Chemical emission rates from personal computers

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ABSTRACT
Chemical emission measurements from different brands of personal computers (PCs) were conducted in a 1 m^3 glass chamber. Eight PCs were tested individually. Each consisted of the same brand of PC tower and one of the 4 different brands of PC monitors. Within each brand both cathode-ray tube (CRT) and thin-film transistor (TFT) flat panel monitors were evaluated. Volatile organic compounds (VOCs) and aldehydes were quantified using GC/MS and HPLC, respectively. Compared with PCs with TFT monitors, PCs with CRT monitors had slightly higher emission rates of formaldehyde and acetaldehyde, emitted greater quantities of C3-C6 aldehydes having low odor thresholds and had higher emissions of aromatic hydrocarbons. Emission rates of aliphatic hydrocarbons were low for both PCs with CRT and TFT monitors. However, estimated concentrations of these chemicals in a normal office space based on the measured emission rates were much lower than the odour thresholds.

INDEX TERMS
Aldehydes; VOC; Emissions; Personal Computers; Electronic equipment

INTRODUCTION
Not only building materials and furniture, but also electronic appliances contribute to indoor air pollution. European Computer Manufacturers Association (ECMA, 2001) has published a standard measuring method for electronic appliances. Chemical emission rates from personal computers (PCs), electronic equipment widespread in offices and homes, have been reported earlier by several studies (Black and Worthan, 1999; Wensing *et al*., 2002; Bakó-Biró *et al*. 2003; Funaki *et al*., 2003). In the present study, sensory and chemical emission rates from different brands of PCs were measured. Sensory emission rates are reported in a separate paper by Wargocki *et al*. (2003). Chemical emission rates are reported in this paper.

EXPERIMENTAL METHODS
Chemical emission rates from eight PCs were measured. Each consisted of the same brand of PC tower and one of the 4 different brands of PC monitors. Each brand included cathode-ray tube (CRT) and thin-film transistor (TFT) flat panel monitors (Table 1). Top-selling brands in the world market were selected. New PCs were purchased at local electronic shops prior to the experiment, unpacked, placed in a ventilated room and operated continuously for several days before the chemical measurements were made (Table 1). PCs were in normal operation mode during the measurements.

The experimental set-up is shown in Figure 1. A pair of identical PCs were placed in a 1 m^3 glass chamber ventilated at 1 h^{-1}, thus the ventilation rate per PC was 0.14 l/s. The ventilation rate was adjusted using tracer gas. The glass chamber was placed in a 30 m^3 stainless steel chamber ventilated with outdoor air at a rate corresponding to 16.6 h^{-1}. To maintain the temperature of exhaust air from the glass chamber at about 22^{o}C, air temperature in the stainless steel large chamber was kept at 18^{o}C. To increase heat flow from the glass chamber,

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small mixing fans were used in the glass chamber. In between measurements the glass chamber was baked-out at 40°C to reduce background concentration.

Table 1 PC-code, monitor type and size, and the period of operation before the chemical measurements were taken

Identifier	Type and size of monitor	Period of operation before measurement after unpacking (h)
A-CRT-PC	CRT – 17 in.	195
B-CRT-PC	CRT – 17 in.	215
C-CRT-PC	CRT – 19 in.	270
D-CRT-PC	CRT – 17 in.	195
A-TFT-PC	TFT – 15 in.	265
B-TFT-PC	TFT – 15 in.	220
C-TFT-PC	TFT – 17 in.	340
D-TFT-PC	TFT – 15 in.	150
D-CRT (monitor only)	CRT – 17 in.	170
D-CRT (case only, heated)	CRT – 17 in.	150
Tower	NA	390

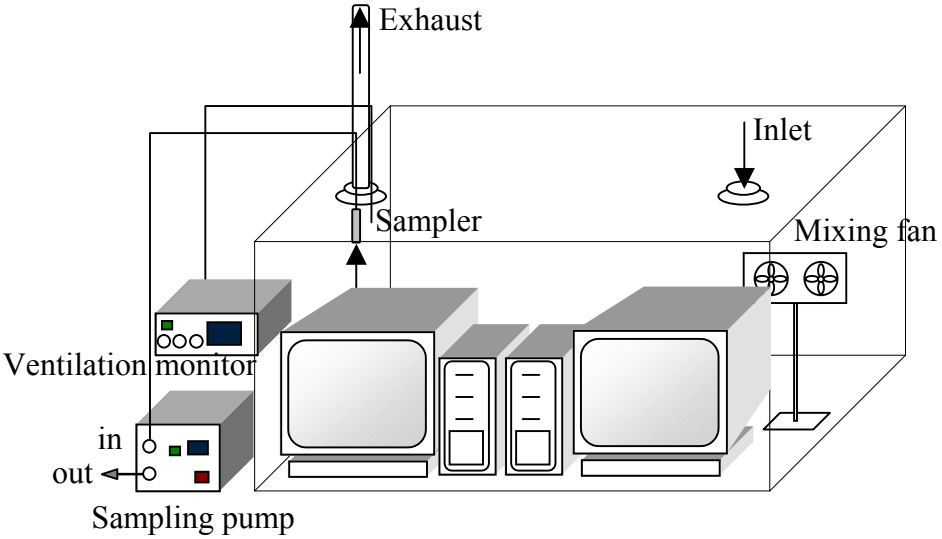

Figure 1 Experimental set-up; glass chamber had dimensions 1.0 × 0.6 × 1.7 m.

The air supplied to and exhausted from the glass chamber was sampled actively with pumps on tubes (Table 2). Travel blanks were taken randomly during the experimental period. Fifty VOCs were identified and quantified according to analytical method showed in Table 2. Toluene equivalent total concentration of VOCs (TVOC) was calculated from the peaks between n-hexane and n-hexadecane. The emission rates per PC were calculated using measured concentrations at the exhaust and ventilation rate in the glass chamber. They were corrected for background concentration in the glass chamber. Sink effects were not accounted for in the calculations but were expected to be of neglible consequence.

Table 2. Sampling methods

Items	Aldehydes	VOCs
Sampling tube	Sep-Pak DNPH-Silica (short type)	Tenax TA (60/80 mesh) 200mg
Airflow	1 l/min	0.1 l/min
Volume	120 l	5 l
Analysis method	HPLC	GC/MS

RESULTS AND DISCUSSION

Formaldehyde and Acetaldehyde

Emission rates of formaldehyde and acetaldehyde from PCs with CRT monitors were slightly higher than those with TFT monitors (Figure 2). Average emission rates of formaldehyde and acetaldehyde were 12.8±3.6 µg/(unit h) and 3.6±1.2 µg/(unit h) for PCs with CRT monitors, and 9.7±3.2 µg/(unit h) and 1.5±1.2 µg/(unit h) for PCs with TFT monitors. Emission rates of formaldehyde and acetaldehyde from a laptop PC measured by Funaki *et al*. (2003) were 8 µg/(unit h) and 2 µg/(unit h), respectively, thus were close to those of PCs with TFT monitors measured in this experiment. Generally, these emission rates are very low. When a ventilation rate of 7 l/s per PC is assumed in an office space, the concentration of formaldehyde is estimated to increase by only 0.5 µg/m^3 for CRT-PCs with well mixed condition. This value is less than 0.05% of odour threshold of formaldehyde.

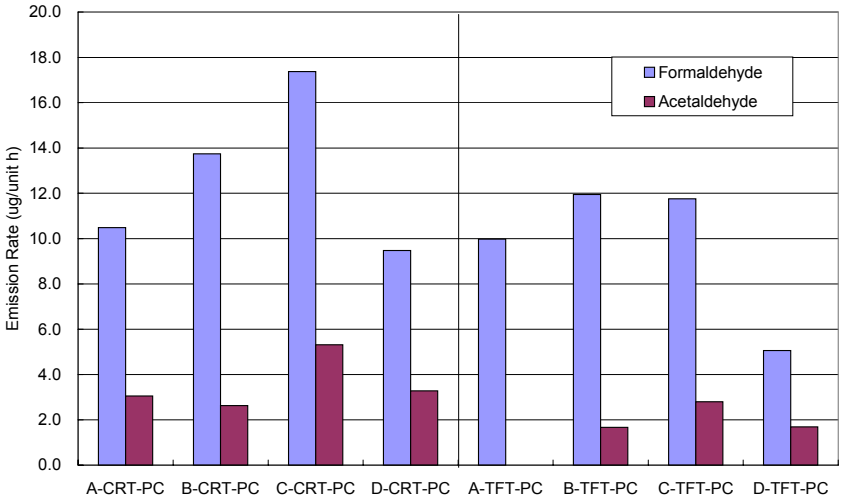

Figure 2 Emission rates of formaldehyde and acetaldehyde from PCs.

Propionaldehyde, n-Butyraldehyde, Valeraldehyde, and Hexaldehyde

Figure 3 shows that the emission rates of propionaldehyde, n-butyraldehyde, valeraldehyde and hexaldehyde from PCs with CRT monitors are higher than those from PCs with TFT monitors. Hexaldehyde is observed from both types of PCs, since it is commonly included in consumer products. These four aldehydes were selected because they have relatively low odour thresholds (Table 3) and can thus cause sensory effects. Table 4 shows the numerical figures of emission rates. Parallel sensory measurements showed that sensory emission rates were high for PCs with CRT monitors and negligible for PCs with TFT monitors (Wargocki *et al*., 2003). Based on the measured chemical emission rates, it was estimated at which concentrations these four aldehydes occurred during sensory measurements of PCs with CRT monitors. The calculations showed that they were much below odour thresholds. If ventilation rate of 7 l/s per PC is assumed in an office space, the concentration of valeraldehyde is estimated to increase by only 0.12 µg/m^3 for CRT-PCs. This is 0.6% of its odour threshold.

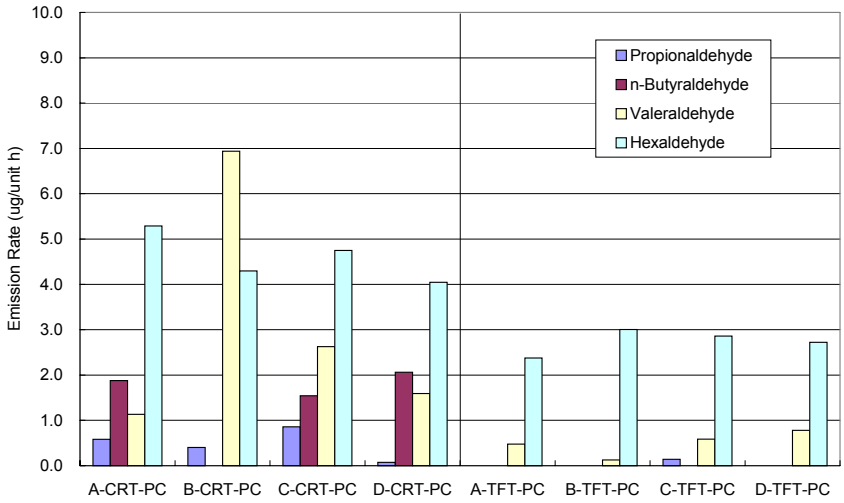

Figure 3 Emission rates of C3 to C6 aldehydes, i.e. propionaldehyde, n-butyraldehyde, valeraldehyde and hexaldehyde.

Table 3 Odour thresholds for some of the detected aldehydes

Compound	ppb	$\mu g/m^3$
Formaldehyde	870	1070
Acetaldehyde	186	340
Propionaldehyde	5	14
n-Butyraldehyde	9	28
Valeraldehyde	6	22
Hexaldehyde	14	58

Table 4 Averaged emission rates from CRT and TFT PCs (µg/unit h)

Identifier	CRT-PC (SD)	TFT-PC (SD)
Formaldehyde	12.8 (3.6)	9.7 (3.2)
Acetaldehyde	3.6 (1.2)	1.5 (1.2)
Propionaldehyde	0.5 (0.3)	ND (-)
n-Butyraldehyde	1.4 (0.9)	ND (-)
Valeraldehyde	3.1 (2.7)	0.5 (0.3)
Hexaldehyde	4.6 (0.5)	2.7 (0.3)
Aromatic hydrocarbons	103 (36.1)	32 (14.0)
TVOC	180 (56.0)	113 (31.8)

VOCs

Figure 4 shows the emission rates of aliphatic and aromatic hydrocarbons; the measurements of A-CRT-PC and A-TFT-PC failed and are not included in the figure. TVOC is also shown. Benzene, toluene, ethylbenzene, xylene, styrene, m-ethyltoluene, p-ethyltoluene, 1,3,5-trimethylbenzene, o-ethyltoluene, 1,2,4-trimethylbenzene, 1,2,3-trimethylbenzene and 1,2,4,5-tetramethylbenzene were identified and quantified. The emission rates of aliphatic hydrocarbons, terpenes, halogens, esters, ketones and alcohols were not significantly different for PCs with CRT and TFT monitors. Aromatic hydrocarbons were higher for PCs with CRT monitors than those with TFT monitors. Relatively high peaks were observed for toluene, xylene, phenol, 2,2,4,6,6-pentamethyl 3-heptene, 4-tert butyltoluene, ethylbenzene, 1,2,4-trimethylbenzene and butylated hydroxy toluene. High peaks of toluene, octane, 1-butanol, styrene, ethylbenzene, decane, xylene, 1,2,4-trimethylbenzene and phenol were found by Funaki *et al.* (2003), who measured emission rates from a laptop PC.

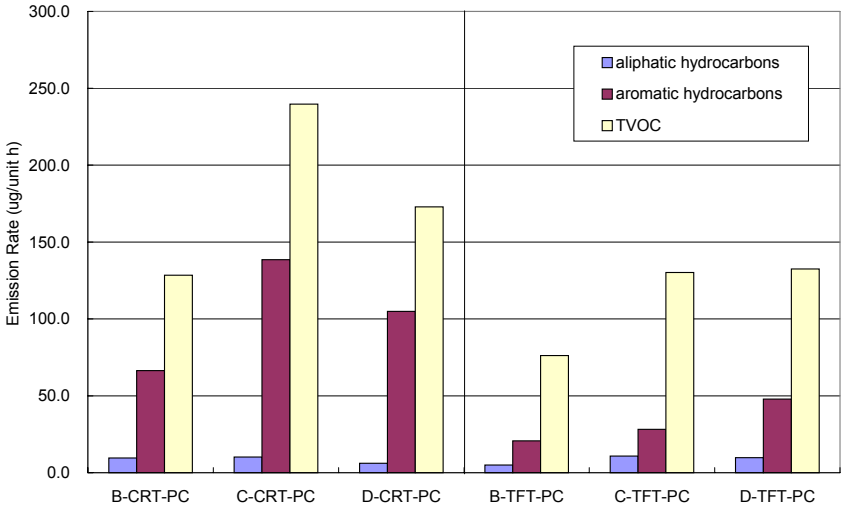

Figure 4 Emission rates of VOCs.

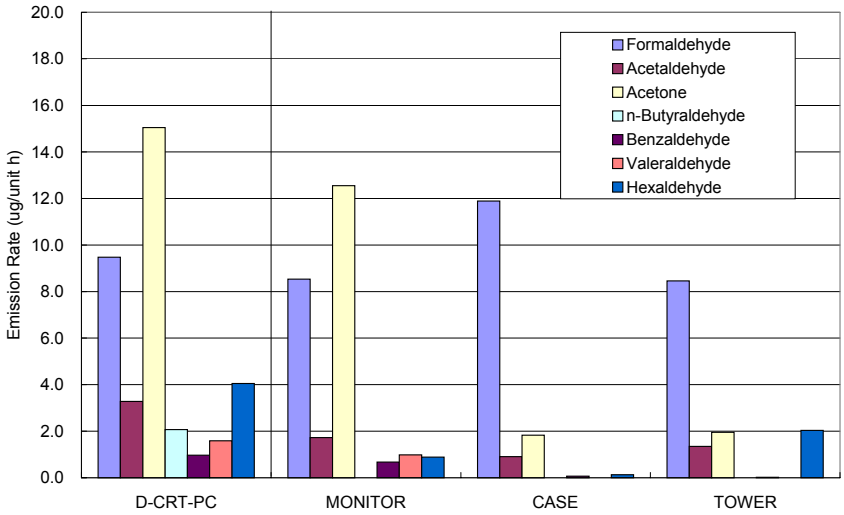

Figure 5 Emission rates of aldehydes and acetone from D-CRT-PC and its components.

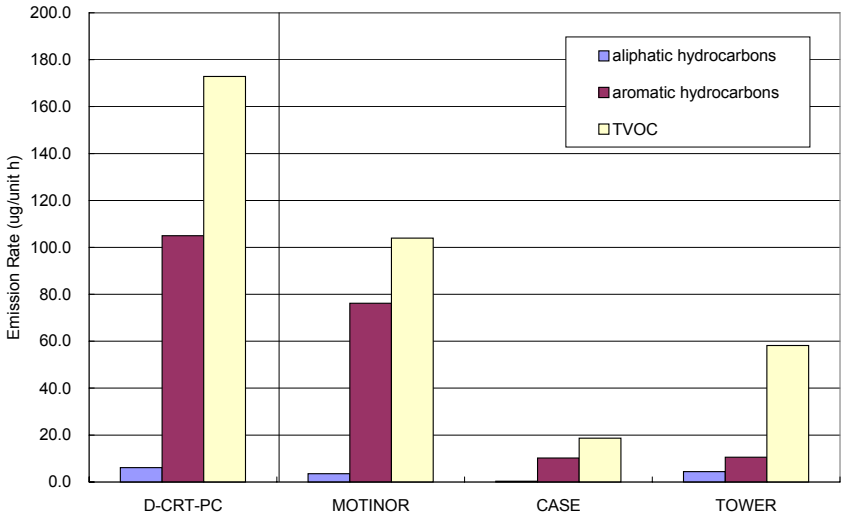

Figure 6 Emission rates of aliphatic and aromatic hydrocarbons and TVOC from D-CRT-PC and its components.

Main Source of Chemical Emissions

Figures 5 and 6 show the emission rates of aldehydes and VOCs from PC coded D-CRT-PC and separately from its monitor, its heated monitor casing and its PC tower. To heat the monitor casing, ordinary bulbs with Wolfram filament with the same power rating as an operating CRT monitor were used. With the exceptions of formaldehyde and hexaldehyde, the monitor was the main source of chemical emissions. The emission rate of formaldehyde from the heated monitor casing was higher than from the PC, suggesting that the heated casing might have reached higher temperature than this occurring during normal operation.

CONCLUSIONS AND IMPLICATIONS

Measurements of chemical emission rates from world's top-selling brands of PCs having both CRT and TFT monitors showed that:

- emission rates of formaldehyde and acetaldehyde from PCs with CRT monitors were higher that those for PCs with TFT monitors;
- emission rates of propionaldehyde, n-butyraldehyde, and valeraldehyde having relatively low odor thresholds, for PCs with CRT monitors were much higher than those for PCs with TFT monitors;
- estimated concentrations of these aldehydes in the sensory test rooms based on the measured chemical emission rates were much below odour thresholds;
- emissions of aromatic hydrocarbons were higher for PCs with CRT monitors compared with PCs with TFT monitors;
- CRT monitor was the main source of pollution.

Taking into account the sensory effects of emissions from PCs (Bakó-Biró *et al*., 2003; Wargocki *et al*.,2003) these results suggest that PCs are an important but often overlooked indoor pollution source. This should be considered when establishing ventilation requirements for spaces containing PCs.

ACKNOWLEDGEMENTS

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