzene	0.05		0.051	0.006
Styrene	1.0		0.366	0.004
Ozone	2.0		< LOD	< LOD
Dust	4.0		0.6	-

Pre-operating phase Device R monochromatic

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-2	4.4	0.004
Butanol	71-36-3	15.6	0.016
n-propyl acetate	109-60-4	13.5	0.013
Hexamethylcyclotrisiloxane	541-05-9	48.5	0.048
Ethylbenzene	100-41-4	16.3	0.016
m,p–xylene	108-38-3/106-42-3	19.5	0.019
Styrene	100-42-5	4.3	0.004
o–xylene	95-47-6	10.3	0.010
Benzaldehyde	100-52-7	6.0	0.006
Phenol	108-95-2	26.9	0.027
Octamethylcyclotetrasiloxane	556-67-2	40.7	0.041
Ethylhexanol	104-76-7	6.3	0.006
Decamethylcyclopentasiloxane	541-02-6	68.0	0.068
TVOC (calculated, exclusively identified substances)		280	0.280
Sum of unidentified VOC		50	0.050
TVOC (calculated, incl. unidentified substances)		**331**	**0.330**

Printing phase Device R monochromatic

Substance	CAS No	Concentration [µg/m³]	Emission rate [mg/h]
Benzene	71-43-	5.6	0.061
Butanol	71-36-3	61.5	0.777
1,2-propanediol	57-55-6	14.5	0.195
n-propyl acetate	109-60-4	15.0	0.159
Hexamethylcyclotrisiloxane	541-05-9	28.5	0.229
Ethylbenzene	100-41-4	14.2	0.139
m,p–xylene	108-38-3/106-42-3	30.9	0.353
Styrene	100-42-5	11.6	0.142
o–xylene	95-47-6	17.3	0.200
Benzaldehyde	100-52-7	23.1	0.291
Propylbenzene	103-65-1	7.0	0.087
Phenol	108-95-2	18.2	0.160
Octamethylcyclotetrasiloxane	556-67-2	23.0	0.180
Ethylhexanol	104-76-7	8.8	0.098
Decamethylcyclopentasiloxane	541-02-6	40.3	0.326
Dipropylene glycol-mono-n-butyl ether1	29911-28-2	19.6	0.262
Dipropylene glycol-mono-n-butyl ether2	358884-42-5	22.6	0.303
o-hydroxybiphenyl	90-43-7	4.8	0.064
TVOC (calculated, exclusively identified substances)		367	4.030
Sum of unidentified VOC		62	0.638
TVOC (calculated, incl. unidentified substances)		**429**	**4.674**

Summary Device R monochromatic

	Requirements for granting the environmental award		**Measured emission rates**	
Emitter	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**	**Printing phase [mg/h]**	**Pre-operating phase [mg/h]**
TVOC	10	1	4.674	0.330
Benzene	0.05	-	0.061	0.004
Styrene	1.0	-	0.142	0.004
Ozone	2.0	-	< LOD	< LOD
Dust	4.0	-	0.4	-

12.2 Printer pattern 5% black coverage

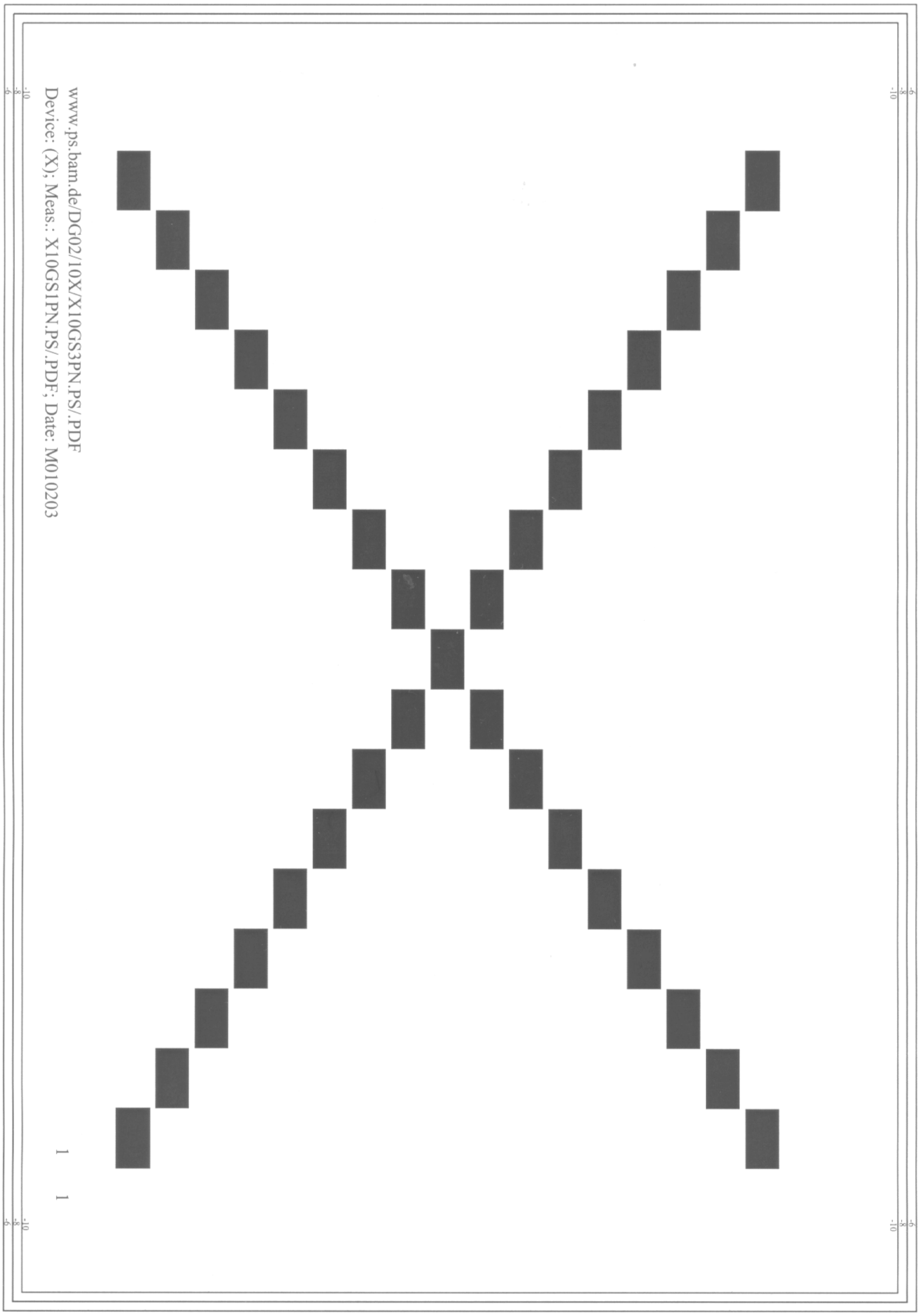

Figure 54: Printer pattern 5% black coverage, as per DIN 33870

12.3 Printer pattern 20% colour coverage

The printer pattern can be downloaded from http://www.ps.bam.de/RALUZ122.

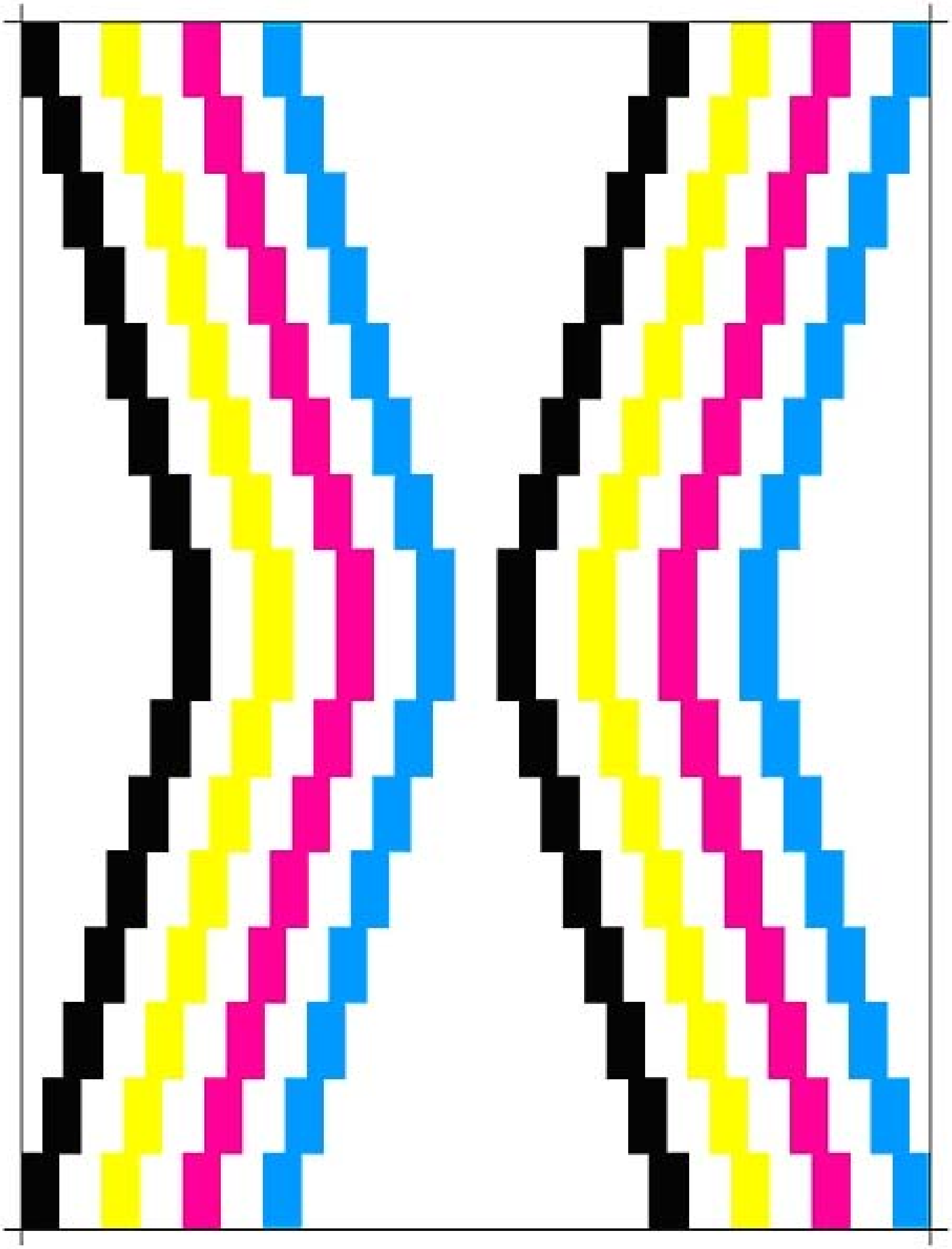

Figure 55: Printer pattern for the testing of colour Devices, 20% coverage

12.4 Pictures of the analysis Devices used

Figure 56: Ozone analyser

Figure 57: Particle spectrometer Grimm 1.108 Portable Aerosol Spectrometer

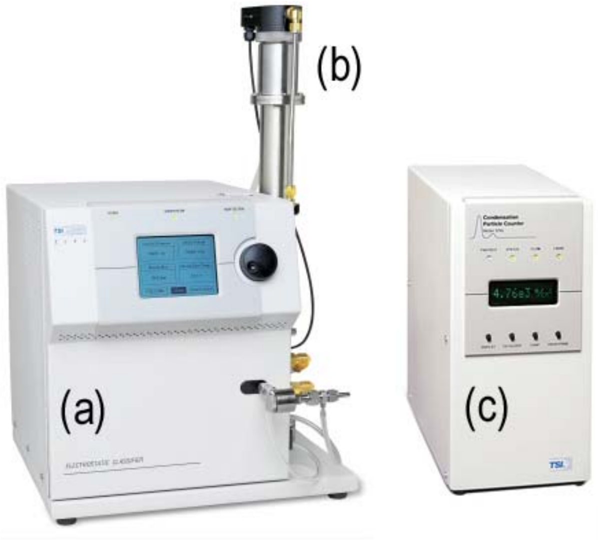

Figure 58: Particle spectrometer TSI 3080L SMPS (Scanning Mobility Particle Sizer), control device (a), sizer (b) and condensation particle counter (c).

Figure 59: Arrangement of the particle spectrometers at the 1 m³ test chamber

Figure 60: Ultra micro scale

Figure 61: Gas chromatograph with a thermal desorption system and MS detector

12.5 Members of the project-advisory working group

A project-advisory working group was formed to provide advice while carrying out the project. The working group held three meetings in which preliminary results were presented and discussed and advice was given during the project.

The members of the working group, which convened in a small or large circle depending on the topic, belonged predominantly to research and/or testing institutes, equipment manufacturers and the Federal Environment Agency (UBA). The names of all members of this advisory board are listed below.

The aim of the working group was to integrate the experts’ opinion and knowledge into the selection criteria and the associated testing method as early in the project as possible, since reasonable results and practical standards can only be achieved with the buy-in of all those involved. The activities mentioned did form a basis for the official RAL hearing procedure for the revised RAL UZ 62 and RAL UZ 85 environmental labels and the new ZU 122 environmental label, but did not pre-empt the RAL procedure.

The supportive guidance to the project provided by the members of the advisory panel is once again gratefully acknowledged.

Members of the project-advisory working group on 18 January 2005:

Ms. Thies	Ricoh Deutschland
Mr. van Heiningen	OCE-Technologies
Dr. Zietlow	Sony Deutschland
Dr. Schmitt	Lasercare GmbH
Prof. Mersch-Sundermann	University Gießen
Mr. Pesch	Canon Deutschland
Dr. Wensing	WKI
Mr. Pinz	WKI
Dr. Jungnickel	LGA
Dr. Maciej	LGA
Dr. Wildermann	LGA
Mr. von der Heyden	BGIA
Ms. Dr. Kuropka	TPU, TÜV Rheinland Group
Mr. Mochizuki	JBMIA
Mr. Bazlen	Hewlett Packard
Ms. Dr. Jacobs	UBA
Ms. Böttcher-Tiedemann	UBA
Dr. Ullrich	UBA
Dr. Jann	BAM

Dr. Wilke	BAM
Dr. Hahn	BAM
Mr. Rockstroh	BAM
Mr. Krocker	BAM
Mr. Stolle	BAM
Mr. Noske	BAM
Mr. Schneider	BAM
Ms. Rother	BAM

Members of the project-advisory working group on 15 and 16 September 2005:

Dr. Bake	UBA
Mr. Bazlen	Hewlett Packard
Ms. Bergmann	BAM (15 Sep only)
Ms. Brödner	BAM (not all day on 15 Sep)
Mr. Fujimoto	JBMIA
Ms. Dr. Gorzawski	TPU, TÜV Rheinland Group
Ms. Dr. Heurich	TPU, TÜV Rheinland Group
Ms. Dr. Jacobs	UBA
Dr. Jann	BAM
Ms. Juritsch	BAM (not all day on 15 Sep)
Ms. Dr. Kemmlein	BAM (15 Sep only)
Mr. Krocker	BAM
Dr. Maciej	LGA
Mr. Mochizuki	JBMIA
Prof. Mersch-Sundermann	University Gießen
Mr. Pesch	Canon Deutschland
Dr. Seeger	BAM (not all day on 15 Sep)
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Mr. Schneider	BAM
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Dr. Ullrich	UBA
Mr. van Heiningen	OCE Technologies
Mr. von der Heyden	BGIA
Dr. Wensing	WKI
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Members of the project-advisory working group on 13 June 2006:

Dr. Bake	UBA
Mr. Bazlen	Hewlett Packard, BITCOM
Ms. Brödner	BAM
Mr. Fujimoto	JBMIA
Mr. Hayashi	JBMIA, interpreter
Ms. Dr. Heurich	TPU, TÜV Rheinland Group
Ms. Dr. Jacobs	UBA
Dr. Jann	BAM
Ms. Dr. Kemmlein	BAM
Mr. Krocker	BAM
Dr. Maciej	LGA
Dr. Seeger	BAM
Dr. Schmitt	Lasercare GmbH
Mr. Schneider	BAM
Dr. Ullrich	UBA
Mr. van Heiningen	Océ Technologies, BITCOM
Mr. von der Heyden	BGIA
Dr. Wensing	WKI
Dr. Wilke	BAM
Dr. Bücker	BAM
Dr. Böcker	BAM
Mr. Emerson	Hewlett Packard, guest
Mr. Herb	Kyocera, BITCOM
Dr. Thurner	UBA

12.6 Test method for the determination of emissions from hardcopy devices

April 2006

Test method

for the determination

of emissions from hardcopy devices

with respect to awarding the environmental label

for office devices with printing function

according to RAL-UZ 122

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Preface

This test method to implement new emission criteria (VOC, ozone and dust) in the requirements for awarding the Blue Angel environmental label for hard copy devices (printers, photocopiers and multifunction devices) was improved and expanded to multicolour devices. It is based on the test method as of June 2003 [1, 2] on the ECMA 328 (2001, [3]) standard detailed in ECMA International (European Association for Standardizing Information and Communication Systems), on ISO 16000-9 (draft) international standard for emission test chambers [4] and on ISO 16000-6 for VOC analysis [5]. An international standardisation of the test methods is being planned.

It is absolutely vital to understand and comply with these standards before using the test method, as long as they do not stand in opposition to the test method.

The objective of the test method is to achieve a reliable determination of the emission rate within the short uninterrupted printing time available, usually less than one hour, by means of a dynamic test chamber procedure with a well-defined air exchange rate. Various improvements in precision of the above-mentioned standards were necessary in order to obtain a practical test method.

Since the devices themselves can emit certain VOCs, decreasing with time, the test method must also enable the measurement of VOC emission rates in the pre-operating phase.

It must be understood that the measured emission rates are system-specific, since printers, photocopiers or multifunction devices show characteristic emission behaviour depending on the consumable materials used (e.g. toner, ink, paper).

The measured emission rates may not exceed the permissible emission rates specified in the criteria for awarding the environmental label. They may also be used, for VOCs particularly, to estimate the resulting concentrations in model rooms or in real rooms.

It is generally assumed that the devices do not print continuously, that they are not designed to do so, but that it is appropriate to allow a usage factor of < 1. Model calculations of Indoor air concentrations are, in reality, strongly influenced by adsorption effects on surfaces within the room, so that maximum concentrations will in reality be less than those calculated.

The test method was revised in the Federal Institute for Materials Research and Testing (BAM) within the framework of a project supported by the Federal Environmental Agency (UBA) (Project No 204 95 373) and with the technical support from other testing institutes, manufacturers, UBA and associations. A detailed description will be available in the final report to be published in the series of the UBA texts (2006).

1. Definitions

Pre-operating phase
With experimental set-up under normal climate conditions, the test object is located in the chamber, switched on and ready for use. The pre-operating phase directly follows the conditioning phase without reopening the chamber. Explanation: with the start of the pre-operating phase, power supply of the test object is ensured by plugging in the power plug. Then, the test object is operated using standard default settings according to the specifications of the RAL-UZ 122 Award Criteria.

Blank value
Background concentration of the measuring system (Emission test chamber, test tube and device for analysis) for individual substances (VOC) as well as TVOC.

Printing phase (operating phase)
Test subject is printing. Printing phase follows the pre-operating phase without opening the chamber. Printing phase starts with printing out the first page.

Emission test chamber
A closed container with sampling and access ports and adjustable operational parameters (atmospheric conditions, air exchange rate) for the determination of the emissions (VOC, ozone, dust) from printing and photocopying apparatus under an air flow [4].

Emission rate (product- or system-specific) SER_u [µg $piece^{-1}$ h^{-1}]
Product-specific (or system-specific, see preface) rate, which characterises the mass of the analyte (VOC, ozone, dust), emitted by the test object per time, at a given time from the start of the test.

Chamber loading
Placing the test subject in the emission test chamber.

Conditioning phase
With the Experimental set-up under normal atmospheric conditions, the test subject is conditioned in the chamber with paper already inserted, the power switch is switched to "on ", but the plug is not connected to the electricity supply. This technique allows the operator to bring the device into the pre-operating phase by inserting the plug into the socket without having to open the chamber.

Air exchange rate n [h^{-1}]
The ratio of the clean air volume brought into the emission test chamber hourly and the free emission test chamber volume in identical units, expressed in air changes per hour.

Air flow rate °V [$m^3 h^{-1}$]
Air volume supplied to the emission test chamber per unit time.

Air velocity v [ms^{-1}]
Air speed over the surface of the test subject (distance 10 mm).

Post-operating phase
With experimental set-up the test subject is still in the chamber, and the air exchange rate is the same as during the printing phase, but the printing cycle has already finished. The post-operating phase follows directly on from the printing phase without opening the chamber.

Normal atmospheric conditions
Standard atmospheric conditions: 23°C ± 2 K, 50 ± 5% relative humidity per ISO 554 [6].

Ozone half-life
The time that elapses whilst the ozone concentration decreases to half the initial concentration.

Test subject
Hardcopy device to be tested including consumables (paper and toner, respectively ink).

VOC, volatile organic compounds
Generally: organic compounds which are emitted by the test object and are detected in the chamber's air. In this case, according to the test method, the identified and unidentified organic compounds, which in case of gas chromatographic separation elute between n-hexane and n-hexadecane on a non-polar column, inclusive of these compounds.

VVOC, very volatile organic compounds
Here, as defined by the test method, the identified and unidentified organic compounds, which in a gas chromatographic separation elute on a non-polar column before n-hexane (e.g. ethanol, isopropanol, acetone, pentane).

TVOC, Total Volatile Organic Compounds
The total of the concentrations of identified and unidentified volatile organic compounds, which elute between n-hexane and n-hexadecane, inclusive of these compounds, during gas chromatographic separation on a non-polar column.

2. Measuring devices

- Emission test chamber as described in Section 4.1
- Atmospheric measurement devices with recorder as described in Section 4.4.1
- Colour mouse to determine the lightness and colour values (CIELAB [10]) as described in Section 4.4.2
- Current measuring instrument as described in Section 4.4.3
- Air sampling systems and adsorbents as described in Section 4.5
- Capillary gas chromatograph with a thermal desorption unit, coupled to a mass spectrometer (example see Section 8.6).
- Ozone analyser as described in Section 4.7
- Dust measurement area as described in Section 4.8

3. Test subjects

3.1 Selection

The client is responsible for delivery of the subjects. A device is usually a brand new prototype or taken from the current production series. The manufacturer is responsible for the prototype to be identical with the latter serial product. The delivery contents are checked by the test laboratory and afterwards stored in the original packaging in an air-conditioned store (23 °C, 50 % R. H.). The measurement should take place as soon as possible, no more than ten working days after delivery at the latest.

3.2 Preparation of test subjects

Utility and suitability of the test subject are checked after delivery. In particular, the manufacturer together with the test institute must ensure that the devices can be operated in the test chamber (By remote control via cables, mechanical trips or radio the it has to be sure that the printing process can be started from outside the chamber).

In agreement with the manufacturer, a printing mode has to be selected for electrophotographic devices which allows maximum printing time. Capacities of the paper cassettes and paper stackers have to be considered. For inkjet printers, a default setting (standard quality) is to be selected.

If possible, printing time must not be less than ten minutes. Devices which, due to their method of construction, cannot reach a printing time of 10 minutes, are tested with their maximum possible printing time.

Power consumption in the pre-operating phase and printing phase has to be determined. In addition the maximum printing time is determined with a sample printout of test pages (5 % surface black coverage or 20% surface colour coverage). It is important that paper stacking takes place in a well organised way. If necessary, an additional receptacle made from inert material has to be used.

The device to be tested is placed in the emission test chamber with sufficient paper and toner on the day before the emission test.

3.3 Consumable materials

Toner, ink

The toner module supplied for any device should either be the manufacturer’s original configuration or compatible in type to that identified in the product documents. The testing institute has to be advised as to the exact specification of the toner so that a replacement of the same toner can be arranged.

Toners have to be stored according to the manufacturer’s specification prior to the test. (The toner can also remain in the device with agreement of the manufacturer.) The storage conditions are the same as for the test subject. Sufficient toner material and toner modules have to be made available.

Paper

The paper used for the tests must be a DIN A4 format with a paper humidity between 3.8% and 5.6%. Grammage must be within the range of 60 to 80 gram per square metre. Paper moisture can be determined meeting the requirements of DIN EN 20287 (1994-06) [7].
Recommendation: a prior analysis of the paper (e.g. according to RAL-UZ 14) allows an estimation of the paper’s contribution to VOC emissions, and as the case may be a minimisation if the paper is selected accordingly.

Paper humidity should not exceed 4 % for this type of test. Higher paper humidity can lead to condensation in the chamber during printing and make the use of larger chambers or larger air exchange rates necessary.

4. Measurements in emission test chambers

4.1. General

Emission test chambers and their specifications are described in [1, 2, 3, 4]. A chamber with a suitable volume (cf. equation 1) has to be selected depending upon the size of the test subject to be examined.

The various ports of the test chamber must make good seals with the power cables and sensor lines passing through allowing VOC, dust and ozone to be sampled simultaneously. The test chambers must meet the requirements described in [4]. In particular this means:

- VOC-, ozone- and dust-free clean air supply
- Clean water supply
- Glass or special steel chamber walls
- Omission of sealing materials as far as possible
- Efficient air mixing

The following test conditions have to be adhered to by analogy with [4].

• Temperature	23 °C ± 2 K 1)
• Relative air humidity	50 % ± 5 % 1)
• Adjustable air exchange rate	
Large chamber ($V > 5\ m^3$)	$(1 \le n \le 2) \pm 5\%$
Small chamber ($V \le 5\ m^3$)	$(1 \le n \le 5) \pm 5\%$
• Air flow velocity	0.1 – 0.3 ms^{-1}

1) These atmospheric conditions cannot generally be maintained for the period shortly after loading the sample into the chamber and during the test in the printing phase.

Both 1 m^3 chambers and large chambers with volumes > 5 m^3 (e.g. 20 m^3) are suitable emission test chambers according to [2]. Chambers are regarded as suitable if they adhere to the above conditions and exhibit sufficiently small blank values, in particular for VOC, ozone and dust, and ensure sufficiently large ozone half-lives.

Chambers must be checked for compliance with the test requirements before they are first used. The chamber blank values must stay below the following levels at an air exchange rate of $n=1\ h^{-1}$:

Single substances	2 μgm^{-3}
TVOC	20 μgm^{-3}
Ozone	4 μgm^{-3}
Dust	10 μgm^{-3}

The ozone half-life of the chamber has to be checked at an air exchange rate of $n = 1\ h^{-1}$ by introducing a concentration of 0.1 to 0.2 ppm to the chamber. If the ozone half-life is at least ten minutes, the test chamber is suitable for ozone determination. However, if the ozone half-life is less than ten minutes, the chamber has to be cleaned in an appropriate way, until the target value is achieved. With air exchange rates other than $n = 1\ h^{-1}$, different ozone half-lives occur.

Air exchange rates needed for the measurement have to be regularly checked and recorded with the chamber empty, by means of an independent procedure, e.g. tracer gas method per DIN V ENV 717-1 (2005) [8].

4.2. Test procedure (compare 8.1, flow diagram)

For the determination of the blank value and for the testing in the pre-operating phase an air exchange rate of $n = 1\ h^{-1}$ must be set in the chambers.

The device to be tested is placed in the emission test chamber with sufficient paper and toner on the day before the emission test.
Measurements of the internal atmospheric conditions are recorded from the start of this conditioning phase. VOC measurements begin 20 minutes before the end of the pre-operating phase, then recording of ozone concentration can take place.

In large chambers after the end of the pre-operating phase, the air exchange is set at $n = 1 – 2\ h^{-1}$. In small chambers (1 to 5 m^3) the air exchange rate is adjusted to a value of $n = 1 - 5\ h^{-1}$ (dry input air flow, if necessary (R. H. < 10%)) to keep relative air humidity below critical values (≤ 85%), which otherwise generally (electrophotographic devices) rises due to water being given off by the paper during printing.

Under no circumstances must water condensation take place in the chamber, since this has an unacceptable influence on the measurement results.

VOC, ozone and dust sampling starts at the beginning of the printing phase and should be carried on during the post-operating phase which starts after printing. The post-operating phase runs over a period of up to four air exchanges (one hour with quadruple air exchange, and four hours with single air exchange).

Testing of monochrome devices is carried out using the print pattern as described in Section 8.3, for testing of colour devices the printing pattern as described in Section 8.4 is used.

To determine the size of the chamber needed for the equipment, the following size range can be used:

$$0.01 < \frac{V_{EUT}}{V_K} < 0.25 \qquad (1)$$

V_{EUT}: volume of the test subject (EUT: equipment under test) [m³]
V_K: volume of the test chamber [m³]

If in doubt, a smaller chamber size should be selected, since concentration values are higher and measurement uncertainty is reduced.
During testing the emission test chamber must neither be opened nor are persons permitted to stay in the chamber. Therefore, the test must be repeated when interruptions (e.g. a paper jam) occur. Such interruptions should be excluded as far as possible by careful preparation.

4.3 Methods for quality assurance

Maintenance of quality-assurance standards when using the test method is an essential prerequisite for the determination of reliable emission rates. An overview of this subject can be found in the ECMA 328 standard [3].
Accredited test institutes are obliged to regularly participate in a comparison test. Comparison tests are organised by the BAM.

4.4 Atmospheric conditions, determination of lightness respectively colour value, printer control

4.4.1 Atmospheric conditions

It is necessary to record atmospheric data over the entire sequence of the test cycle to analyse the measurement results. In addition a measuring system with attached data logger is needed. After calibration the following measurement accuracy must be achieved:

Temperature:	± 0.5 K
Relative humidity:	± 3.0 %.

In section 8.5, the development of atmospheric conditions during a test is shown as an example. The calibrated Almemo 3290-8 device with climate recording facility and an FH A 646-R sensor of the Ahlborn company is one example of a suitable device for recording atmospheric data.

4.4.2 Determination of lightness and colour value respectively

A print pattern with 5% black coverage and 20% colour coverage respectively (5% needed for each colour [black, magenta, cyan, yellow] (cf. Section 8.3 and 8.4 respectively)) is used to prepare for emission tests on hardcopy devices.
The required print patterns are made available to the accredited test institutes by the BAM.

From the printouts the lightness (L*) and colour values (L*, a*,b*) respectively is determined according to CIE [10] using, for example, a Color Mouse CM2C (Savy Systems Limited, USA).

The measured lightness and colour values respectively have to be recorded in the test protocol.

4.4.3 Printer control

The printing process has to be managed and controlled by means of the remote control capabilities of the test device as advised by the manufacturer. The operating conditions of the printer have to be recorded in the pre-operating, printing and post-operating phase. This can be done, for example, by checking the power consumption of the test device using a multimeter (e.g. multimeter M 3850 M, Metex Corp., in the 20 A range, with data logger for electronic recording).

Measuring power consumption clearly shows the start and end of printing. Disturbances in operation are also recorded. Section 8.5 shows an example of a power consumption record with the relevant operational phases indicated. Additionally, with access to the data network, the number of the printed pages can be requested, which is standard for modern printers.

4.5 VOC

VOC sampling is accomplished using Tenax with subsequent thermal desorption [5] and GC / MSD analysis. Experimental set up is to be defined in such a way that a recording of individual substances with a concentration of ≥ 1.0 µg/m^3 and with a concentration of ≥ 0.25 µg/ m^3 of benzene is ensured.

When in doubt, positive findings of benzene are to be verified via a second independent sampling (e.g. using Carbotrap or activated carbon). Samples are taken at the following points in time~~s~~ as a minimum:

a) Blank value before loading the sample in the chamber

b) 20 minutes before the end of the one-hour pre-operating phase (for 20 minutes with 100 to 200 ml/min) as a repeat determination

c) From the start of the printing phase then continuously until the point in time when a single air exchange is completed in the post-operating phase (with 100 to 200 ml/min) as a repeat determination

If possible, all substances have to be identified and individually quantified using the relative response factors determined from a calibration by internal standard. If substances cannot be identified or the relative response factor cannot be determined, quantification has to be performed based on the response factor of toluene.

The TVOC value shall be calculated as the sum of the concentrations of all identified and unidentified substances, having retention time between n-hexane and n-hexadecane and having emission rates above the following values.
For measurements in chambers ≤ 5 m^3: SER$_B$ ≥ 0.005mg/h, SER$_{DN}$ ≥0.05 mg/h.
For measurements in chambers > 5 m^3: SER$_B$ ≥ 0.02 mg/h, SER $_{DN}$ ≥0.2 mg/h.
Additionally, as described in [5], the TVOC value has to be calculated based on the response factor of toluene.

Concentrations to be used for the following calculations are to be determined by subtracting the blank values from the measured values.
Note: particular attention needs to be paid to the Tenax tube's blank value, since it usually constitutes the major part of the (total) blank value.

Calculation of the emission rate during the pre-operating phase

The emission rate for the pre-operating phase can be calculated from the concentration of the sample taken over the last twenty minutes of the one-hour phase using the equations:

$$SER_B = c_B * n_B * V \qquad (2) \qquad\qquad c_B = \frac{m_{VOC_B}}{V_P} \qquad (3)$$

c_B: VOC concentration [µg m^{-3}] during the pre-operating phase

SER_B: VOC emission rate [µg h^{-1}] during the pre-operating phase

m_{VOC_B}: Analysed mass [µg] of VOC during the pre-operating phase

n_B: Air exchange rate [h^{-1}] during the pre-operating phase

V: Volume of test chamber [m³]

V_P: Sample volume [m³] during the pre-operating phase

Calculation of the emission rate during the printing phase

The emission rate during the printing phase is calculated by the following equation with the sample's concentration from the start of the printing phase to that point in time, when a single air exchange in the post-operating phase is completed.

$$SER_{DN} = \frac{\frac{m_{VOC_{DN}}}{V_P} * n_{DN}^{\ 2} * V * t_G - SER_B * n_{DN} * t_G}{n_{DN} * t_D - e^{-n_{DN}*(t_G - t_D)} + e^{-n_{DN}*t_G}} \qquad (4)$$

SER_{DN}: VOC emission rate [µgh^{-1}] determined from the printing and post-operating phases

SER_B: VOC emission rate [µgh^{-1}] determined from the pre-operating phase

$m_{VOC_{DN}}$: Analysed mass [µg] of VOC during the printing phase and post-operating phases

n_{DN}: Air exchange rate [h^{-1}] during the printing and post-operating phases

t_D: Absolute printing or copying time [h]

t_G: Overall sampling time [h]

V: Volume of test chamber [m³]

V_P: Sample volume [m³] during the printing and post-operating phases

The method of sampling and analysis as described in Section 8.6 is suitable for a broad range of emitted compounds. A list of compounds which can occur in emission measurements of printing and copying devices is also given in section 8.6.

4.6. VVOC

VVOCs which are recorded in VOC sampling using Tenax are to be quantified in the same way as VOCs and listed in the test report. VVOCs are not to be included in the TVOC value.
If very volatile solvents are contained in inks of inkjet printers (according to the applicants' information or the material safety data sheet), it is of particular importance to prevent test results be falsified by a "breakthrough". In order to prevent this, two Tenax tubes can be connected in a row or the sampling using Carbotrap to measure benzene can be analysed.

4.7 Ozone

The measurement procedure is preferably based on a flameless reaction between ozone and ethylene. The chemoluminescence produced can be measured photometrically. Ozone emission testing of printers and copiers has to be performed as follows:

a) Determination of the blank value.

b) In the pre-operating phase ozone concentration can already be recorded.

c) Ozone determination during printing / copying:

Ozone determination starts at the beginning of the printing phase and continues until the end of the post-operating phase. The concentration should be recorded every 30 seconds at least, or better still, at every 15 seconds. If a suitable concentration range has been selected, the ozone concentration can be recorded permanently using an electronic data logger.

Ozone half-life can be determined from the decay curve in the post-operating phase, where a good approximation of the conditions of the print job still prevails. Ozone emission rate can be calculated using the following equations:

$$SER_u = \frac{c_{\max} * k' * V * p}{T * R} \qquad (5) \qquad\qquad k' = \frac{\ln 2}{H'} \qquad (6)$$

SER_u : Ozone emission rate [µg or mg unit time^{-1}]

$c_{\max}$: Maximum ozone concentration [µg m^{-3}] during the first 10 minutes of the printing phase

k' : Proportionality factor [min^{-1}]

H' : Ozone half-life under test conditions [min]

V : Volume of test chamber [m³]

p : Air pressure [Pa]

T : Absolute temperature [K]

R : Gas constant [Pa K^{-1}], (339.8 [Pa K^{-1}] for ozone)

For very small ozone emission rates the determination of the ozone half-life is difficult under test conditions. However, to facilitate an analysis, the smallest ozone half-life ever measured by the test institute in the test chamber loaded with a hardcopy device can be used. Calculation can then be performed using the above equations.

Example for an ozone test instrument

Model 3010 Ozonanalysator (ozone analyser). Manufacturer: UPM, Umwelt Pollution-Messtechnik (Environment Pollution Measurement Techniques). This gives continuous determination of ozone concentration.

4.8 Dust

Dust emission rate is determined using the gravimetric method.

Sampling

Air sampling is performed from the beginning of the printing phase to the end of the post-operating phase. During this time interval, air is sampled from the test chamber using a pump and is drawn through a glass-fibre filter. The volume of air drawn through the filter is measured (in m³). The absolute weight of dust is obtained in µg by differential weighing of the filter. From both values, dust concentration in the test chamber (in $\mu g*m^{-3}$) can be calculated and from this the specific emission rate (in $\mu g*h^{-1}$).

Standard conditions for gravimetric dust measurement

Dust filter:	Glass-fibre filter with appropriate mounting plate
Sampling point:	Preferable the centre of the chamber wall
Volume Sampling - rate:	Up to 80 % of the air flow rate in the chamber during the sampling phase
Sampling time:	Total printing phase and post-operating phase

Procedure for gravimetric dust measurement – moisture correction

The glass-fibre filters (measuring filters), used for gravimetric dust measurement, must be stored in an air-conditioned room (weighing room) before the measurement and must be conditioned in the prevailing climate until the mass is constant. Since even the slightest unavoidable fluctuations in the relative humidity of the weighing room affect the mass of the glass-fibre filters, at least one empty glass-fibre filter (reference filter) is weighed at the same time as the measuring filters, before dust sampling (tare weight). Through this correction the influence of the atmospheric conditions on the filter mass is minimized.

Climate conditions in the weighing room:

Temperature:	23°C ± 2 K
Relative humidity:	50 % ± 5 %

During dust sampling in the test chamber air is drawn through the measuring filter. Since the relative humidity of this air can deviate from that in the weighing room, the measuring filter must be returned to the weighing room after dust sampling, and again conditioned to constant mass.

The reference filter remains in the weighing room and is re-weighed when the dust filter weighing (gross weight) is carried out. The mass difference between the first and the second weighing of the reference filter is due to climate changes and is subtracted from or added to the gross mass of the measuring filter.

Determination of absolute dust weight on the measuring filter (moisture correction)

$$m_{St} = (m_{MF_{gross}} - m_{MF_{tare}}) + (m_{RF_1} - m_{RF_2}) \qquad (7)$$

m_{St}: Weighed mass of dust (moisture-corrected) [µg]

$m_{MF_{gross}}$: Mass of conditioned measuring filter after dust sampling [µg]

$m_{MF_{tare}}$: Mass of conditioned measuring filter before dust sampling [µg]

m_{RF_1}: Mass of conditioned reference filter weighed at the same time as measuring filter before dust sampling [µg]

m_{RF_2}: Mass of conditioned reference filter weighed at the same time as measuring filter after dust sampling [µg]

Calculation of dust concentration and emission rate

$$SER_{u_{St}} = \frac{m_{St} * n * V * t_G}{V_P * t_D} \qquad (8) \qquad\qquad c_{St} = \frac{m_{St}}{V_P} \qquad (9)$$

c_{St}: Dust concentration in test chamber [µg m^{-3}]

$SER_{u_{St}}$: Dust emission rate [µg h^{-1}]

m_{St}: Weighed mass of dust (moisture-corrected) [µg]

n : Air exchange rate [h^{-1}]

t_D: Total printing or copying time [min]

t_G: Overall sampling time [min]

V: Volume of test chamber [m^3]

V_P: Volume of air sucked through glass-fibre filter [m^3]

Example for a gravimetric dust measurement method

Ultramicro scale: Type UMX2/M

Pump: Müller inc. GSA 50

Gas flow rate meter: Schlumberger inc. REMUS 4 G 1,6

Glass-fibre filter: Schleicher & Schuell inc., diameter 50 mm

5. Evaluation and test report

The test and analysis of the test subject must both be fully documented in the test report.

The following data have to be included:

- Manufacturer,
- Product description, indication if tabletop/floor-mounted device, device number, print or copy speed according to manufacturer information, toner description, and description of paper used,
- Date of manufacture,
- Date of delivery,
- Type of packaging,
- Storage prior to measurement,
- Test date/time period,
- Lightness or colour value of the printouts,
- Test conditions (type and size of chamber, temperature, relative humidity, air exchange rate or air flow rate),
- Duration of printing job,
- Print speed during testing,
- Number of pages printed,
- Time and interval of air sampling, volume and flow rate of air sampling for VOC, ozone and dust,
- Name, CAS-No. and concentration of identified VOCs, as well as concentration of unidentified VOCs in pre-operating phase and printing phase, and calculated emission rates. Benzene and styrene have to be separately listed in every case.
- The TVOC value calculated as the sum of the concentrations of all identified and unidentified substances, additionally the TVOC value calculated based on the response factor of toluene,
- Information on VVOCs, if detected,
- Ozone half-life of empty chamber and from the post-operating phase,
- Ozone concentration and calculated ozone emission rate during printing,
- Dust mass measured gravimetrically and dust emission rate calculated from it,
- Detection limits of VOC-, dust- and ozone emission rates,
- Disruptions and deviations from test algorithm,
- Summary of the results by the testing institute with respect to environment label criteria (if necessary, indication that the determined emission characteristic is only valid in connection with the tested toner type),
- Signature under the summary which must once more include the exact device description

6. Test institutes

Emission tests may be performed by suitable institutes only.

Test institutes are suitable if they have the necessary apparatus and a quality management system (or are accredited in the field of these tests) and have proved their expertise for these tests by successfully participating in relevant co-operative tests or comparative measurements. The same applies to the testing laboratories of manufacturers.

The proof of adherence to these requirements can be provided to the Federal Institute for Materials Research and Testing, Division "Environmental Material and Product Properties/Emission from Materials ". In the case of present suitability, this is confirmed in writing.

7. Literature

1 Test method for the determination of emissions from hardcopy devices with respect to awarding the environmental label for office devices RAL-UZ 62, 85 and 114. www.blauer-engel.de

2 Entwicklung einer Prüfmethode und Untersuchungen zur Begrenzung von Emissionen aus Druckern und Kopiergeräten im Rahmen der Umweltzeichenvergabe. [Development of a test method and investigation into limiting emissions from hardcopy devices within the framework of an environmental label award.] UBA-Texte-No. 88/2003, Umweltbundesamt, Berlin 2003

3 ECMA-Standard 328, Detection and measurement of chemical emissions from electronic equipment, August 2001 (currently under revision), www.ecma-international.org

4 ISO 16000-9: Indoor air - Part 9: Determination of the emission of volatile organic compounds – Emission test chamber method

5 ISO 16000-6: Indoor air - Part 6: Determination of VOC in indoor and chamber air by active sampling on TENAX TA sorbent, thermal desorption and gas chromatography using MSD/FID

6 ISO 554, Edition:1976-07 Standard atmospheres for conditioning and/or test; Requirements

7 DIN EN 20287, Edition: 1994-09 Papier und Pappe - Bestimmung des Feuchtegehaltes - Waermeschrankverfahren (Paper and cardboard - Determination of humidity content - Warming cupboard procedure] (ISO 287:1985); Deutsche Fassung [German Version] EN 20287:1994

8 DIN ENV 717-1, Edition: 2005-01, Holzwerkstoffe - Bestimmung der For-

maldehydabgabe - Teil 1: Formaldehydabgabe nach der Pruefkammer-Methode [Wooden materials - Determination of formaldehyde emission - Part 1: Formaldehyde emission per the test chamber method]

9 DIN 33870, Edition: 2001-01 Informationstechnik - Buero- und Datentechnik - Anforderungen und Pruefungen für die Aufbereitung von gebrauchten Tonermodulen schwarz fuer elektrophotographische Drucker, Kopierer und Fernkopierer [Information technology - Office and data processing technology - Requirements and tests for the processing of used black toner modules for electrophotographic printers, copiers and telecopiers]

10 CIE Document No. 15, Colorimetry, 2004

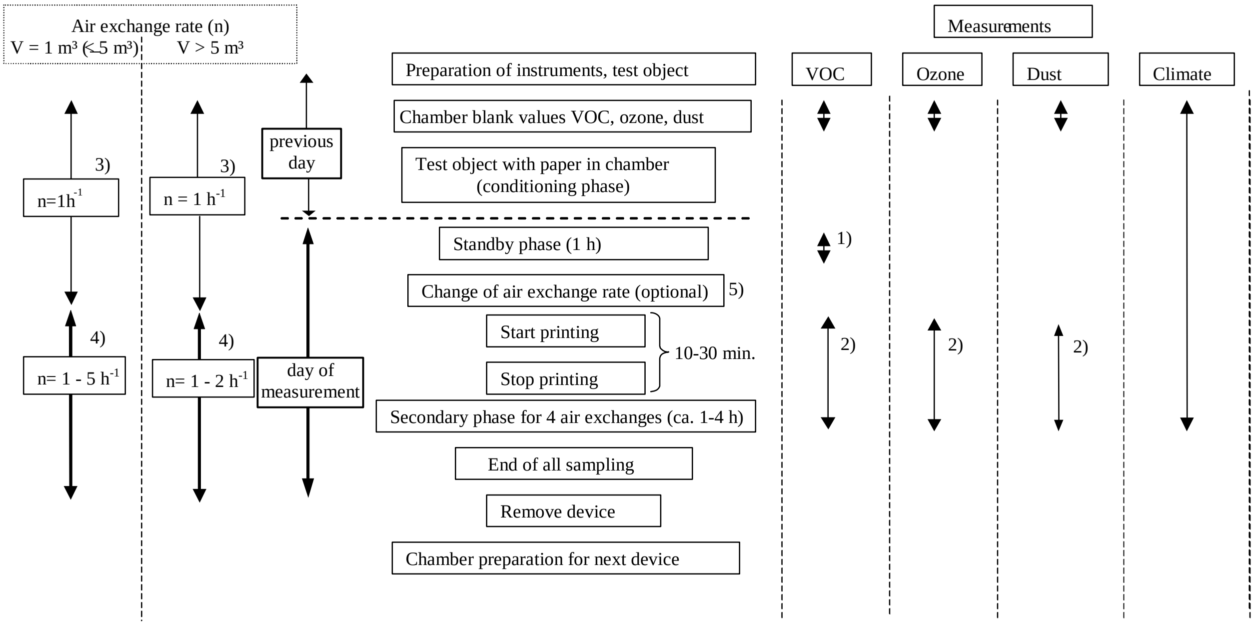
Further literature

J. Rockstroh, O. Jann, O. Wilke, W. Horn: Development of a reliable test method for laser printers, copiers and multifunctional devices in emission test chambers, Gefahrstoffe - Reinhaltung der Luft 65 (2005), 3, page 71-80.

O. Jann, J. Rockstroh, O. Wilke: Influence of emissions from hardcopy devices to indoor air quality, Proceedings of Indoor Air 2005, Beijing, Vol.2, 2123-2128.

8. Illustrations and examples

8.1 Test flow diagram



1) Sampling over last 20 minutes (100 – 200 ml/min).

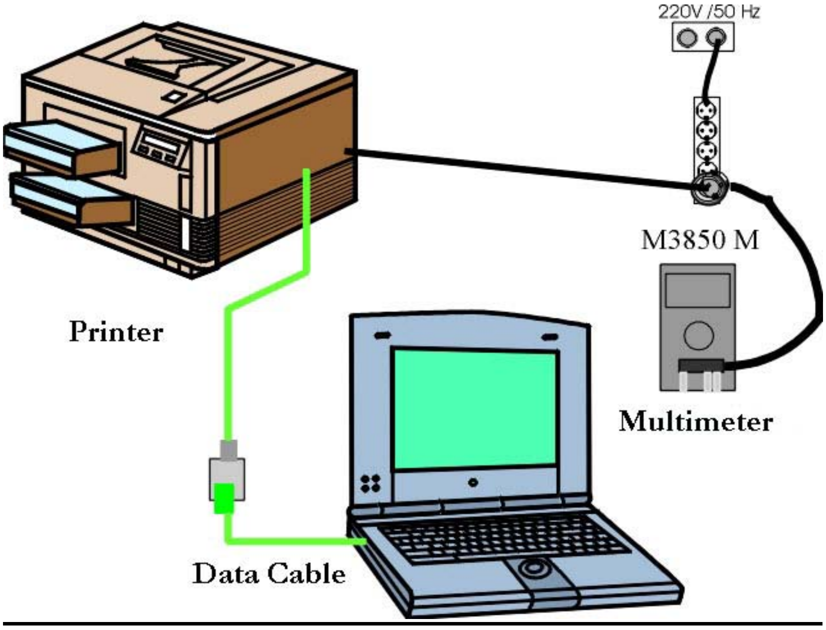
2) Continuous sampling (for VOC 50 – 200 ml/min. depending on duration of sampling)

3) Air exchange rate has to be known and steady

4) Air exchange rate dependent on humidity entry during printing operation (a relative humidity of 85% must not be exceeded in the test chamber); if necessary: dry feed air flow (< 10 % R.H.); air exchange rate has to be known and steady

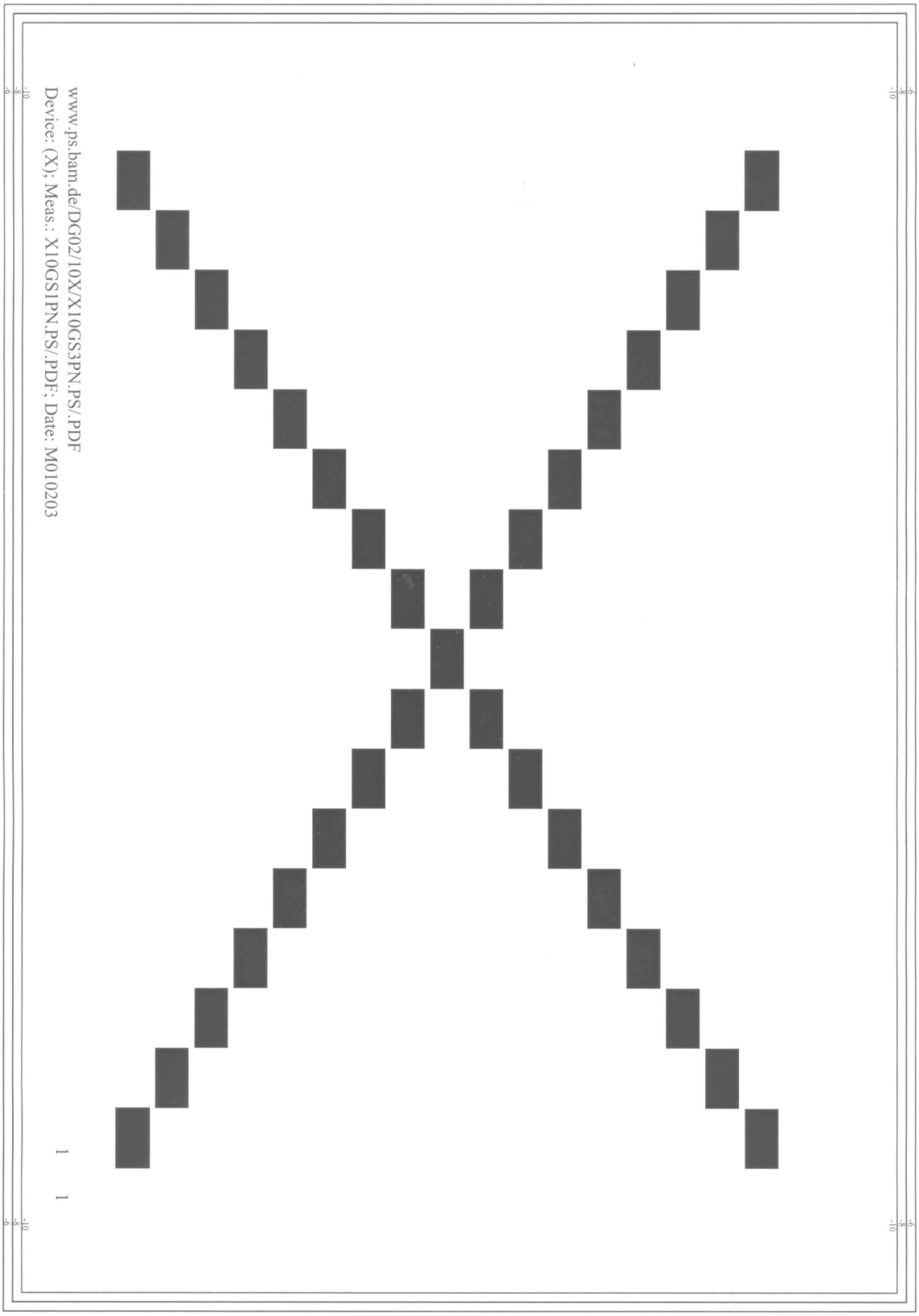
5) If changing the air exchange rate, the time for at least one air exchange must be awaited until the start of printing

8.2 Measurement set-up for testing devices



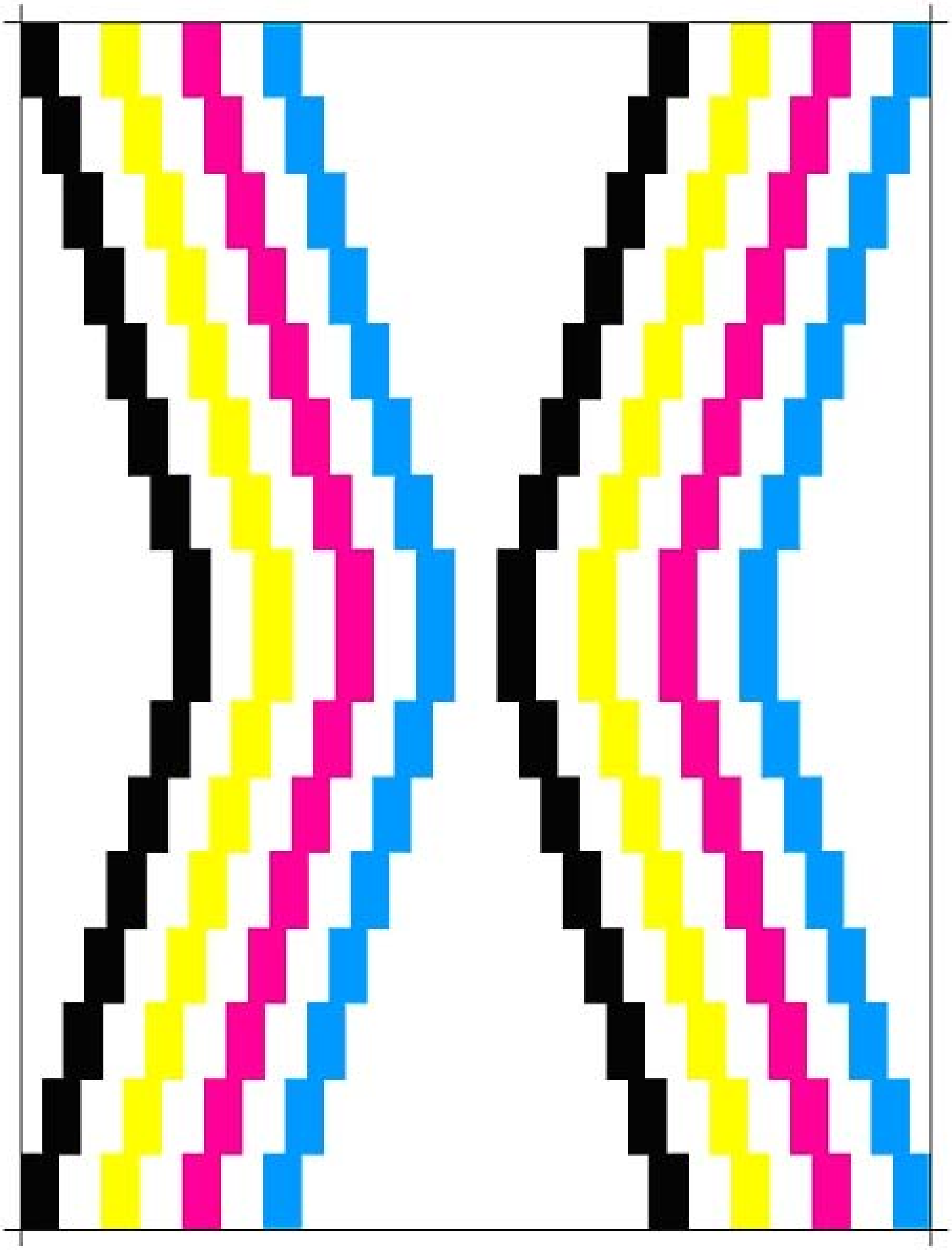
8.3 Master print pattern 5 % coverage, monochrome (see DIN 33870 [9])

The print pattern is available electronically from http://www.ps.bam.de/RALUZ122E

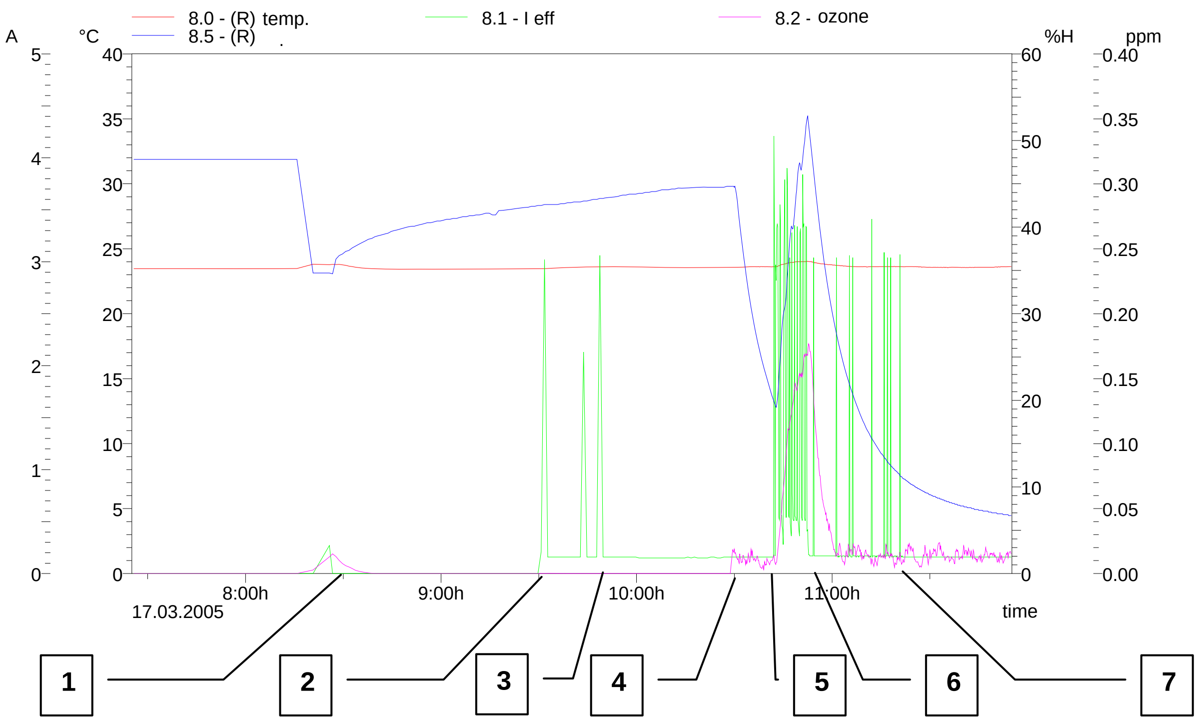


8.4 Master print pattern for testing colour devices, 20% coverage

The print pattern is available electronically from http://www.ps.bam.de/RALUZ122E



8.5 Example of the development of atmospheric conditions, power consumption and ozone concentration during testing



1 Loading (8:25 until 8:30 h)
2 Beginning of pre-operating phase (9:30 h)
3 Energy-saving mode comes into effect
4 Change of air exchange, lowering humidity
5 Beginning of printing phase
6 End of printing phase
7 Energy-saving mode comes into effect

8.6 Example of a proven VOC measurement method (cf. [2], [5])

Sampling pipes: Tenax TA (tube length 178 mm, OD 6 mm, ID 4 mm, 200 mg Tenax TA (60-80 mesh) with glass wool plug); Sampling volume > 1.0 l (100 ml/min). Before sampling the Tenax tubes have to be spiked with an internal standard diluted in methanol.

The calibration is performed in such a way that the calibration substances, dissolved in methanol, are applied (spiked) to separate Tenax tubes are rinsed with one litre of synthetic air or nitrogen (purity 5.0) to simulate sampling. In doing so, methanol remaining on the Tenax after spiking is desorbed.

Analysis system:

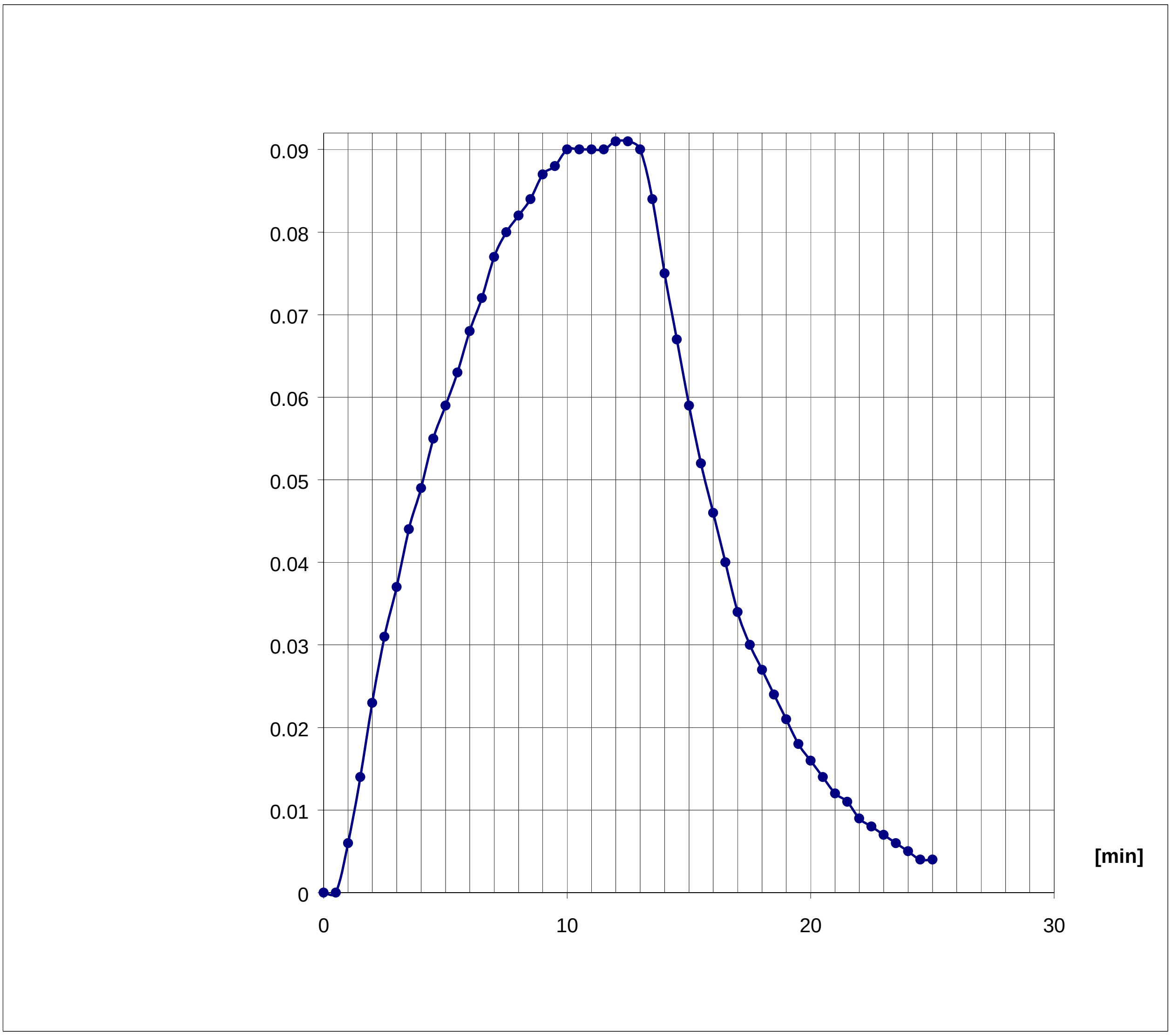
Gerstel TDS-2 / KAS-3 thermal desorption/cold feed system (program 40-280°C with 40°C/min, keep 5 min at 280°C / at -150 °C, heating with 10°C/s up to 290°C / He flow 35 ml/min)

HP GC 5890 II + / HP-MSD 5972 (column HP 1; 60 m; 0.25 mm; 0.25 µm; temperature program 40°C for 4 min, 5°C/min up to 140°C, 10°C/min up to 240°C, 25°C/min up to 290°C, keep for 3 min / MSD: scan 25 - 400; 1.9 scans/s; 300°C; NBS-75k - database)

Potential compounds

Acetophenone
n-Alkanes (C10-C16)
Benzaldehyde
Benzene
BHT (2.6-di-tert.-butyl-4-methylphenol)
Ethylbenzene
Ethylhexanol
Unsaturated aldehydes (C6-C10)
n-Butanol
n-Propylbenzene
Phenol
Propyleneglycol
Siloxane (e.g. D3-D6)
Styrene
Toluene
Trimethylbenzenes
Xylenes

8.7. Development of ozone concentration during printing at high concentration (data in ppm)



For the calculation of the emission rate the ozone half-life can be determined from the declining slope of the ozone concentration curve (after the end of the printing cycle).