

Emissions From Office Equipment

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Introduction

Indoor air quality (IAQ) is a global issue. Numerous studies by government and environmental health specialists have shown indoor air to be a significant environmental threat to human health.[1] Typical contaminants in building are gases and particles, and may include volatile organic compounds (VOCs) such as formaldehyde and styrene; inorganic gases such as ozone and nitrogen oxides; and respirable particles. The air of a typical office building will have 200-500 different individual volatile organic compounds. Their sources are numerous in buildings and may include construction materials and furnishings, combustion sources, office equipment, cleaning processes and contaminated outdoor air being brought into the building. If the sources are significant and ventilation is insufficient in buildings, contaminant levels can increase to concentrations which can be irritating to people. In some cases, these emissions can produce unacceptable odors.

Significant emissions testing has been conducted on construction materials and furnishings, such as flooring, ceiling systems, office furniture, and insulation.[2-4] However, limited data have been obtained on office equipment operation. VOCs, ozone, and particle emissions have been associated with operating equipment, such as computers, printers, and photocopiers.[5,6] Some studies have indicated that these emissions have resulted in headaches, mucous membrane irritation, and dryness of the throat, eyes, and nose.[6,7] Limited guidance has been given on acceptable levels of ozone and other contaminants from office equipment, and regulations for permissible levels are not currently available.[8,9] Outdoor air standards do exist in the United States for ozone and respirable particles, and these are frequently used as default standards for indoor air. Germany's Federal Environmental Agency has developed IAQ emissions criteria for ozone, styrene, and particles or dust for copiers and printers.[10] Certain other voluntary criteria programs have been developed in the Unites States.[9,11]

This current study presents emissions data obtained during the operation of dry process photocopiers, laser printers, and computers. Studies have been conducted in dynamic environmental chambers designed to simulate normal room conditions. Temperature, relative humidity, and ventilation are controlled and the chamber is constructed and operated to allow measurement of low levels of contaminants, as found in indoor air. Results among the tested products have been compared. In addition, potential exposure concentrations in a room with this equipment operating have been determined and compared to existing standards and guidelines. This data and the measurement technologies can be used by manufacturers to understand the IAQ impact of their products, to evaluate health hazards, and to evaluate potential source reduction measures.

Methodology

Environmental Chamber

Equipment was tested in electropolished, stainless steel chambers, 6 m^3 in volume. Environmental chamber operation and control measures complied with ASTM D 5116.[12] Supply air to the chamber was stripped of all measurable levels of formaldehyde, VOCs, particles, and ozone, so that contaminant backgrounds were < 2 $\mu g/m^3$ TVOC, < 10 $\mu g/m^3$ total particles, < 2 $\mu g/m^3$ formaldehyde, and < 0.01 ppm ozone. Air supply to the chamber was maintained at a temperature of 23ºC ± 2ºC and relative humidity at 50% RH ± 5% RH, and the air exchange rate was 1.0 air change per hour (ACH). A flow chart of the environmental chamber testing methodology is given in Figure 1. Each printer or photocopier was continuously operated for a 45 minute period or until the paper supply was exhausted, whichever occurred first. Personal computers were powered during the entire test period. Emissions were continuously monitored for 4 hours following completion of the printing to ensure complete collection of all released contaminants. New white paper was used in the test runs, and black print only was evaluated. For standard black printing (on white paper) an upper case letter "O" character was used to achieve a page coverage of 5%-15%.

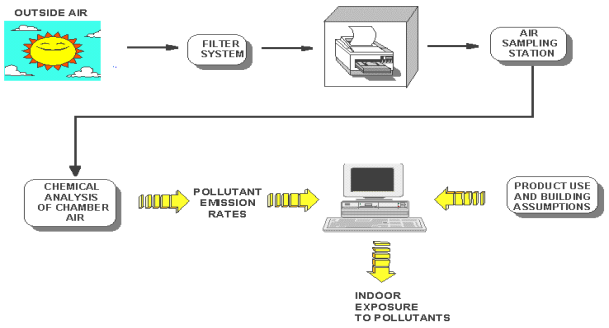

Figure 1.

Analytical Measurements

For VOC analysis, an integrated chamber air sample was collected over the complete 4.75 hour test period. The VOCs were collected on multisorbent tubes following the guidelines of EPA Method IP-1B.[10] These tubes were subsequently analyzed by thermal desorption/gas chromatography/mass spectrometry (TD/GC/MS) with a mass selective detector. The total VOC (TVOC) concentrations were determined along with identifiable specific VOCs. This technique is generally applicable for compounds in the C_5 - C_{16} hydrocarbon range and has a detection limit of 1 $\mu g/m^3$ for TVOC and most individual VOCs at the sample collection volume used.

Continuous particle monitoring was performed using an aerosol monitor. This monitor uses a 901 light scattering measurement to continuously determine airborne particle concentrations over time. The analytical range of this instrument is 0.001 to 100 mg/m^3, with the measurement of particles ranging from 0.1 to 10 μm in diameter. The monitor is calibrated relative to a standard test aerosol ("Arizona road dust") with fine particle sizes ranging from 0.1 - 15 μm; particle values measured in this study reflect instrument response to that material, with no attempt made to correct the data for the actual distribution of particles emitted by the test units. Particle size determinations of the actual printer emissions were not determined.

Ozone monitoring was conducted with continuous reading instrumentation. This analyzer operates based on the strong UV absorbance of ozone at 254 nm. A ratio of the sample absorbance to that of air with ozone catalytically removed is used to determine the concentration in the sample. The instrument is pre-calibrated prior to use, and satisfies requirements for EPA ambient ozone monitoring, including an analytical range of 0.002 to 1.000 ppm.

A constant source model was used to analyze the contaminant data. The determination of the emission rate for a constant source in a well-mixed environmental chamber begins with a mass balance on the chamber with the following assumptions: the unit emits at a constant rate over a defined period of time; the supply air to the chamber contains no measurable contaminants; and the chamber air is well-mixed and is representative of the homogeneous concentration.

Results

Emissions data obtained for VOCs, particles, and ozone as determined from five dry process photocopiers, twelve laser printers and six personal computers are presented in Table 1. Emission rates are expressed as milligram (mg) of contaminant emitted per hour of equipment operation. Background total VOC (TVOC) emissions were measured from the printers and photocopiers while energized (but not actively printing). This TVOC background averaged 1.4 mg/hr but there were no measurable background levels of ozone or particles. TVOC, ozone, and particle emission rates showed a wide range of emissions among the available equipment, as listed in Table 1. Dry process photocopiers showed the highest average TVOC and ozone emission rates at 42.2 mg/hr•copier, and 5.2 mg/hr•copier, respectively. Laser printers showed lower average TVOC and ozone emission rates, but the range of values measured was similar. Personal computers were not a source of ozone, but they did emit TVOC and particles. Particle emissions among the laser printers and photocopiers were similar but personal computers emitted significantly less particles.

Table 2. Summary of Emission Rate (ER) Data for Office Equipment.

Equipment/ Process	Average Contaminant ER, mg/hr (Range of Values)		
	TVOC	Total Particles	Ozone
Laser Printers	38.6 (2.4-130)	1.6 (<0.02-5.5)	1.2 (<0.02-6.5)
Dry Process Copiers	42.2 (15.0-108)	1.8 (<0.7-6.2)	5.2 (1.2-6.3)
Personal Computers	12.2 (0.05-24.2)	0.05 (<0.027-0.12)	<0.02

Primary individual VOCs detected in emission studies are shown in Table 2. These VOCs represent each of the ten highest emitting VOCs from each product group. The VOCs were similar among the laser printer and photocopier emissions, consisting of aldehydes, styrene, xylenes, ethylbenzene, and hydrocarbons. Potential VOC sources for the laser printers and photocopiers are the dry powder toner and paper. Those VOCs originating from the computers consisted of alcohols, esters, phenol, and aromatic solvents. These most likely originate from residual solvents and plastic construction materials.

Table 3. Primary VOC Emissions from Office Equipment.

Laser Printers	Photocopiers	Computers
1-Butanol	Acetaldehyde	1-Phenylethanone
Acetone	Acetone	2-Ethyl-1-hexanol
Ethylbenzene	Benzaldehyde	Ethylbenzene
Formaldehyde	Ethylbenzene	Ethylhexylpropenoic ester
Hexanal	Formaldehyde	Hexamethyl-cyclotrisiloxane
Methylpropylnonane	Hexane	Methylacrylate
Octamethyl-Cyclotetrasiloxane	Nonanal	Phenol
Pentamethylheptane	Octanal	Trichloroethane
Styrene	Stryrene	Toluene
Xylenes	Xylenes	Xylenes

Discussion

Emission rate data may be used to predict indoor concentration levels of specific contaminants, given the room characteristics. These concentrations may, in turn, be used to evaluate potential health hazards from exposure. For example, in a room with a volume of V (m^3) and an air

exchange rate of N (hr^{-1}), the steady state concentration C_{SS} ($\mu g/m^3$) of a contaminant being emitted at a rate E_U ($\mu g/hr$) by a continuously operating unit can be determined (based on mass conservation principles) from the equation:

$$C_{SS} = E_U/(N*V) \quad (1)$$

This equation allows estimation of an approximate air exposure concentration at any time under other conditions of equipment operation, although the assumption must be made that the equipment emissions are relatively constant for each processed page. At any time t (hr), the concentration C(t) ($\mu g/m^3$) of a contaminant being emitted at a constant rate E_U ($\mu g/hr$) into a room of volume V (m^3) and air exchange rate N (hr^{-1}) can be determined from:

$$C(t) = \frac{E_U}{N*V} *(1 - e^{-NT}) \quad (2)$$

Finally, an estimate of a concentration under static conditions (assuming no airflow in the space, but the space is completely mixed) may also be made for a given E_U, time of operation, and room volume. If a unit with an emission rate of E_U ($\mu g/hr$) is operating for time t (hr) in a room of volume V (m^3), assuming there is no air exchange in the room (worst case), the concentration C ($\mu g/m^3$) in the room at the end of operation is determined from:

$$C = E_U * t/V. \quad (3)$$

Table 4. Contaminant Exposure Concentrations from Office Equipment for Room Occupant, mg/m^3

Contaminant	Laser Print	Photocopier	Personal Computer
TVOC	0.63	0.87	0.28
Particles	0.02	0.03	0..001
Ozone	0.01	0.10	<0.001

Average exposure concentrations were determined based on two hours of equipment operation within a typical office space. Exposures were determined for a room occupant assumed to be in the perimeter area of a room, 32 m^3 in volume with an air exchange rate of 1.0. Calculated exposure concentrations are given in Table 3. Considering exposure to a typical room occupant, ozone and particle concentrations range from 1-30 $\mu g/m^3$ (0.001-0.03 mg/m^3) for particles and 1-100 $\mu g/m^3$ (0.001-0.10 mg/m^3) for ozone. These are below the general indoor air quality guidelines of 50 $\mu g/m^3$ of particles and 0.1 ppm (0.2 mg/m^3) of ozone.[9,13,14] The TVOC levels ranged from 0.28 mg/m^3 for personal computers to 0.87 mg/m^3 for photocopiers. Currently, there are no regulated levels for TVOC. General guidance documents have suggested that TVOC exposures be controlled to $\leq$0.2 mg/m^3 to prevent irritation and discomfort among people.[8,9] Certain, individual VOCs, regardless of TVOC levels, should be monitored an evaluated for potential odor or toxicity concerns. For example, styrene, which has been found as a primary emitter from printers and photocopiers, has a low odor threshold (70 $\mu g/ m^3$) and may be found objectionable by some people.

References

1. U.S. Environmental Protection Agency. 1990. Reducing risk: setting priorities and strategies for environmental protection. SAB-EC-90-021, Washington, DC.
2. Colombo, A., M. DeBortoli, E. Pecchio, H. Schauenburg. H. Schlitt, and H. Vissers. 1990. Chamber testing of organic emissions from building and furnishing materials. *The Science of the Total Environment*, 91;237-249.
3. Black, M.S., W.J. Pearson, and L.M. Work. 1991. A methodology for determining VOC emissions from new SBR latex backed carpet, adhesives, cushions, and installed systems and predicting their impact on indoor air quality. *Proceedings of IAQ 91*. Atlanta: American Society of Heating and Air-Conditioning Engineers.
4. Molhave, L. 1982. Indoor air pollution due to organic gases and vapors of solvents in building materials. *Environ. Int.*, 8:117-127.
5. Selway, M.D., R.J. Allen, R.A. Wadden. 1980. Ozone production from photocopying machines. *Am. Ind. Hyg. Assoc. J.*, 41:455-459.
6. Wolkoff, P., C.K. Wilkins, P.A. Clausen, and K. Larsen. 1993. Comparison of volatile organic compounds from processed paper and toners from office copiers and printers. *Indoor Air* **3**:113-123.
7. Skoner, D.P., M.D. Hodgson, and W.J. Doyle. 1990. Laser printer rhinitis. *NE J. Med.* 322, **18**:1323.
8. Tucker, W.G. 1990. Building with low-emitting materials and products: where do we stand? *Indoor Air '90*, Toronto, Canada.
9. State of Washington Indoor Air Quality Specifications. 1989. Department of General Administration, East Campus Plus Program.
10. German Federal Environmental Agency, Blue Angel Program. 1997. Basic Criterial For the Award of the Environmental Label.
11. AQ*Spec*™ List. Air Quality Sciences, Atlanta, Georgia. 1999.
12. Winberry, T. 1990. Compendium of methods for the determination of air pollutants in indoor air. Environmental Protection Agency Report 600/4-90/010, Washington, DC: EPA.
13. American Conference of Govermental Industrial Hygienists. 1995. Threshold limit values (TLVs) for chemical substances and physical agents. Cincinnati: American Conference of Govermental Industrial Hygienists.
14. U.S. Environmental Protection Agency. Ambient Air Quality Standard, 40CFR, Part 50.

Biography

Anthony W. Worthan, MPH

Mr. Worthan directs AQS' technical operations including the chemical analytical laboratory, the environmental chamber testing facility, and customer services. He

has served as project manager and lead investigator for complex field investigations across the country, such as the state of Washington's IAQ pilot studies . His experience includes evaluation of chemical and microbial building contamination and building system design and operations. He assists facility owners and design professionals in selecting low-emitting products and materials. He manages significant testing programs including the measurement of aldehydes and VOCs in air samples; VOC emissions from flooring materials, office furniture, and office machines; and the effect of cleaning processes on IAQ.

Mr. Worthan holds a Masters of Public Health degree in environmental and occupational health from Emory University in Atlanta, and a B.S. from Shorter College in Georgia. He is a member of the American Conference of Governmental Industrial Hygienists (ACGIH), the American Public Health Association, and the American Society of Heating, Refrigeration, and Air Conditioning Engineers. He is also an active member of AIHA, serving on the IEQ Committee and the Tuberculosis Task Force.

Marilyn S. Black, Ph.D.

Dr. Marilyn S. Black, founder and Chief Scientist of AQS, directs all of AQS' scientific studies. A leading expert in characterizing indoor air pollutants and their sources for more than 15 years, many of her efforts at AQS are directed toward working with manufacturers in the design and qualification of low-emitting products. Dr. Black has directed numerous research projects sponsored by the Environmental Protection Agency, National Science Foundation, Department of Energy, Department of Defense, and private industry.

She pioneered the research and development of environmental chamber technology for measuring VOC emissions from construction materials and furnishings, and she has directed numerous projects involving chemical emissions from building materials, furnishings, and processes; indoor air exposure modeling of formaldehyde and other VOCs to determine potential health risks; the effect of flooring products on IAQ; sources of microbiological contamination in schools; and cleaning and maintenance procedures for improving IAQ. She has developed numerous chamber methodologies for evaluating product emissions such as carpet and adhesive emissions adopted by the EPA Carpet Dialogue; office furniture as adopted by the numerous U.S. state agencies, the U.S. EPA and Canada; and she designed the state of Washington's IAQ program for new construction.

Dr. Black holds a B.S. from the University of Virginia, a M.S. from the University of Florida, and a Ph.D. from the Georgia Institute of Technology, all in chemistry. Prior to the founding of AQS, Dr. Black was a principal research scientist at a leading university where she developed a nationally recognized indoor air quality research program and a national indoor air quality symposium. She has written more than 100 publications on environmental chemistry and air quality and is a participant in numerous professional organizations. Dr. Black is a founding member of the International Society of Indoor Air Quality and Climate (ISIAQ), and the Indoor Environmental Quality (IEQ) Committee of the American Industrial Hygiene Association (AIHA). She is also an active member of the American Society for Testing and Materials (ASTM), American Chemical Society, and the United Nations Tall Building Committee concerning indoor air quality, and serves on Federal committees establishing scientific policies for managing environmental health risks.