Sensory emission rates from personal computers and television sets

P Wargocki[a,*], Z Bakó-Biró [a,b], S Baginska[a,c], T Nakagawa[a,d], P O Fanger[a], C Weschler[a,e], S Tanabe[a,d]

[a]*International Centre for Indoor Environment and Energy, Technical University of Denmark;* [b]*Department of Building Services Engineering I., Budapest University of Technology and Economics, Hungary;* [c]*Institute of Heating and Ventilation, Warsaw University of Technology, Poland;* [d]*Department of Architecture, Waseda University, Japan;* [e]*Department of Environmental and Community Medicine, UMDNJ/Robert Wood Johnson Medical School, USA*

ABSTRACT

Sensory emissions from personal computers (PCs), PC monitors + PC towers, and television sets (TVs) having been in operation for 50, 400 and 600 h were assessed by a panel of 48 subjects. One brand of PC tower and four brands of PC monitors were tested. Within each brand, cathode-ray tube (CRT) and thin-flat-transistor (TFT) monitors were selected. Two brands of TVs were tested. All brands are prevalent on the world market. The assessments were conducted in low-polluting 40 m^3 test offices ventilated with a constant outdoor air change rate of 1.3 ± 0.2 h^{-1} corresponding to 7 L/s per PC or TV with two units placed at a time in the test offices; air temperature was controlled at 22 ± 0.1°C and relative humidity at 41 ± 0.5%. The subjects entered the offices individually and immediately assessed the air quality. They did not see the PCs or TVs that were placed behind a screen and were in operation. The average sensory emission rate for PCs with CRT monitors was 2.7 ± 1.7 olf/PC after 50 h of operation. It decreased to 1.4 ± 1.2 olf/PC when the operation time was 600 h, suggesting a half-life equal to 4 months of normal use. The sensory emission rates for PCs with TFT monitors were negligible. The average sensory emission rate for TVs was 1 ± 0.6 olf/TV after 50 h of operation and decreased to a negligible level after 400 h of operation. Present results indicate that air pollution from electronic equipment should be considered when calculating the ventilation requirements for acceptable indoor air quality.

INDEX TERMS

Perceived air quality; Sensory; Emissions; Personal computers; Electronic equipment

INTRODUCTION

Recent experiments have shown that the air pollution from a popular brand of personal computers (PCs), consisting of a tower and a cathode-ray-tube (CRT) monitor, in operation for 500 h, reduced perceived air quality, caused Sick Building Syndrome (SBS) symptoms and reduced the productivity of office workers (Bakó-Biró *et al*., 2002). These results require generalization to other brands and types of PCs, e.g. for PCs with thin-flat-transistor (TFT) monitors, with different operation time, and for other electronic equipment, e.g. for television sets (TVs), which are also suspected of being a source of pollution indoors. The present study meets these requirements by providing data on sensory emission rates for some of the most common brands and types of PCs and TVs and examining whether they are dependent on the duration of operation.

[*]Corresponding author. E-mail: pw@mek.dtu.dk

METHODS

Sensory assessments of air polluted by operating PCs and TVs were made by a sensory panel of untrained subjects. The assessments were made immediately upon entering low-polluting test offices with a volume of 40 m^3. The offices were ventilated by axial fans mounted in the window with a constant outdoor air supply rate, which corresponded to an average air change rate of 1.3 ± 0.2 h^{-1}; the supply air was not filtered but had an excellent perceived quality (Wargocki *et al*., 2000). The air in the offices was conditioned by electric heaters and ultrasonic humidifiers to a constant temperature of 22 ± 0.1°C and a constant relative humidity of 41 ± 0.5%; there was no traditional HVAC system. Additional small fans were used to ensure good mixing.

PCs consisted of a PC monitor and a PC tower. The PC monitors were represented by four different brands. Within each brand they included both CRT and TFT monitors. Three CRT monitors were 17" and one 19", while three TFT monitors were 15" and one 17". The PC towers were of one brand, the same as one of the monitor brands. They had a Pentium 4 processor. TVs were of two brands; all had a 28" picture tube. A selection was made from top-selling brands on the world market. Altogether, eight CRT monitors, eight TFT monitors and four TVs (i.e., two identical units within each brand), as well as four identical PC towers were purchased at local electronic shops, unpacked, placed in a ventilated room and operated continuously during the entire period of the study. Video splitters were used so that one PC tower could support the operation of eight PC monitors in between sensory assessments. PCs and TVs were placed in test offices 12 h prior to sensory measurements and the assessments were taken when they had been in operation for 50, 400 and 600 h. These periods correspond for PCs to ca. 1, 11 and 16 weeks of normal office use, assuming operation to be 37.5 h per week; the same applies for TVs assuming that they are turned on for 5–6 h per day. Upon completion of the sensory measurements, PCs and TVs were placed back in the ventilated room and the test offices were ventilated at an outdoor air change rate of 5–6 h^{-1} for at least 3 h before the next PCs/TVs were installed in the test offices. During the sensory measurements, two PCs having an identical configuration, i.e. the same brand of towers and the same brand and type of monitors, as well as two TVs of the same brand were placed in each test office. To examine the extent to which various parts of PCs contribute to the total sensory emission rate, sensory measurements were also made when two identical PC towers, as well as two identical CRT monitors and their heated casings were placed in the test offices. The last two measurements were made for only two brands. To heat the casing, ordinary bulbs with Wolfram filament with the same power rating as an operating CRT monitor were used. With the designed air change rate in the test offices, the outdoor air supply rate was 7 L/s per PC or per TV. The same outdoor air supply rate was maintained in the ventilated room where the PCs and TVs were in continuous operation in between assessments. PCs and TVs were randomly assigned to test offices. Each type and brand of PC or TV studied was always tested in the same office to account for possible differences in air quality between empty offices when PCs or TVs were absent. During sensory evaluations, the PCs/TVs were in operation but the subjects could not hear them or see them because they were placed behind a screen.

Forty-eight subjects assessed the air quality using the continuous acceptability scale (Clausen, 2000). They were all students; 17 were females and 1 was a smoker. They took olfactory tests in which they ranked 10, 80, 320 and 1280 ppm (vol./vol.) of *n*-butanol with increasing odour intensity and matched with references 640 ppm (vol./vol.) of *n*-butanol, 2-butoxyethanol, 2-butanone and a 'blank' with no chemical compound (ISO, 1988, 1993). Thirty-three subjects passed the ranking test without errors and 32 passed the matching test with a maximum of two errors. No subjects were excluded. Sensory measurements were carried out over 3 weeks, each week on 4 days, from Monday to Thursday. Each day, the subjects assessed perceived air quality in four test offices in which PCs, or their parts, or TVs

were either present or absent. The assessments were balanced for order of presentation. The subjects entered each test office singly and assessed the air quality by marking the acceptability scale immediately upon entering and approaching the same spot marked on the floor in the middle of the test office; the doors in test offices were closed during the evaluations. The subjects took a break of at least 2 min before the next evaluation. The break was taken in a well-ventilated space adjacent to the test offices where the air temperature and relative humidity were similar to the conditions in the test offices. Moreover, there was a break of at least 2 min between assessments in the same office.

Parallel to sensory measurements, temperature, relative humidity and outdoor air supply rate were measured in the test offices. The air in the test offices and outdoor air was collected on Tenax TA and DNPH for subsequent analysis of VOCs and aldehydes. In addition, each PC and TV tested was placed and operated in a 1 m^3 glass chamber ventilated at an outdoor air supply rate of 0.28 L/s, i.e. 50 times lower than in the test offices. The air supplied to the glass chamber and exhausted from it was also collected on Tenax TA and on DNPH for further chemical analysis. The results of these analyses are reported by Nakagawa *et al*. (2003). The power consumption of each PC and TV was measured. Furthermore, the temperatures of the air leaving the casing of a PC monitor and TV were measured. A thermographic camera was used to register operating surface temperatures.

Ratings of acceptability of air quality in test offices were subjected to analysis of variance. Based on acceptability ratings, perceived air quality in decipol was calculated (Clausen, 2000) and averaged across different brands of PCs with CRT monitors, PCs with TFT monitors and TVs to obtain mean values for different types of electronic equipment; no distinction between brands was made since too few units within each brand were tested and the study looked for general trends. Using average perceived air quality in decipol and measured average outdoor air supply rates, the sensory pollution loads in test offices were calculated (Fanger, 1988). The sensory emission rates from PCs and TVs were derived by subtracting the sensory pollution load in the empty test offices from the loads in the offices with PCs and TVs (Wargocki *et al*., 1996).

RESULTS

The effects of pollution from electronic equipment on perceived air quality are illustrated in Figure 1. When PCs with CRT monitors were in operation in the test offices, the perceived air quality decreased significantly ($P < 0.001$). PCs with TFT did not significantly affect the perceived air quality in test offices. The perceived quality of air in offices with TVs was significantly reduced ($P < 0.001$) only when they had been in operation for more than 50 h. Because CRT and TFT monitors were connected to the same PC towers, the results presented in Figure 1 suggest that the negative effects on the perceived air quality were caused by the CRT monitors. This is further indicated in Figure 1 showing the perceived air quality in test offices polluted by different PC parts. Comparing with empty offices, the presence of CRT monitors in rooms significantly reduced the perceived air quality ($P < 0.001$), while the presence of PC towers and of heated CRT monitor casings had no effect on perceived air quality.

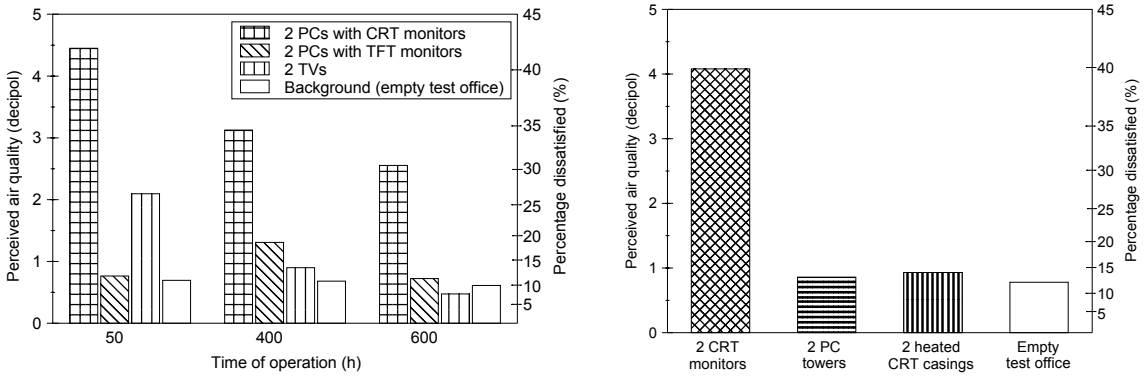

Figure 1 Left: The impact of presence or absence of PCs/TVs in operation for various lengths of time on perceived air quality in test offices. Right: Perceived air quality in offices with different PC parts present or absent.

Table 1 shows the average sensory emission rates for PCs and TVs. The sensory emission rates for PCs with TFT monitors and for TVs that had been in operation for 400 h and 600 h were not calculated because when they were present in test rooms, the perceived air quality was not significantly different from the perceived air quality in empty test offices.

Table 1 Average sensory emission rates (mean ± standard deviation) from PCs and TVs

Operation time (h)	Sensory emission rates olf/PC		olf/TV
	PC with CRT	PC with TFT	TV
50	2.7 ± 1.7	*	1.0±0.6
400	1.8 ± 2.8	*	*
600	1.4 ± 1.2	*	*

*Indicates that pollution loads were not significantly different from those in empty test offices

Table 2 shows that the average power consumption for CRT monitors is similar to the average power consumption for TVs and PC towers but it is nearly twice as much as for TFT monitors. The temperature of the air leaving the casing of CRT monitors reached nearly 32°C, i.e. 10ºC higher than the ambient air temperatures in the test offices. Thermographic pictures indicated the biggest areas with the highest surface temperatures for CRT monitors (Figure 2).

Table 2 Average (mean ± standard deviation) power consumption and temperature of the air leaving the casings of the tested electronic equipment

	CRT monitors	TFT monitors	PC tower	TVs
Power consumption [W]	96 ± 15	49 ± 8	90	109 ± 21
Temperature of air leaving the casing [°C]	31.7 ± 1.3	27.0 ± 2.9	Not measured	25.2 ± 1.7

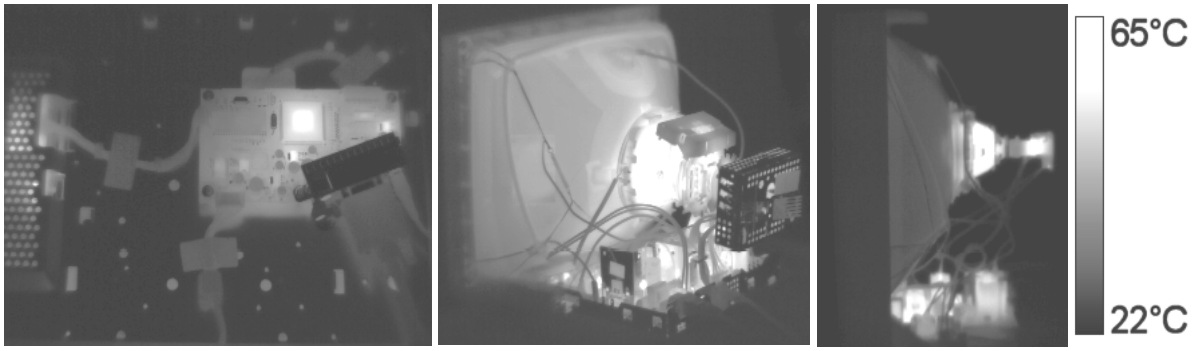

Figure 2 Thermographic pictures of the rear of a TFT monitor (left), CRT monitor (middle) and TV (right), all without casing.

DISCUSSION

A finding of the present study was that after 50 h of operation of four common brands of PCs with CRT monitors the perceived air quality in offices with these PCs caused on average more than 40% dissatisfied, i.e. four times as much as in offices without PCs. The same percentage dissatisfied with air quality was observed in a previous study when PCs with CRT monitors of one common brand were placed in an office, causing SBS symptoms and reduced office productivity (Bakó-Biró *et al*., 2002). Even in rooms with PCs with CRT monitors in operation for 600 h (corresponding approximately to 4 months of normal office use) there was still on average 30% dissatisfied with the air quality. Considering that the four top-selling PC brands were tested, present results confirm and generalize the previous findings of Bako-Biro *et al*. (2002) showing the negative impact of PCs with CRT monitors on perceived air quality, SBS symptoms and productivity.

The average sensory emission rate from PCs with CRT monitors in operation for 50 h was nearly 3 olf/PC. The same emission rate but for a single brand was measured in the above-mentioned earlier study of Bakó-Biró *et al*. (2002). After 600 h of operation, the sensory emission rate was halved, which suggests a half-life of approx. 4 months for normal use of PCs in offices. But even then, it was still higher than the average sensory emission rate from a standard person (Fanger, 1988). These results imply that during the first year of PC use, i.e. for about one-third of a typical life-time of a PC, the ventilation requirements in spaces where PCs with CRT monitors are in operation should be substantially higher than the ventilation required to remove and dilute bioeffluents. This may seem costly, but taking into account recent studies showing the negative effect of poor air quality on office productivity (Wargocki *et al*., 2000; Bakó-Biró *et al*., 2002), the cost is small compared to the potential benefits of improving the air quality (Wargocki and Djukanovic, 2003).

Present results showed that the sensory emission rate from PCs with TFT monitors is negligible. Hence, the emission from PCs can be reduced by replacing CRT monitors with TFT monitors. This substitution will at the same time reduce the cooling load. TFT technology is still relatively expensive, and hence it seems reasonable to expect that CRT monitors will be more often used by private users in homes, whereas TFT monitors will become more prevalent in offices.

High emissions from a CRT monitor seem likely to emanate from the electronic components placed at the rear of the monitor, because sensory measurements showed that a heated casing was not a source of emissions. These electronic components operate at elevated temperatures, as indicated by the measurements of the air leaving the CRT monitor casing and the thermographic pictures, and can lead to the release of a number of chemical compounds that affect the perception of air quality. The results of chemical analysis of the air, not reported here, may provide further data on this issue.

The present study showed that new TVs can emit as much perceived air pollution as one standard person (Fanger, 1988). Although short-lived, these emissions and the emissions from PCs with CRT monitors, abundant in many homes, can have a much greater detrimental effect on perceived air quality in homes than in offices, considering that outdoor air supply rates are often much lower in homes than in offices. They can also have a negative effect on health, especially on children who often spend long periods at a PC or a TV in small rooms. Future studies should investigate the effects of emissions from electronic equipment on children's health in homes.

Taking into account the high emission rates from PCs with CRT monitors, present results imply that these types of PCs, prevalent in offices for the last 15–20 years, have been an overlooked source of air pollution which may explain the reduced air quality and increased prevalence of SBS symptoms reported in many previous field studies.

CONCLUSIONS AND IMPLICATIONS

- Studies on four of the world's top-selling brands of PCs with CRT monitors showed a sensory emission rate of nearly 3 olf/PC after they had been in operation for 50 h. This is a similar order of magnitude as in a previous study with one popular brand of PC which documented a negative impact of pollution from PCs on SBS symptoms and office productivity.
- The half-life of emissions from PCs with CRT monitors was approximately 4 months of normal office use. The CRT monitor was the major source of pollution.
- PCs with TFT monitors had a negligible sensory emission rate.
- TVs had a sensory emission rate of 1 olf/TV after 50 h of operation. It decreased to a negligible level already after 400 h of operation.
- PCs with CRT monitors and new TVs are an important but hitherto overlooked pollution source indoors, and extra ventilation is required in order to maintain a desired perceived indoor air quality in spaces with this electronic equipment.

ACKNOWLEDGEMENTS

This work was supported by the Danish Technical Research Council (STVF) as part of the research programme of the International Centre for Indoor Environment and Energy established at the Technical University of Denmark for the period 1998–2007.

REFERENCES

Bakó-Biró, Z., Wargocki , P., Weschler, C.J. *et al.* (2002). Personal computers pollute indoor air: effects on perceived air quality, SBS symptoms and productivity in offices. *Proceedings of the 9th International Conference on Indoor Air Quality and Climate—Indoor Air 2002*, Monterey, **2**, 249–254.

Clausen, G. (2000). Sensory evaluation of emissions and indoor air quality. *Proceedings of Healthy Buildings 2000,* Espoo, **1**, 53–62.

Fanger, P O. (1988). Introduction of the olf and decipol units to quantify air pollution perceived by humans indoors and outdoors. *Energy and Buildings* **12**, 1–6.

ISO. (1988). *ISO 8587,* Sensory analysis—Methodology–Ranking test*,* Geneva: International Organization for Standardization.

ISO. (1993). *ISO 8586-1,* Sensory analysis—General guidance for the selection, training and monitoring of assessors—Part 1: selected assessors*,* Geneva: International Organization for Standardization.

Nakagawa, T., Wargocki, P., Tanabe, S. *et al.* (2003). Chemical emission rates from personal computers, *Proceedings of Healthy Buildings 2003.* Singapore: Healthy Buildings 2003 (in press).

Wargocki, P., Clausen, G. and Fanger, P O. (1996). Field study on addition of indoor air sensory pollution sources. *Proceedings of the 7th International Conference on Indoor Air Quality and Climat— Indoor Air '96*, Nagoya, **4**, 307–312.

Wargocki, P., Wyon, D P. and Fanger, P O. (2000). Pollution source control and ventilation improve health, comfort and productivity, *Proceedings of Cold Climate HVAC '2000*, Sapporo, pp 445–450.

Wargocki, P. and Djukanovic, R. (2003). Estimate of an economic benefit from investment in improved indoor air quality in an office building, *Proceedings of Healthy Buildings 2003,* Singapore: Healthy Buildings 2003 (in press).