

# **Investigations on VOC, ozone and dust emissions from hardcopy devices (laser printers, copiers and multifunctional devices) in test chambers—development of a test method**

J. Rockstroh\*, O. Jann, O. Wilke, R. Noske, D. Brödner, U. Schneider, W. Horn

*Federal Institute for Materials Research and Testing, 12200 Berlin, Germany*

## **ABSTRACT**

The background to these investigations was the revision of the current selection criteria of the German ecolabel ('Blue Angel') for copiers (RAL-UZ 62) and printers (RAL-UZ 85). In the requirements limits were set for ozone, dust and styrene emissions. The old test methods did no longer correspond to today's requirements with regard to emission measurements. In addition, the contrary emission behaviour of hardcopy devices due to the use of different and non-comparable test methods has been recently discussed.

For this reason, a new test method had to be developed which enables a reliable, reproducible determination of emission rates (ER) for dust, ozone and VOC. The basis for this was the European Computer Manufacturers Association (ECMA) Standard 328 compiled by the ECMA using dynamic chamber measurements. Nine different machines, desktop laser printers as well as office devices like bigger copiers and multifunctional devices were investigated.

As a result of the study, new criteria for the Blue Angel for copiers, printers and a new created for multifunctional devices (RAL-UZ 114), concerning TVOC, ozone and dust emissions were determined.

Three of the tested devices would not fulfil the new emission criteria. A model for the calculation of theoretically resulting concentrations in a real room under normal printing conditions derived from the test chamber results is also presented.

## **INDEX TERMS**

Emissions; Printers; Copiers; VOC; Dust; Ozone; Blue Angel

## **INTRODUCTION**

Different aspects of emissions from hardcopy devices were investigated in test chambers with the aim to develop a reliable and comparable test method (Jann *et al.*, 2003). In addition to former measurements (Black and Worthan, 1999; Wensing *et al.*, 2002) different emission test chambers and higher air exchange rates were used in order to get an equilibrium concentration within the short printing time.

Because of possible health effects on, e.g. office workers, focus was put on the emissions of VOCs, ozone and dust from toner particles (Wolkoff *et al.*, 1993). With a reduction of emissions from hardcopy devices a further step for an improvement of indoor air quality will be done. The basis for the new test method was the ECMA 328 standard and the international standards DIN ENV 13419-1 for emission test chambers and DIN ISO 16000-6 for VOC analysis

## **MATERIALS AND METHODS**

### **Test Objects—Hardcopy Devices**

Nine different hardcopy devices from seven manufacturers were tested, desktop laser printers as well as office devices like bigger copiers and multifunctional devices. They were usually

---

\* Corresponding author. E-mail: jens.rockstroh@bam.de

taken from the current series production run. Only one printer was taken directly from an office.

### **Toner and Paper**

The toner module was the manufacturer's original configuration. For tests, both recycling paper and different papers produced from primary fibres were used. The paper humidity had a range between 3.8 and 5.6% and the weight per unit area was 80 g/m<sup>2</sup>. The experiments showed that paper humidity should not exceed 4%. Higher paper humidity of recycled paper could lead to water condensation in the chamber during printing when small chambers (1 m<sup>3</sup>) are used. Therefore, recycled paper was dried at 50°C for 7 days. The paper humidity was determined by DIN EN 20287.

### **Emission Test Chambers**

One 20 m<sup>3</sup> and two different 1 m<sup>3</sup> emission test chambers were used for the tests. Their specifications are described in Jann *et al.* (2003), DIN V ENV 13419-1 and ECMA 328 standard. Air exchange rates needed for the measurement were regularly checked and recorded by means of an independent procedure, e.g. tracer gas method by DIN V ENV 717-1 in an empty status.

### **Test Procedure—Printing Process**

All measurements were performed in 2002. The print mode for testing was 'best quality'. Blank values were determined before each measurement by setting an air exchange rate of 1 h<sup>-1</sup> in all chambers. During printing process in the 20 m<sup>3</sup> chamber, the air exchange rate was set at 1 h<sup>-1</sup> and in the 1 m<sup>3</sup> chambers to 4–5 h<sup>-1</sup> (dry air, RH < 10%) to keep relative air humidity below critical values and to shorten the time for reaching an equilibrium concentration. Since last copy was printed, at least 12 h passed. Blank values measured later showed a clean chamber.

VOC, ozone and dust sampling started at the beginning of the printing phase and were carried on until the end of the follow-up phase after printing. The follow-up phase was run over a period of four air exchanges. For VOC also samples from the devices without power supply (equipment completely switched off and power plug out of power socket), in standby (power plug in the power socket, equipment switched on and ready for use, so that printing could begin in the shortest possible time but no printing) and in three to four steps during printing were taken. Unlike the procedure practised previously, neither the emission test chamber may be opened nor are persons permitted to stay in the large chamber during tests. For a standard black printing a 5% page coverage was used for the printing procedure according to DIN 33870 as used in the productivity tests of toner modules.

### **VOC**

VOC sampling was accomplished using Tenax TA tubes with a follow-up thermal desorption (DIN ISO 16000-6) and GC/MSD analysis. Sampling volume was between 0.5 and 2 l with an airflow of 100 ml/min. The ER during the printing phase was calculated in two ways, depending on the time of sampling:

- (a) Using the continuous sample from the start of the printing phase to the end of the follow-up phase (calculation according to Eqn 1).
- (b) Using the sample taken 6 min before the end of the printing phase. This technique is however only applicable to small chambers at high air exchange rates and a minimum of 10 min printing time (calculation according to Eqn 2).

$$SER_{U-PF} = \frac{m_{VOC-PF} * n_{PF} * V * t_S}{t_P * V_S} \quad (1)$$

$$SER_{U-P} = \frac{c_P * V * n_P}{1 - e^{-n_P * t}} \quad (2)$$

$SER_{U-PF}$ : VOC ER [ $\mu\text{g unit}^{-1} \text{h}^{-1}$ ] determined from the printing and follow-up phases,  $SER_{U-P}$ : VOC ER [ $\mu\text{g unit}^{-1} \text{h}^{-1}$ ] determined from the printing phase,  $m_{VOC-PF}$ : analysed mass [ $\mu\text{g}$ ] of VOC during the printing and follow-up phases,  $n_{PF}$ : air exchange rate [ $\text{h}^{-1}$ ] during the printing and follow-up phases,  $t_P$ : printing time [min],  $t_S$ : overall sampling time [min],  $V$ : volume of test chamber [ $\text{m}^3$ ],  $V_S$ : sample volume [ $\text{m}^3$ ] during the printing phase,  $c_P$ : VOC concentration [ $\mu\text{g m}^{-3}$ ] during the printing time,  $n_P$ : air exchange rate [ $\text{h}^{-1}$ ] during the printing phase,  $t$ : medium time of sampling [h].

The TVOC value was calculated as the sum of the concentrations of all identified and unidentified substances, having  $\geq 2 \mu\text{g m}^{-3}$  concentration and retention times between *n*-hexane and *n*-hexadecane. If possible, all substances were identified and individually quantified using the relative response factors determined from a calibration by internal standards. If substances could not be identified or the relative response factor could not be determined, quantification was performed based on the response factor of deuterated toluene.

The analysis was carried out by thermal desorption (final temperature  $290^\circ\text{C}$ , Gerstel TDS-2 / CIS-3) combined with gas chromatography (HP 5890 II plus) and a mass spectrometer (HP MSD 5972).

### Dust

Dust ER was determined using a gravimetric method. Air sampling was performed over both printing and follow-up phases. During this time interval, a defined air volume was led through a glass-fibre filter. The absolute dust weight is obtained in micrograms using an ultra microbalance (UMX 2/M, Mettler-Toledo) (DIN EN 13284-1).

### Ozone

The measurement procedure is based on a flameless reaction between ozone and ethylene. The resulting chemoluminescence was continuously measured by the ozone analyser (model 3010, UPM). Data recording was done using an electronic data logger.

Ozone determination started immediately at the beginning of the printing job and continued until the end of the follow-up phase. Ozone half-life was determined from the decay curve in the follow-up phase. For small ozone concentrations, ozone was injected into the chamber after the follow-up phase and the ozone half-life determined while the chamber remained loaded. The ozone ER was calculated according to Eqn (3).

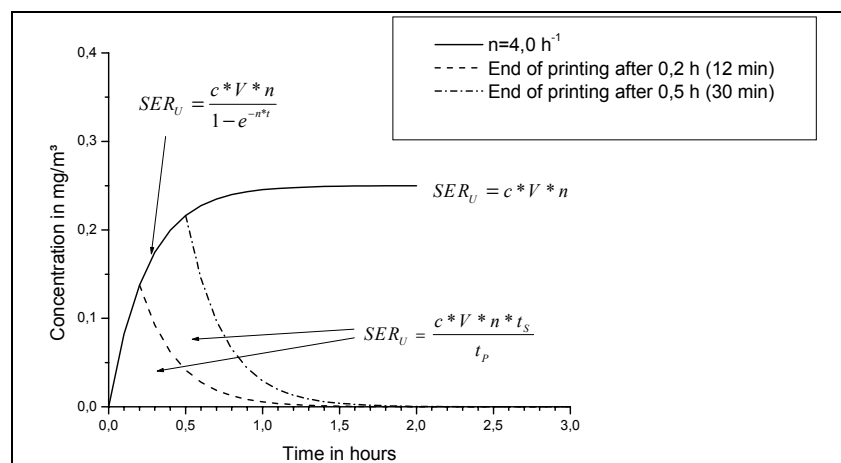
$$SER_U = \frac{c_{\max} * \ln 2 * V * p}{T * H' * R} \quad (3)$$

$SER_U$ : ER of ozone [ $\mu\text{g unit}^{-1} \text{h}^{-1}$ ],  $c_{\max}$ : maximum ozone concentration [ $\mu\text{g m}^{-3}$ ],  $H'$ : ozone half-life under test conditions [h],  $V$ : volume of test chamber [ $\text{m}^3$ ],  $p$ : air pressure [Pa],  $T$ : absolute temperature [K],  $R$ : gas constant [ $\text{Pa K}^{-1}$ ].

## RESULTS AND DISCUSSION

To calculate ER directly from the measured concentration, a high air exchange rate has to be adjusted due to the short printing time. Alternatively, the ER under non-equilibrium conditions can be calculated by correcting the concentration data with an e-function (see Methods—VOC, Eqn 2) or by measuring continuously from the start of the printing phase to the end of the follow-up phase (see Methods—VOC, Eqn 1). Figure 1 shows the theoretically

course of concentration in the case of an air exchange rate of  $4 \text{ h}^{-1}$ , an end of printing after 0.2 h and/or 0.5 h and depicts the possible calculation methods.



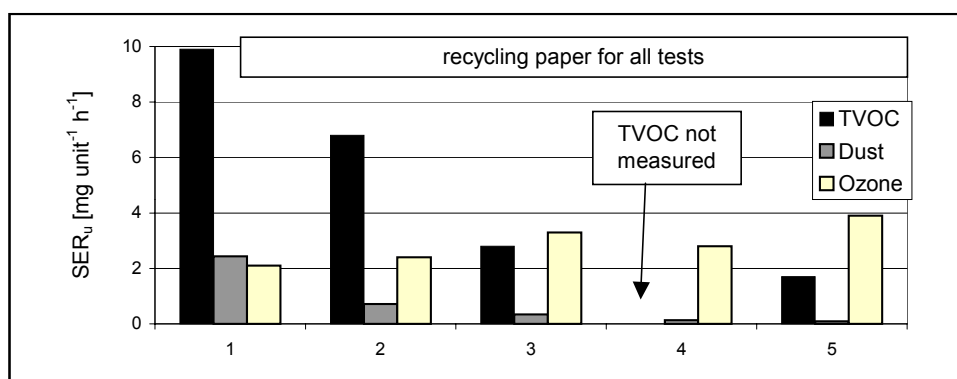
**Figure 1** Theoretically course of concentration in the case of an air exchange rate of  $4 \text{ h}^{-1}$  for an equilibrium approach and an end of printing after 0.2 h and/or 0.5 h.

Emission data for TVOC, dust and ozone as determined from nine hardcopy devices are presented in Table 1 for the printing phase. ERs are expressed as milligram (mg) of contaminant emitted per hour (h) of hardcopy device operation. Additionally, TVOC emissions rates are listed without power supply and in standby mode. In this modes neither dust nor ozone emissions could be detected. As listed in Table 1, the data showed a wide range of emissions among the tested equipment.

**Table 1** Range of the emission rates for nine tested hardcopy devices

	Emission rates/(range of values) [ $\text{mg u}^{-1} \text{ h}^{-1}$ ]				
	TVOC			Dust	Ozone
	Without power supply	Standby	Printing phase	Printing phase	Printing phase
Hardcopy devices	0.03–1.40	0.03–2.26	0.40–22.7	0.10–2.70	<0.02–4.6

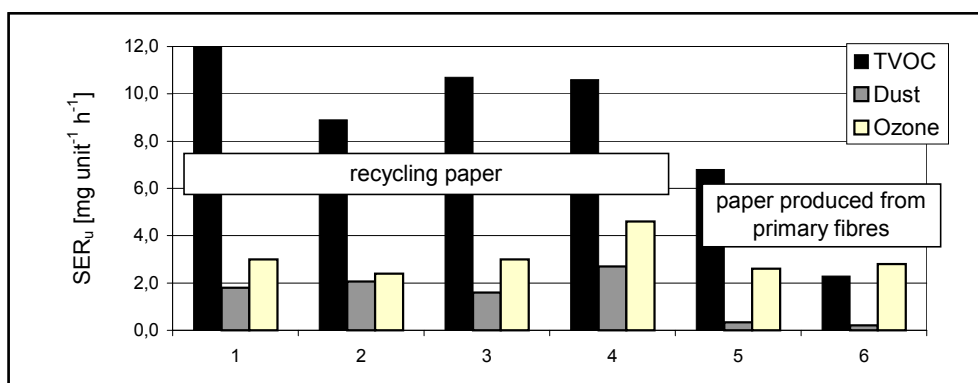
As an example Figure 2 shows the ER of TVOC, dust and ozone for a single hardcopy device (no. 4) using recycling paper for all repetitive measurements. The other test conditions were equal and comparable with the ones used for the tests shown in Figure 3. Contrary to the tested device pictured in Figure 3, a decrease for both dust and TVOC ER could be shown while the ozone ER is nearly constant. It is assumed that this emission behaviour especially for TVOC is due to an ageing of materials used in the device.



**Figure 2** Repetitive emission rates of single hardcopy device (no. 4) (1 m<sup>3</sup> chamber)

As an example, Figure 3 shows the ER of TVOC, dust and ozone of another single hardcopy device (no. 3) for repetitive measurements under nearly the same conditions (different papers). The comparability of measurements is good, provided that the same paper is used. This means the ERs were relatively constant over a longer period (results from 1 to 4 over a period of 6 months). We further see the significant lower ER for dust when paper produced from primary fibres instead of recycling paper is used for printing.

Both kind of papers used consist of fibres. Due to the fabrication procedure of the recycling paper the fibres could be shorter than the fibres in the paper produced from primary fibres. It is assumed that only these short fibres in recycling paper were the reason for the higher dust ER. For the new test method developed paper produced from primary fibres is recommended.



**Figure 3** Repetitive emission rates of single hardcopy device (no. 3) (1 m<sup>3</sup> chamber)

## CONCLUSION AND IMPLICATIONS

The main advantage of the new test method developed is to get comparable results from different institutes because measuring conditions for hardcopy devices are now well defined. Instead of using concentrations for the definition of regulatory limits for German ecolabels for copiers (RAL-UZ 62), printers (RAL-UZ 85) and new created for multifunctional devices (RAL-UZ 114), ERs were used for the first time.

To predict indoor concentration levels from ER a standardized room volume of 17.4 m<sup>3</sup> and an air exchange rate of 0.5 h<sup>-1</sup> were assumed. The maximum concentration values for different contaminants are given in Table 2. Calculations were based on 1 h operation time in 10 h and a printing of 1000 pages equally distributed over this time. Resulting ER and maximum concentrations in test chambers were calculated by the equations given in Table 2.

**Table 2** Maximum concentration values for indoor air and derived ER and concentrations in test chambers

		Maximum value in a model room ( $c_R$ ) [ $\mu\text{g m}^{-3}$ ]	Coefficient of use ( $F$ )	Emission rate in chamber ( $ER_C$ ) [ $\mu\text{g unit}^{-1} \text{h}^{-1}$ ] calculated by:	Resulting maximum concentration in the chamber ( $c_K$ ) [ $\mu\text{g m}^{-3}$ ] calculated by:	
Working conditions Substance				$ER_C = C_R * n_R * V_R * F^{-1}$	$C_K = C_R * n_R * V_R * n_C^{-1} * V_C^{-1} * F^{-1}$	
		$V_R = 17.4 \text{ m}^3$ $n_R = 0.5 \text{ h}^{-1}$			$V_C = 1 \text{ m}^3$ , $n_C = 5 \text{ h}^{-1}$	$V_C = 20 \text{ m}^3$ , $n_C = 1 \text{ h}^{-1}$
Printing (1000 pages in 10 h)	TVOC	100		8700.0	1740.0	435.0
	Benzene	0.5		43.5	8.7	2.2
	Styrene	12	0.1	1044.0	208.8	52.2
	Ozone	20		(1740)	(348)	(87)
	Dust	40		3480.0	696.0	174.0
Stand-by	TVOC <sup>a</sup>	100	1	870.0	174.0	43.5

<sup>a</sup>TVOC for desktop devices.

The figures for ozone in Table 2 are in brackets because in this case ozone-decay has been neglected in the calculation for the reason of simplification. Table 3 shows the maximum ER derived from Table 2 and defined by the revised ecolabels.

**Table 3** Maximum emission rates for hardcopy devices (RAL-UZ 62, 85 and 114)

Parameter	SER <sub>U</sub> printing phase [mg unit <sup>-1</sup> h <sup>-1</sup> ]	SER <sub>U</sub> desktop devices stand-by [mg unit <sup>-1</sup> h <sup>-1</sup> ]	SER <sub>U</sub> big office devices stand-by [mg unit <sup>-1</sup> h <sup>-1</sup> ]
TVOC	10	1	3
Ozone	2	—	—
Dust	4	—	—

## ACKNOWLEDGEMENTS

The German Federal Environmental Agency is gratefully acknowledged for the financial contribution to the project under no. 201 95 311 / 02 and the manufactures and testing institutes for their assistance and good cooperation.

## REFERENCES

- Black, M.S., Worthan, A.W. (1999). Emissions from office equipment. *Proceedings of the 8th International Conference on Indoor Air Quality and Climate—Indoor Air '99*, Edinburgh, Vol. 2, pp. 454–459.
- DIN V ENV 717-1 (Normentwurf), 02-1999. Wood based panels—Determination of formaldehyde release—Part 1: Formaldehyde emission by the chamber method.
- DIN EN 13284-1, 04-2002. Emissionen aus stationären Quellen—Ermittlung der Staubmassenkonzentration bei geringen Staubkonzentrationen—Teil 1: Manuelles gravimetrisches Verfahren.
- DIN V ENV 13419-1 (Normentwurf), 10-1999. Building products—Determination of the emission of volatile organic compounds—Part 1: Emission test chamber method.
- DIN ISO 16000-6 11-2000. Innenraumluftverunreinigungen—Teil 6: Bestimmung von VOC in der Innenraumluft und in Prüfkammern. Probenahme auf TENAX TA, thermische Desorption und Gaschromatographie/MSD bzw. FID.
- DIN EN 20287 09-1994. Papier und Pappe—Bestimmung des Feuchtegehaltes.

- DIN 33870, 01-2001. Informationstechnik—Anforderungen und Prüfungen für die Aufbereitung von gebrauchten Tonermodulen schwarz für elektrophotographische Drucker, Kopierer und Fernkopierer.
- ECMA-Standard 328, 08-2001. Detection and measurement of chemical emissions from electronic equipment ([www.ecma.ch](http://www.ecma.ch)).
- Jann, O., Wilke, O., Noske, R. *et al.* (2003). Development of a test method and investigation into limiting emissions from hardcopy devices within the framework of an environmental label award. UBA-Project-No. 201 311/02, German Federal Environmental Agency (Umweltbundesamt, UBA), UBA-Texte (in print), Berlin.
- Wensing, M., Kummer, T., Riemann, A. and Schwampe, W. (2002). Emissions from electronic devices: examination of computer monitors and laser printers in a 1 m<sup>3</sup> emission test chamber. *Proceedings of the 9th International Conference on Indoor Air Quality and Climate—Indoor Air '02*, Monterey, CA, Vol. 2, pp. 554–559.
- Wolkoff, P., Wilkins, C.K., Clausen, P.A. and Larsen, K. (1993). Comparison of volatile organic compounds from processed paper and toners from office copiers and printers. *Proceedings of the 3rd International Conference on Indoor Air Quality and Climate—Indoor Air '93*, Vol. 1, pp. 113–123.