PERSONAL COMPUTERS POLLUTE INDOOR AIR: EFFECTS ON PERCEIVED AIR QUALITY, SBS SYMPTOMS AND PRODUCTIVITY IN OFFICES

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ABSTRACT
Perceived air quality and Sick Building Syndrome (SBS) symptoms were studied in a low-polluting office space ventilated at an air change rate of $2h^{-1}$ (10 L/s per person with 6 people present) with and without personal computers (PCs). Other environmental parameters were kept constant. Thirty female subjects were exposed for 4.8 h to each of the two conditions in the office and performed simulated office work. They remained thermally neutral by adjusting their clothing and were blind to the interventions. In the absence of PCs in the office the perceived air quality improved, odour intensity was reduced and air freshness increased; all effects were significant. In the presence of PCs the performance of text typing significantly decreased. The sensory pollution load of the PCs was found to be 3 olf per PC, i.e. three times the load of the occupants. Present results indicate negative effects of PCs on human comfort and performance.

INDEX TERMS
Pollution source; Computers; Office; Air quality; SBS symptoms, Performance

INTRODUCTION
The use of electronic equipment in the indoor environment has increased along with technological development in the world. Electronic equipment represents a potential pollution source in the environment even though it is considered beneficial and sometimes even an indispensable tool for human activity. Previous studies have shown that personal computers (PCs) and video display units (VDU) emit a variety of volatile organic compounds (VOCs) (Corsi and Grabbs, 2000; Black and Worthan, 1999; Brooks *et al.*, 1993) and different types of flame retardants that are used as additives in the plastic components of PCs (Carlsson *et al.*, 2000; Pardemann *et al.*, 2000; Sjödin *et al.*, 2001). Although the adverse health effects of PCs have not yet been clarified, emissions from VDUs may have allergenic effect on humans (Carlsson *et al.*, 2000) and may be linked to symptoms associated with the sick building syndrome (SBS). Modern office work requires that a substantial amount of time be spent in front of a PC, resulting in direct exposure to PC emissions. The objective of the current study was to evaluate the impact of emissions from PCs on perceived air quality, SBS symptoms and performance of office work as well as to quantify the sensory pollution source strength of a PC.

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METHODS

Approach: The air pollution level in an office space was modified by introducing or removing PCs, all other environmental parameters remaining unchanged. Female subjects were exposed for 4.8 hours to each of the two conditions in the office in a design balanced for order of presentation and assessed perceived air quality, indoor climate and SBS symptoms. They were unaware of interventions since the PCs were placed behind a partition. During each exposure the subjects performed simulated office work comprising text typing, proofreading and arithmetical calculations. They remained thermally neutral by adjusting their clothing.

Facilities: The experiments were carried out in an office described in detail by Wargocki *et al.* (1999). The materials and furnishings in the office are low-emitting (CEN CR 1752, 1998). The office was divided by a 2-m-high partition into a space for the equipment used to supply and condition the outdoor air and for PCs to be placed, and a space where the subjects were exposed. The outdoor air was supplied by an axial fan mounted in the window and several small fans provided good mixing in the office. The air in the office was heated by electric oil-heaters or cooled by a SPLIT-type air-conditioner, and humidified by ultrasonic humidifiers. No traditional HVAC system was in operation. The condensate from the air-conditioner was re-vaporized with ultrasonic humidifiers to avoid any loss of pollutants. The space used for exposure had six workstations, each consisting of a table, a chair, a desk-lamp and a 6-year-old "innocent" PC with a sensory pollution strength of 0.3 olf/PC as quantified by sensory evaluations carried out prior to the experiment.

Test conditions: To modify the air pollution level in the office, six PCs were introduced behind a partition as an additional pollution source. The PCs operated continuously with a screensaver running. The electric power consumption was the same as if any other program had been running on the PC. Each PC was the same type and brand that is commonly found on the market and consisted of a 17" cathode-ray tube (CRT) VDU connected to Pentium III configuration PC tower. Prior to the experiments the PCs had been in operation for 500 hours, corresponding to approx. 3 months of normal office use, assuming 40 hours of operation per week. Six PCs were used to simulate conditions in the office as if they had been in operation instead. The outdoor air supply rate of 60 L/s (corresponding to 2 h^{-1} or 10 L/s per person with 6 persons in the office), air temperature at 24.5°C, relative humidity level at 50% and noise level at 35dB(A) (without subjects in the office) remained constant throughout the experiments. The office had daylight illumination, but there was no direct sun on the subjects. The illumination level, if needed, could be adjusted by each subject by switching on the desk lamp provided at each workstation.

Subjects: Thirty subjects were selected among 51 female applicants to participate in the experiments. They were all students, aged 19-31 years old, and were either non-smokers or occasional smokers. None of them had allergy, asthma, hay fever or chronic diseases. One subject was sensitive to dust and two had a history of migraine. This information was obtained from questionnaires completed during recruitment; no medical examination was made. In the week prior to the experiments, the subjects received instruction on how to perform tasks simulating office work and how to make subjective evaluations. They also took olfactory tests to evaluate their ability to classify different odour intensities (ranking test) and to identify several odour stimuli (matching test); on average 78% were correct in both tests.

Measurements and procedure: The subjects were divided into 5 groups. Each group comprised 6 persons and was randomly assigned to a given weekday for exposures. The experiments used a balanced design for the order of presentation (with or without PCs behind the partition). The subjects assessed the perceived air quality upon entering, during exposure and upon re-entering after having left the office for a few minutes. Continuous acceptability and intensity scales were used to assess the perceived air quality, odour intensity, and irritation of the eyes, nose and throat (Wargocki *et al.*, 1999). During exposure, the subjects assessed general perceptions of the indoor environment, SBS symptoms and the ability to work using horizontal visual-analogue scales (Wargocki *et al.*, 1999). They also evaluated thermal sensation on a 7-point PMV scale and acceptability of thermal comfort and draught on a continuous scale. During exposure, subjects performed simulated office work consisting of text typing, proofreading and arithmetical calculations (addition and multiplication of numbers). The outdoor air supply rate, temperature and relative humidity, air velocity and concentration of carbon dioxide (CO_2) were measured continuously during the experiments. The noise level was measured occasionally. Ozone concentrations were measured alternately indoors and outdoors at 20-minute intervals. The air in the office and outdoors was sampled on Tenax TA (for VOCs and brominated flame retardants) and silica gel coated with 2,4-DNPH (for saturated aldehydes). The analytical focus was on aldehydes with relatively low odour thresholds that might be produced by air oxidation of various organic precursors. The samples were thermally desorbed and analysed using a gas chromatograph equipped with both a flame ionisation detector (FID) and a mass selective detector (MSD). The detection limits ranged from 0.1-90 μg/m³ for aldehydes and 2-50 μg/m³ for brominated flame retardants.

Data analysis: The subjective and performance data were analysed using Wilcoxon matched-pairs test and paired t-test depending on whether the data were normally or not normally distributed. All p-values are 1-tailed of an effect in the expected direction.

RESULTS

The air temperature, relative humidity, noise level and the outdoor air supply rate did not deviate from the intended levels. The difference between indoor and outdoor CO_2 concentration, after steady-state levels were achieved, was slightly but significantly lower when PCs were placed behind the partition. Indoor ozone and TVOC concentrations (toluene equivalent) did not differ between exposure conditions. Due to relatively high detection limits, only three aldehydes could be measured (Table 1).

Table 1. Results of chemical measurements in the office with bioeffluents.

Compound	*Without PCs behind partition Concentration μg/m³*			*With PCs behind partition Concentration μg/m³*		
	outdoor air (O)	*office air (I)*	*I/O-ratio*	*outdoor air (O)*	*office air (I)*	*I/O-ratio*
hexanal	0.4	n.i.	-	0.5	n.i.	-
heptanal	0.5	0.4	0.9	0.5	0.5	1.0
octanal	1.0	1.1	1.1	0.6	2.0	3.3

n.i. - compound not identified in the sample

Among these, the indoor/outdoor ratio for octanal was significantly greater than unity (3.3) when PCs were behind the partition, but close to unity (1.1) when PCs were absent, indicating that the PCs were a source of this aldehyde. It is worth noting that formaldehyde, a potential irritant often emitted during thermal oxidation events, was below its detection limit of 6 μg/m³ in all of the experiments. Brominated flame retardants were not detected, but given the level at which such compounds are expected (Carlsson *et al.*, 2000; Sjödin *et al.*, 2001) and the limitation of the analytical methods (2-50 μg/m³), this result is inconclusive. The subjects assessed that the acceptability of the air was significantly lower upon entering the office when PCs were present behind the partition compared with the condition without PCs behind the partition ($P<0.0005$). Similar assessments were made during the exposure ($P<0.015$) and upon re-entering ($P<0.001$) the office (Figure 1). With PCs behind the screen the odour intensity was significantly higher, as judged upon entering and re-entering the office, and the air was perceived to be significantly more stuffy during exposure ($P<0.005$) compared with the condition without PCs behind the partition.

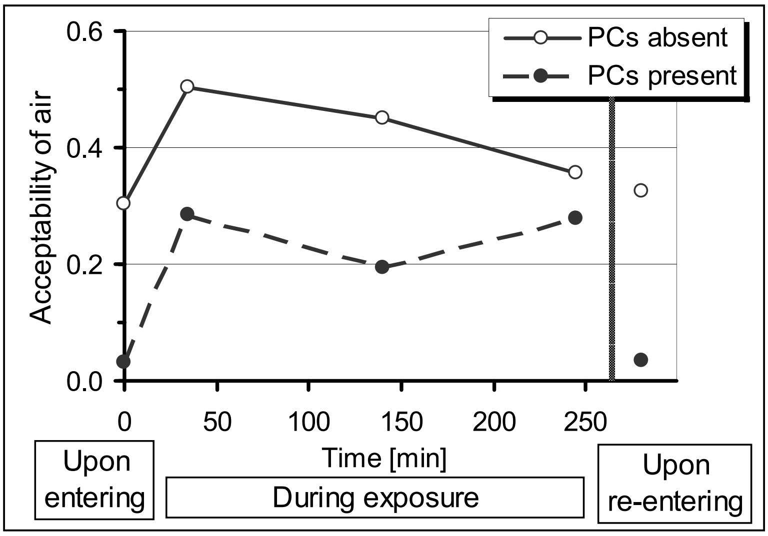

Figure 1. Acceptability of air quality as a function of PCs present or absent behind the partition.

Using the assessments of acceptability and measured ventilation rates, the percentage of dissatisfied and the sensory pollution loads were calculated (Fanger, 1988) (Table 2). The presence of PCs behind the screen increased the percentage of dissatisfied from 14% to 41% and the total sensory pollution load by ca. 20 olfs (office floor area equals 36 m^2). This observation means that each additional PC behind the screen increased the pollution load in the space by ca. 3 olfs.

Table 2. Perceived air quality and sensory pollution loads in the office

Exposure in the office	*% dissatisfied*		*Sensory pollution load ($olf/m^2 floor$)*	
	office with PCs absent	*office with PCs present*	*office with PCs absent*	*office with PCs present*
Upon entering (without bioeffluents)	14	41	0.13	0.70
During exposure (with bioeffluents)	8	18	-	-
Upon re-entering (with bioeffluents)	13	41	0.12	0.69

There was no significant difference in the intensity of SBS symptoms between the two conditions studied. When the PCs were present in the office behind the partition the subjects made significantly more typing errors ($P<0.014$) (Figure 2) calculated by summing up the number of worlds incorrectly typed, punctuation errors and the number of words skipped. There was also an indication that a greater number of subjects had a higher typing speed when

PCs were absent (binominal test, $P<0.03$). Hence the performance of text typing has been calculated by multiplying the typing speed with the accuracy of typing (i.e. the percentage of correctly typed words and punctuation marks relative to the overall number of words and punctuation marks). The performance of text typing showed a significant decrease of 1.2% ($P<0.03$) when PCs were placed behind the partition (Figure 2).

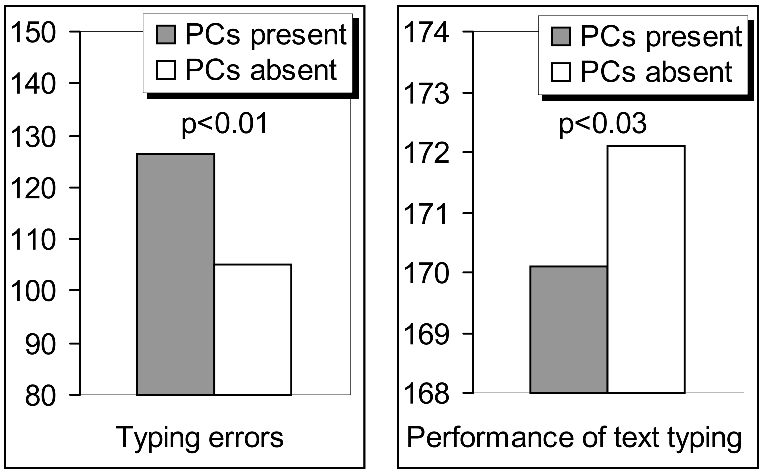

Figure 2. Left: Number of typing errors. Right: Performance of the text typing task as a function of presence or absence of PCs behind the partition.

DISCUSSION

When PCs were present behind the partition the perceived air quality was decreased, the odour intensity increased (first impression) and the air was perceived as being less fresh. Subjects' performance of text typing decreased in the polluted environment, matching well their self-estimated work-ability at the end of the exposure. Thus the present results demonstrate that PCs have a negative impact on human comfort and performance. The exposure period may have been too short for the development of SBS symptoms. Although some differences in the expected tendency towards SBS symptoms were observed, no significant differences were found. This indicates that reduced air quality may negatively affect human performance even before SBS symptoms are seen. It should also be noted that in the condition where PCs were present, more cooling was required and 20% more water was condensed on the cooling coil, even though some of it was re-evaporated by ultra-sonic humidifiers. The resultant "air scrubbing effect" might have removed some airborne pollutants and thus reduced the magnitude of the observed effects on the subjects.

The results of this study are similar to findings of Wargocki (1999) and reconfirm that poor air quality negatively affects human comfort and performance in the office environment. However, this time another pollution source was used to change the pollution level in the office - PCs rather than a typical used carpet.

The current study shows that a substantial sensory pollution load can be associated with a PC that has been used for 3 months in an office environment. This effect may be extended over one year due to the exponential profile with ca. 3 months half-life of the sensory pollution load shown by sensory evaluations made prior to the experiments for two brands of VDU. In the present study the polluting computers were placed far from the occupants so the pollutants were well mixed with the room air. In real offices, the PC would be placed close to each occupant and the impact of pollutants may be even greater. But only one brand of PC was used to investigate potential effects. Future studies should involve other representative brands and types of computer that are on the market, including PCs with flat-type VDUs. The CRT displays of the PCs used in this study were the major polluting element as confirmed by sensory evaluations carried out for two brands of VDU prior to the experiment. Thermal images made by an infrared camera showed that several components on the cathode-ray tube and inside the CRT display reached high temperatures, over 60°C. Due to this heat load, the casing, other plastic accessories and several regions on the circuit board were at elevated temperatures. Such temperatures may increase the release of odorous compounds, plastic additives and flame-retardants from these components. The release of pollutants may be driven by the same mechanism in the case of PC towers, but to a lesser extent due to the lower operating temperatures of the CPU and other components (Corsi and Grabbs, 2000).

CONCLUSIONS

- Personal computers can be a strong indoor pollution source having a negative effect on perceived air quality and productivity in offices.
- The average sensory pollution load of the PCs tested was 3 olf, i.e. three times the load caused by an occupant.

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