EMISSIONS FROM ELECTRONIC DEVICES: EXAMINATION OF COMPUTER MONITORS AND LASER PRINTERS IN A 1M^3 EMISSION TEST CHAMBER

M Wensing*, T Kummer, A Riemann and W Schwampe

TÜV NORD Umweltschutz GmbH & Co.KG, Hamburg, Germany

ABSTRACT
Investigations were carried out using the test chamber method to determine which influence VOC emissions from computer monitors and laser printers in normal operation can have on the quality of indoor air. Theoretical indoor air concentrations were computed for a model room using specific emission rates. In individual cases it was determined that concentrations may occur during the initial start-up of the devices, which are above the indoor recommended values for TVOC. The VOC emissions from the monitors revealed a clearly defined decay behaviour within a few hours after the initial start-up as a result of ageing. Therefore a comparably low contribution to the indoor air composition is to be expected with long-term use. The emissions from laser printers are influenced decisively by the printing process. In this case recurring emissions on the same level are to be expected over limited periods.

INDEX TERMS
Electronic device, VOC, Measurement method, Chamber method, Exposure assessment

INTRODUCTION
In earlier investigations on televisions/video recorders (Wensing, 1999a) and photocopiers (Brown, 1999) it was found that electronic devices are significant as an emission source for the indoor air. The study for the present paper examined the possible influence of VOC emissions from computer monitors and laser printers on the indoor air. For this reason 19 different monitors and 14 different laser printers in normal operation were examined and compared under standardized test conditions in a 1m^3 emission test chamber. Device-specific emission rates were calculated using the concentrations measured in the test chamber. These values were then used to determine the indoor air concentrations theoretically to be expected in a model room and then compared with the recommended values for indoor air.

METHODS
The monitors (M-1 to M-19) and laser printers (P-1 to P-14) were delivered as new devices in their original packaging to TÜV NORD in Hamburg. The devices were sealed in aluminium-coated PE foil and stored until the beginning of the emission testing in an air-conditioned room at T = 23 °C and RH = 50 %. Each device was examined separately in a 1m^3 emission test chamber with inner walls of electropolished stainless steel. The chamber conforms with the requirements of ENV 13419-1 (1999) and is fitted with special cable bushings to enable the control of electronic devices from the outside. Each device was tested in normal operation using a standardized test cycle for VOC. The sequence of the investigation also essentially accords with a recently published ECMA standard (ECMA, 2001). Prior to the start of each test the chamber was heated up overnight to 240 °C. The devices were placed in the chamber cleaned using this method and initially acclimatized in standby mode overnight (16 hours) at

* Contact author email: mwensing@tuev-nord.de

T = 23 °C, RH = 50 %, ACH = 0.5 h^{-1}. On the following morning the monitors were then switched on; for all devices air samples were taken after a running time of 6 hours at the air outlet of the chamber to determine the VOC. Long-term investigations were also carried out on certain monitors. The laser printers were also switched on the following morning. Here a test page was printed out continuously at a speed of approx. 4 pages per minute. The VOC sampling was then started after 30 minutes.

The VOC determination (screening analysis) was carried out using enrichment with Tenax TA (5 l, 0.5 l/min), thermal desorption (PE-ATD 400) and GC/MS combination (HP 5890/HP5970) using a DB-5MS separation column. The VOC identification was carried out using mass spectrometry and retention indices. The TVOC value was determined by totalling the individual VOC in the gas chromatogram between C_6 and C_{16} (EC, 1997). In the investigation of the monitors the quantities of toluene and phenol were determined in parallel with other sampling. The determination of toluene was carried out by enrichment with activated carbon type NIOSH (50 l, 1 l/min), solvent desorption (CS_2) and GC/MS evaluation (HP 5890/HP5970) using a DB-5MS separation column to the method of the internal standard. The phenol determination was carried out by enrichment with silica gel type NIOSH (50 l, 1 l/min), solvent desorption (acetone) and GC/MS evaluation (HP 5890/HP5970) using a DB-624 separation column to the internal standard method.

In consideration of the experimental test conditions (ACH = 0.5h^{-1}, loading factor = 1 unit), the concentration values for an ideal chamber without sink effects were converted to the unit specific emission rate SER_U with the unit µg/(unit h). The theoretical indoor air concentrations were calculated on the basis of the SER_U for a model room with 17.4 m^3 and an ACH of 0.5h^{-1} (ENV 13419-1, 1999).

RESULTS

Using the GC/MS technology in principle the same compounds were found as in the investigation of televisions and video recorders (Wensing, 1999a). Tables 1 and 2 show the concentrations quantitatively measured in normal operation of the examined monitors and laser printers as well as the theoretically derived indoor air concentrations to be expected. A differentiation can be made in the emissions from electronic devices between two types of compounds: On the one hand each device produces emissions that are directly attributable to the materials and additives used in the manufacture of the device. On the other hand devices such as laser printers additionally generate recurring emissions with each printing process. Figure 1 shows the example of monitor M-10 with the general time-concentration progression of the emissions during the investigation of the monitors. When switching over from standby at the time t = 0 hours to the normal operating state the concentrations in the test chamber initially increase. The basic cause for this increase in the emissions is the heat increase in the inside of the devices. Individual electronic components can heat up to over 100 °C (Wensing 2001).

The maximum TVOC concentration was always found after an operating time of 6 hours under the test conditions (Wensing 1999b, Wensing 2001, ECMA 2001). The emissions measured at the time t = 6 hours provide an overview of the typical measured values during an initial start-up. The concentrations of most of the VOCs reveal a clearly defined exponential decay behaviour. The TVOC value is a good indicator for the general time progression of the volatile emissions. The VOC emissions of the computer monitors reveal a significant dependency on age: New devices had clearly higher emission levels compared to older devices. Of the individual substances from the VOC group toluene is a typical solvent used in

the manufacture of electronic devices and which could be identified in every monitor after the initial start-up over a longer period of time. Furthermore the phenol emissions were examined. Phenol originates from circuit boards on phenolic resin basis. The decay behaviour for phenol was not as strongly distinct as for the other VOCs, see Figure 1. This can be attributed to a diffusion-controlled emission process from the circuit boards, where phenol keeps on being emitted from deeper layers.

In corresponding repeat measurements with laser printers it was seen that, on the basis of a comparably low TVOC level in standby mode, the same increased TVOC level was repeatedly achieved during the printing process. A decay behaviour caused by longer running time as was found with the monitors could not be ascertained. The increase in the VOC values accompanied by the printing process cannot be explained solely by temperature increases in the inside of the devices. Emissions from the toner also play a role here. The increase in concentration in the test chamber in this case is directly dependent on the printing speed. In the testing of the laser printers the paper feed capacity represents a limiting time factor. It is therefore not certain whether the steady-state concentration was achieved for all printers by the end of the VOC sampling.

Table 1. Emission investigation of monitors (initial start-up); sampling after 6 hours in operation in the test chamber, SER_U and model room concentration

No.	*TVOC SER_U*	*TVOC Model room*	*Toluene SER_U*	*Toluene Model room*	*Phenol SER_U*	*Phenol Model room*
M-1	526	60	64	7	24	3
M-2	1,376	158	321	37	130	15
M-3	1,545	178	600	69	150	17
M-4	2,231	256	780	90	32	4
M-5	771	89	231	27	31	4
M-6	1,025	118	538	62	74	9
M-7	2,427	279	1045	120	223	26
M-8	2,534	291	219	25	78	9
M-9	1,455	167	146	17	48	6
M-10	1,713	197	758	87	211	24
M-11	1,136	131	210	24	47	5
M-12	1,607	185	189	22	20	2
M-13[1)]	11,099[1)]	1276	207	24	130	15
M-14[2)]	253	29	11	1	18	2
M-15[2)]	301	35	35	4	59	7
M-16[2)]	214	25	32	4	33	4
M-17[2)]	36	4	1	< 1	7	1
M-18	701	81	147	17	134	15
M-19	732	84	91	10	35	4

SER_U = unit specific emission rate [µg/(unit h)]
Model room = calculated indoor air concentration for a model room [µg/m^3]
[1)] main compound limonene
[2)] Not a brand new device, total number of hours in operation prior to the emission testing unknown

Table 2. Emission test of laser printers; print-out at 4 pages per minute; sampling after 0.5 hours in operation.

No.	*TVOC Chamber air*	*TVOC SER_U*	*TVOC Model room*
P-1	520	260	30
P-2	10,730	5,365	617
P-3	2,660	1,330	15
P-4	5,244	2,622	301
P-5	708	354	41
P-6	152	76	9
P-7	1,990	995	114
P-8	342	171	20
P-9	360	180	21
P-10	686	343	39
P-11	4,719	2,358	271
P-12	308	154	18
P-13	987	493	57
P-14	2,566	1,283	147

Chamber air = measured maximum concentration in the test chamber [µg/m^3]
SER_U = unit specific emission rate [µg/(unit h)], estimated from maximum concentration
Model room = calculated indoor air concentration for a model room [µg/m^3]

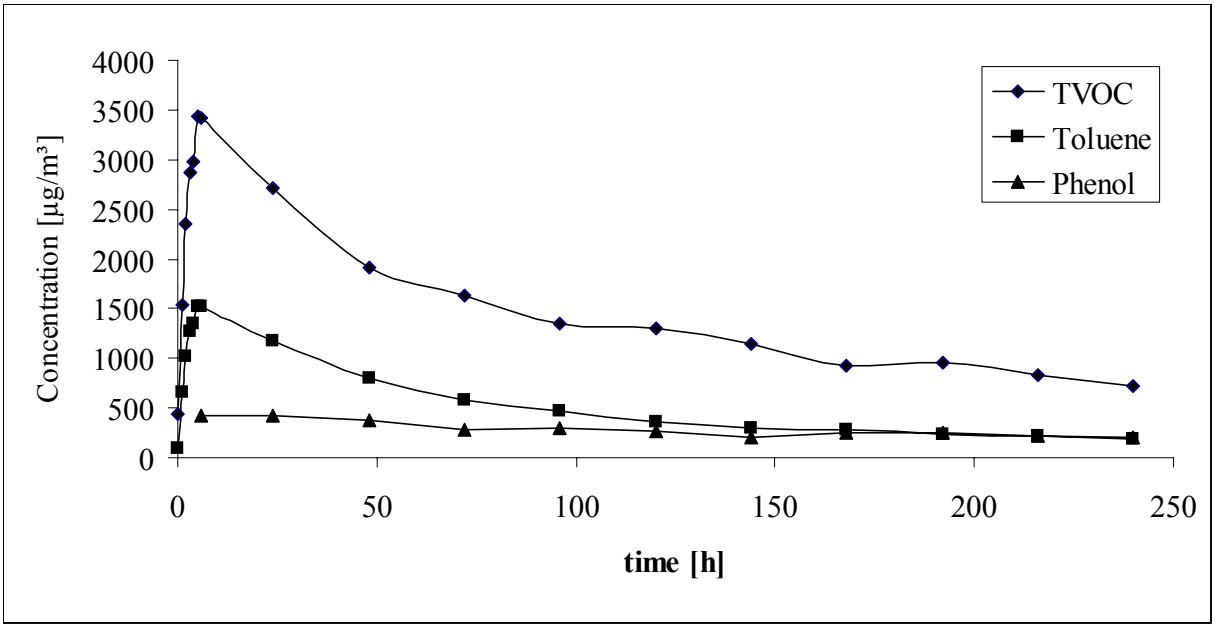

Figure 1. Long-term emissions of TVOC, toluene and phenol from monitor M-10.

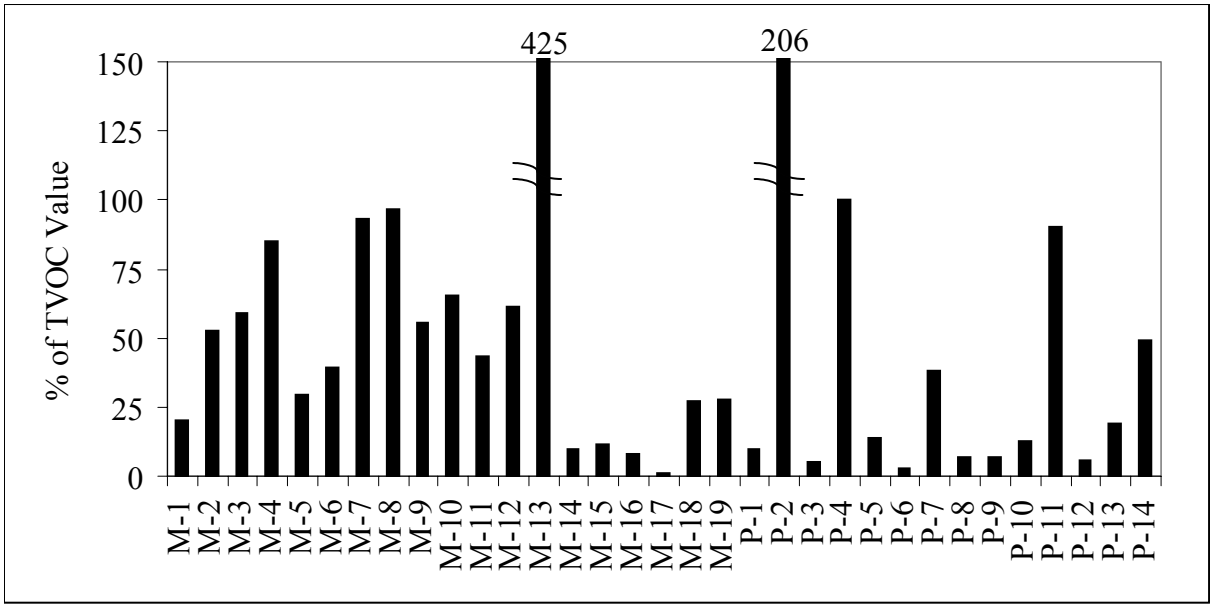

Figure 2. Percentage share of the hygienic precautionary value for TVOC reached by the individual devices in a model room.

DISCUSSION

For the purposes of an indoor air hygienic evaluation, the emissions from the examined devices can be converted on the basis of the SER_U, using a model computation to the indoor air concentrations theoretically to be expected (ENV 13419-1, 1999). The result of this model investigation can be compared with recommended values for indoor air. The TVOC recommended value should not exceed a value of 0.3 mg/m³ in the indoor environment in the long-term average (hygienic precautionary value), a value of 1 – 3 mg/m^3 should not be exceeded (Seifert, 1999). Figure 2 is a graphic evaluation of the measured data showing to which percentage share the hygienic precautionary value for TVOC of 0.3 mg/m^3 was reached by the individual devices in the model computation. This examination also takes into account the maximum measured concentrations. One monitor (M-13, 425 %) achieved a value above 100 % for the initial start-up. The TVOC recommended value of 1 – 3 mg/m^3 was reached by this device with a reading of 1,276 µg/m^3. The remaining theoretically derived indoor air concentrations were all less than the hygienic precautionary value for TVOC. There is a recommended value for toluene in indoor rooms of 0.3 mg/m^3 (Sagunski, 1996). This value was reached by the monitors to a maximum of 40 %. As a result of the ageing-dependent decay of the VOC emissions only a comparatively low contribution to the indoor air composition is to be expected during long-term use of the monitor. As the emissions from laser printers are decisively influenced by each printing process, recurring emissions to a comparable degree are to be expected for these devices. With the printers a favourable aspect is that these are generally only active for a very limited time during the actual printing process as an emission source and over the remaining time do not contribute to the composition of the indoor air. The phenol compound is of interest as an emission from electronic devices from two aspects: Firstly odour-intensive phenol-like compounds can be emitted from printed circuit boards (Walpot, 1996). Secondly the phenol compound is a substance suspected of being a carcinogenic (DFG, 2001). With 26 µg/m^3 monitor M-7 achieved the highest value for the theoretical indoor air concentration of phenol.

CONCLUSION AND IMPLICATIONS

The presented examination results make it possible to perform comparative emission investigations on monitors and laser printers in order to derive e.g. SER_U for hygienic indoor air evaluations. However it must be taken into account in the examination of the printers that the paper feed capacity of the printer can represent a time-limiting factor in the investigation. The results can be used by the manufacturers within the framework of product developments to recognise in good time health-relevant emissions and to avoid or minimise these emissions to the best of their ability. In determining device-specific quality requirements (limit values) for the emission behaviour it must be taken into account that the electronic devices investigated here are always operated in combination with other devices that can emit comparable substances, and that they represent only one potential emission source in the indoor environment together with many others. The setting of such limit values for the monitors should be linked to the age of the device (total amount of operating hours) at the time of the sampling. The TVOC value appears to be a suitable indicator for a general evaluation of the VOC emissions. Substances of particular toxicological relevance (carcinogenic, mutagenic, hazardous to embryos) must be viewed separately. In addition to VOC emissions electronic devices can also produce SVOC emissions (Wensing, 1999a, Pardemann et Wensing, 2002).

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