Printing Systems: Meeting Market Demands for Healthy Indoor Environments

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Abstract

Acceptable indoor environmental quality is a necessary requirement for today's office buildings, schools, public facilities, and personal residences. On a global basis, indoor air quality is one of the top three environmental issues facing all countries and all people. Toxic chemicals, inorganic gases, particles, and microbes that are released by products into the indoor environment can contribute to human irritation, discomfort, and long term health consequences to those exposed. These human effects can lead to excessive medical costs, significant loss of productivity, and undesirable litigation. Printing devices are known contributors of indoor pollution such as respirable particles, volatile organic compounds (VOCs) such as styrene and formaldehyde, and ozone. Sources of these include construction materials, electronic and heating processes, inks and toners, papers and transparencies, plastics, and cleaning solvents. Manufacturers of office equipment are proactively designing for the environment, including indoor air quality as an important part of their product stewardship. Eco-criteria have been established for acceptable levels of airborne contaminants released by operating equipment. This paper will review current international programs addressing allowable emissions from print devices (including Blue Angel, Greenguard, and the State of California), test procedures, and representative emissions data from printers, copier, and computers.

Eco-criteria are based on the performance of operating office equipment and acceptable contributions of certain pollutants. Acceptable pollutant emissions of respirable particles, formaldehyde, styrene, benzene, and total volatile organic compounds are based on existing health and safety data with some consideration for protecting sensitive people from irritants and odorants. The primary measurement technique, environmental chamber technology, has been validated to test products under realistic use conditions and to determine emission rates of pollutant release. These data can be used in exposure models to predict and estimate potential human exposures, and to compare product data with prescribed eco-criteria. This measurement technology has been accepted on a global basis and ISO documentation is being prepared as a joint US/European effort.

Discussion

Significant emissions testing has been conducted on construction materials and furnishings, such as flooring, ceiling systems, office furniture, and insulation [1-3]. 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 [4,5]. Some studies have indicated that these emissions have resulted in headaches, mucous membrane irritation, and dryness of the throat, eyes, and nose [5,6]. 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 [7,8]. 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, benzene and particles or dust for copiers and printers and this standard was recently updated to be more stringent [9]. Certain other voluntary criteria programs have been developed in the Unites States including the GREENGUARD certification program [8,10].

A comparison of acceptable emissions criteria currently used by GREENGUARD and Blue Angel for monochrome print devices are shown in Table 1. Blue Angel also has emissions criteria for color printing which includes 18 mg/hr TVOC, 1.8 mg/hr styrene and 3.0 mg/hr for ozone. Acceptable benzene and dust levels are the same as for monochrome print devices.

Table 1. Acceptable Indoor Air Quality Criteria For Monochrome Printers

GREENGUARD Certification Program (results in air concentration units)	TVOC	0.40 mg/m^3
	Benzene	0.002 mg/m^3
	Styrene	0.04 mg/m^3
	Formaldehyde	0.04 mg/m^3
	Meets 1/10th TLV for emitting VOCs	
	Ozone	0.06 mg/m^3
	Particles (dust)	0.16 mg/m^3
Germany Federal Environmental Agency (Blue Angel) (results in emission units as emitted from printer)	TVOC	10 mg/h
	Benzene	≤ 0.05 mg/h
	Styrene	1.0 mg/h
	Ozone	1.5 mg/h
	Particles (dust)	4.0 mg/h

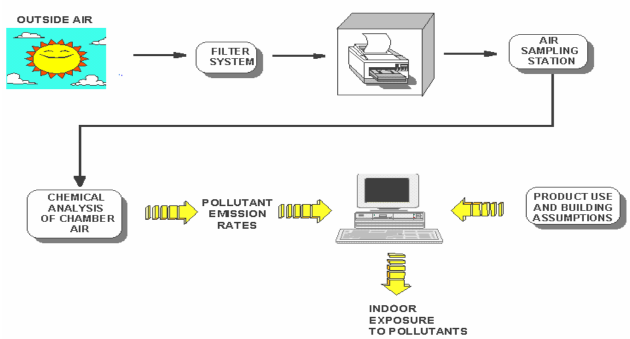
This paper presents emissions data obtained during the operation of dry process photocopiers, laser printers, and computers. Studies have been conducted in dynamic environmental chambers designed to simulate normal room conditions. Temperature, relative humidity, and ventilation are controlled and the 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 6670 [11]. Supply air to the chamber was stripped of all measurable levels of formaldehyde, VOCs, particles, and ozone, so that contaminant backgrounds were < 2 µg/m^3 TVOC, < 10 µg/m^3 total particles, < 2 µg/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 20 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. For standard black printing, a 15 % page cover was used.

Figure 1. A flow chart of the environmental chamber testing



methodology

Analytical Measurements

For VOC analysis, an integrated chamber air sample was collected on Tenax® sorbent tubes following the guidelines of EPA Method IP-1B [12]. 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_6 - C_{16} hydrocarbon range and has a detection limit of 2 µg/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 light scattering measurement technique 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. Gravimetric analysis of dust emitted during operation of the equipment was also performed using standard filter collection.

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. Total dust was also measured gravimetrically according to Blue Angel requirements.

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 six dry process photocopiers, six 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 2. Dry process photocopiers showed the highest average TVOC and ozone emission rates at 36.4 mg/hr per copier, and 4.7 mg/hr per 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	26.4 (1.2-130)	0.9 (<0.02-5.5)	0.8 (<0.02-6.5)
Dry Process Copiers	36.4 (4.6-108)	2.5 (<0.7-6.2)	4.2 (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 3. 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, ethyl benzene, 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
Ethylbenzene	Toluene	2-Ethyl-1-hexanol
Formaldehyde	Benzaldehyde	Ethylbenzene
Octamethyl-	Ethylbenzene	Ethylhexylpropenoic
Cyclotetrasiloxane	Formaldehyde	ester
Pentamethylheptane	Hexane	Methylacrylate
Styrene	Nonanal	Phenol
Xylenes	Octanal	Toluene
Toluene	Styrene	Xylenes
Acetaldehyde	Xylenes	Butylacetate
Acetophenone		Formaldehyde

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} (μg/m^3) of a contaminant being emitted at a rate E_U (μg/hr) by a continuously operating unit can be determined (based on mass conservation principles) from the equation:

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

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) (μg/m^3) of a contaminant being emitted at a constant rate E_U (μg/hr) into a room of volume V (m^3) and air exchange rate N (hr^{-1}) can be determined from:

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

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 (μg/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 (μg/m^3) in the room at the end of operation is determined from:

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

Average exposure concentrations were determined based on two hours of equipment operation over an 8 hour day 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 0.8. Calculated exposure concentrations are given in Table 3. The TVOC levels ranged from 0.12 mg/m^3 for personal computers to 0.36 mg/m^3 for photocopiers. Currently, there are no regulated levels for TVOC. General guidance documents have suggested that TVOC exposures be controlled to ≤0.2 mg/m^3 to prevent irritation and discomfort among people [7,8]. 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 μg/m^3) and may be found objectionable by some people. Other VOCs that fall on potential regulatory lists include formaldehyde, acetaldehyde, phenol, toluene and ethyl benzene.

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

Contaminant	Laser Print	Photocopier	Personal Computer
TVOC	0.26	0.36	0.12
Particles	0.01	0.02	0.001
Ozone	0.01	0.04	<0.001

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Biography

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Dr. Marilyn S. Black , founder and Chief Scientist of Air Quality Sciences, Inc. is a leading expert in characterizing indoor air pollutants and their sources, with more than 18 years of experience. She has directed numerous research studies involving indoor air pollution and human health effects, mold growth in buildings, and the impact of indoor furnishing on indoor pollutant levels. Dr. Black wrote the State of Washington indoor air quality standards for new construction, established the emissions test protocols for carpet and flooring products, and established the GREENGUARD Program for the selection of environmentally preferred, low emitting products. Dr. Black holds Ph.D., M.S. and B.S. degrees in chemistry and environmental health. She has presented numerous training seminars in indoor air quality at EnvironDesign, NEOCON, and AIA's National Convention.