Measurements of aldehydes and VOCs from electronic appliances by using a small chamber

R. Funaki*, H. Tanaka, T. Nakagawa, S. Tanabe

Department of Architecture, Waseda University, Japan

ABSTRACT
Indoor chemicals are emitted not only from building materials but also from various products such as furniture and electronic appliances that were brought by occupants. Usually, these electronic appliances are made of plastics and synthetic materials. Adhesive and sorbent are also used in these materials. In this paper, the emission rates of aldehydes and VOCs from electronic appliances including a portable PC, a remote controller of a TV, a low frequency current massager, a cellular phone and a photo journal were measured by using a small chamber. It was found that the emission rate of formaldehyde for the portable PC during turning on was 9 μg/unit/h, which was nine times higher than that while being switched off. In the second experiment, a portable PC was exposed under relatively high concentration of ozone. The outlet ozone concentration from the chamber with PC was decreased as low as 50% of the blank chamber.

INDEX TERMS
VOCs; Electronic appliances; Chamber; Ozone

INTRODUCTION

Emission rates of aldehydes and VOCs for the building materials such as floorings, carpets and wall coverings have been determined by using a small chamber. However, indoor chemicals are emitted not only from building materials and furniture but also from various products such as electronic appliances. Many of them are made of plastics and synthetic materials. Adhesive and sorbent are also used in these materials. Chemical emission rates from personal computers, electronic appliances widespread in offices and homes have been reported earlier by several studies (Braungart *et al.*, 1997; Black and Worthan, 1999; Wensing, 1999, 2001). Braungart *et al.* (1997) reported emissions from 19 different products that were commonly used in offices and households. Televisions/video recorders (Wensing, 1999, 2001) and computer monitors/laser printers (Wensing *et al.*, 2002) were measured by using a 1 m^3 emission test chamber. It was found that electronic appliances including personal computers had a significant effect on indoor air pollution. In 2001, ECMA (European Computer Manufacturers Association) published a standard measuring method for electronic equipment (ECMA, 2001). In this paper, emission rates of aldehydes and VOCs from a portable PC, a remote controller of a TV, a low frequency current massager, a cellular phone and a photo journal were measured by using a small chamber ADPAC (Tanabe, 2000).

Moreover, electronic appliances like photocopy machine and lazar printers are one of the major sources for ozone indoors. The reaction between ozone and indoor pollutants were reported in several papers (Zhang *et al.*, 1994; Weschler, 2000). Knudsen *et al.* (2000) reported that the secondary emission with ozone had a strong impact on the perceived air quality. In the second part of this paper, a preliminary experiment was conducted to investigate the effects of ozone for a portable PC, by measuring its emission rate in the first part. Oxidation reaction was observed for a portable PC exposed under the relatively high ozone concentration.

*Corresponding author. E-mail: funaki@tanabe.arch.waseda.ac.jp

MEASUREMANETS OF EMISSION RATE

Test Products

All test products except A shown in Table 1 were measured just after purchasing. The portable PC was measured under the conditions of switching on and off (B, C). The photo journal (G) was opened at the mid-page during the measurement period.

Table 1 List of the test products

No.	Product	Period of operation
A		9 months after unpacking
B	Portable PC (A4 size)	New/switched off
C		New/switched on
D	Remote controller of TV	New
E	Low frequency current massager	New
F	Cellular phone	New
G	Photo journal (all colour pages)	New

Methods

Measurements were carried out by using a 20-l chamber ADPAC. Its performance characteristics met with the Japanese Industrial Standard (JIS A 1901, 2003). Throughout the measurements, air temperature and relative humidity inside the test chamber were kept constant at 25 ± 1°C and 50 ± 4%. The chamber was ventilated at 0.5 h^{-1}. However, the internal temperature was increased during the measurement of product C due to heat dissipation.

Ten litres of air was sampled for aldehydes with DNPH-Silica cartridge and 3.2 l for VOCs with Tenax TA tube. The sampling rates for both aldehydes and VOCs were 0.167 l/min. This was the same as the ventilation rate of the small chamber. After the sampling procedures, high-performance liquid chromatography (HPLC) was used for the analysis of aldehydes, and thermal desorption system (TDS) and GC/MS for the VOCs.

Results

The results were expressed by the unit specific emission rate in micrograms per unit and hour. Equation (1) shows the relationship between the unit specific emission rate (EF_u) and the chamber concentration (C_t):

$$EF_u = C_t \times \frac{nV}{u} \qquad (1)$$

where EF_u is the unit specific emission rate (μg/unit/h), C_t is the chamber concentration (μg/m^3), n is air exchange rate (1/h^{-1}), V is chamber volume (m^3) and u is a number test specimen (unit).

Since these measurements were carried out by using a 20-l chamber, and an air exchange rate of 0.5 h^{-1}, the figures of the emission rates per unit were 0.01 times smaller than those of the concentration in the chamber.

Figure 1 shows the unit specific emission rate for aldehydes and those for VOCs and TVOC. Fifty VOCs were identified and quantified. Table 2 shows the chamber concentration and unit

Table 2 Chamber concentrations and unit specific emission rates of identified VOCs

	Identified substances	Chamber concentration ($\mu g/m^3$)	Emission rate (μg/unit/h)
A	***TVOC*** *)	***750***	***7.5***
	Octane	26	<1
	Toluene	23	<1
	Butyl acetate	19	<1
	1-Butanol	16	<1
B	***TVOC***	***2412***	***24.1***
	Octane	115	1.2
	Toluene	85	<1
	1-Butanol	75	<1
	Butyl acetate	63	<1
	Decane	14	<1
	1,2,4-Trimethylbenzene	13	<1
	Undecane	10	<1
	Ethylbenzene	10	<1
	Styrene	10	<1
C	***TVOC***	***16835***	***168.4***
	Butyl acetate	891	8.9
	Toluene	749	7.5
	Octane	672	6.7
	1-Butanol	466	4.7
	Styrene	117	1.2
	Ethylbenzene	105	1.1
	Decane	103	1.0
	Xylene	81	<1
	1,2,4-Trimethylbenzene	79	<1
	Tetradecane	71	<1
	Heptane	58	<1
	Nonanal	53	<1
	Ethyl acetate	44	<1
	Dodecane	39	<1
	Ethanol	29	<1
	Hexadecane	26	<1
	1,2,3-Trimethylbenzene	25	<1
	α-Pinene	23	<1
	Pentadecane	21	<1
	1,3,5-Trimethylbenzene	19	<1
	o-Ethyl toluene	16	<1
	Undecane	15	<1
	n-Hexane	14	<1
	m-Ethyl toluene	12	<1
	p-Dichlorobenzene	10	<1
D	***TVOC***	***545***	***5.5***
	Dodecane	153	1.5
	Tetradecane	93	<1
	Decane	63	<1
	Undecane	37	<1
	Toluene	22	<1
	Hexadecane	18	<1
	n-Hexane	10	<1
E	***TVOC***	***63***	***<1***
F	***TVOC***	***787***	***7.9***
	Dodecane	63	<1
	1-Butanol	49	<1
	Tetradecane	34	<1
	Toluene	17	<1
	Xylene	7	<1
G	***TVOC***	***30521***	***305.2***
	Decane	1469	14.7
	Nonane	522	5.2
	1,2,4-Trimethylbenzene	488	4.9
	Undecane	453	4.5
	Tetradecane	416	4.2
	Dodecane	250	2.5
	Pentadecane	229	2.3
	1,2,3-Trimethylbenzene	194	1.9
	1,3,5-Trimethylbenzene	186	1.9
	Ethylbenzene	171	1.7
	m-Ethyl toluene	153	1.5
	Xylene	146	1.5
	p-Ethyl toluene	111	1.1
	1-Butanol	93	<1
	o-Ethyl toluene	82	<1
	Toluene	78	<1
	Hexadecane	66	<1
	Nonanal	63	<1
	D-Limonene	50	<1
	Heptane	35	<1
	Octane	30	<1
	Ethanol	21	<1
	Styrene	13	<1
	Butyl acetate	10	<1

specific emission rate of the identified VOCs. In this paper, TVOC is defined as the sum of the concentrations of identified and unidentified VOCs between *n*-hexane and *n*-hexadecane (ENV 13419-1, 1999). Toluene response factor was used for the calculation. Table 3 shows the unidentified substances with high peaks for C and G. These substances have been selected based on the literatures (ECA, 1997; WHO, 1999; EPA, 2000; the Ministry of Health, Labor and Welfare, 2001).

Emission rates of a portable PC during switched off mode were very low and little difference was observed between PCs A and B. On the other hand, the emission rate of formaldehyde for the portable PC (C) with switched on mode was 9.0 μg/unit/h, that of acetone 15.9 μg/unit/h and TVOC 168.4 μg/unit/h. Relatively high peaks were observed for toluene, octane, 1-butanol, styrene, ethylbenzene, decane and phenol. Not only power supply but also the PC itself might have emitted these chemical substances through exhaust opening of fan from parts. In these measurements temperature inside the chamber was reached over 40°C during switched on mode. This temperature may be unrealistic in the daily operation, so measurements under comfortable range are planed in the future. Under the well mixing conditions, indoor air concentration of these chemicals might be under guideline values even with high density. Although the emission of formaldehyde for the PC (C) was 9.0 μg/unit/h, the concentration in the chamber was over 900 μg/m^3. If one inhales the exhaust air directly from the PC, there is a possibility of being over the guideline values of formaldehyde.

The photo journal G emitted the highest TVOC of 305.2 μg/unit/h, of which decane was 14.7 μg/unit/h and acetaldehyde was 8.0 μg/unit/h. High peaks of nonane, 1,2,4-trimethylbenzene, undecane, tetradecane, dodecane and ethylbenzene were observed. Alkanes and aromatic hydrocarbons were found relatively higher. The emission rates both from the low frequency current massager and the cellular phone were very low.

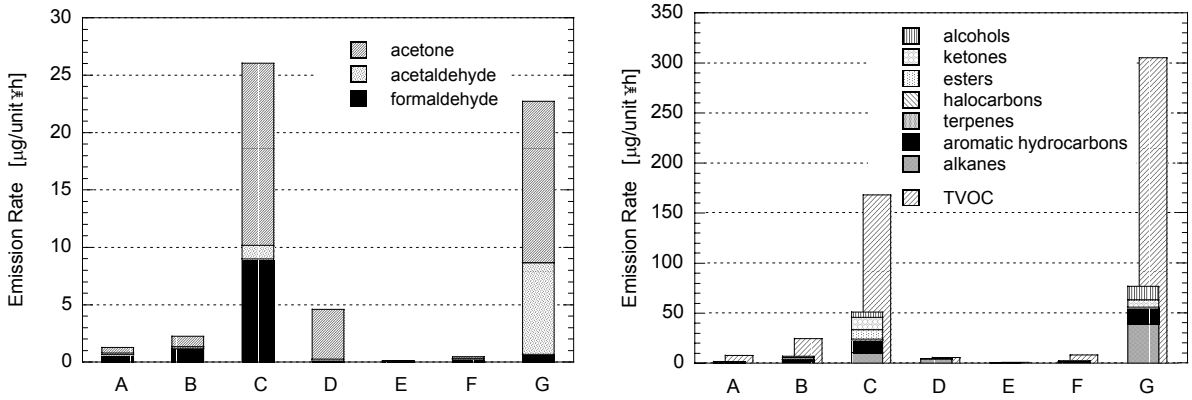

Figure 1 Left is unit specific emission rates for aldehydes after one day, and the right is that for VOCs and TVOC.

Table 3 Unidentified substances of large peaks for portable PC (C) and photo journal (G)

Portable PC (C)	Photo journal (G)
2-Butxyethanol	Hexanal
2-Ethyl-1-hexanol	Naphthalene
Phenol	Pentanal
Acetphenone	1-Pentanol
Cyclohexanon	*n*-Butanal

MEASUREMENT OF OXIDATION REACTION BY OZONE WITH PC

Methods

In the second experiment, a portable PC whose emission rates were measured in the first part of this paper was exposed under the relatively high concentration of ozone. This experiment is a preliminary result of reaction of ozone with a PC. If ozone reacts with VOCs, ozone concentration in the chamber might become lower.

The PC was tested with either switched on or off mode. It was the same portable PC, namely B and C in Table 1. An ozone generator (MODEL 1410, Dylec Inc.) was used with the airflow rate of 1.0 l/min. The inlet concentration of ozone into the chamber was approximately 200 ppb. This is a relatively high concentration in normal office spaces, but we observed this level from the exhaust air from a photocopy machine. The concentration of ozone at the outlet of the chamber was measured continuously for 20 h by MODEL 1150 (Dylec Inc.).

RESULTS AND DISCUSSION

Figure 2 shows the concentration of ozone for 20 h. The concentration of ozone in the chamber with PC was decreased over half compared with the empty chamber even under the switched off mode. Under the condition of switched on mode its decrement was 86% from the initial value. The average concentration of ozone after 4 h was 193 ppb for the empty chamber, 82 ppb for the PC in switched off mode and 27 ppb for PC in switched on mode. The emission rates of chemical substances from the PC in switched on mode were the highest among the three conditions. The oxidation reaction must be higher with the higher chemical concentration in the chamber. On the other hand, the deposition velocities of ozone are influenced by temperature and relative humidity (Weschler, 2000), so increased temperature inside the chamber might also affect the reduction of ozone concentration. The measurements of secondary products are planned.

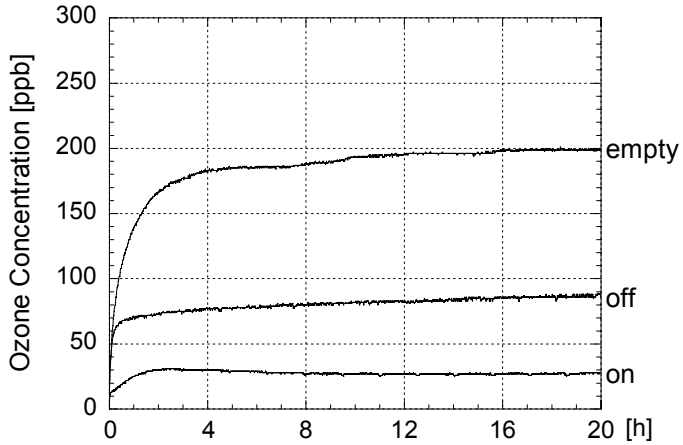

Figure 2 Outlet concentration of ozone for 20 h.

CONCLUSION

Emission rates of aldehydes and VOCs from electronic appliances were measured by using a small chamber. A portable PC was also exposed under the relatively high concentration of ozone. The following conclusions were obtained:

- The emission rates of aldehydes and VOCs from a remote controller of a TV, a low frequency current massager and a cellular phone were low.
- It was found that the emission rate of formaldehyde for the portable PC during turning on mode was 9.0 μg/unit/h, which was nine times higher than that of switched off. That of

TVOC was 168.4 μg/unit/h. Relatively high peaks were observed for toluene, octane, 1-butanol, styrene, ethylbenzene, decane and phenol.

- The emission rate of a photo journal was the highest among them. That of TVOC was 305.2 μg/unit/h, decane 14.7 μg/unit/h, acetone 14.1μg/unit/h, acetaldehyde 8.0μg/unit/h. High peaks of nonane, 1,2,4-trimethylbenzene, undecane, tetradecane, dodecane and ethylbenzene were observed.
- The outlet concentration of ozone from the chamber with a portable PC was decreased, as low as 50% of the blank chamber.

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