Imaging Devices, Sustainable Design and Indoor Air Quality

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Abstract

Manufacturers today must design products to meet global sustainability requirements that include human healthy and indoor air quality standards. 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, and particles 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, loss of productivity, and undesirable litigation. Imaging devices are known contributors of certain indoor contaminants such as respirable particles, volatile organic compounds (VOCs) including styrene and formaldehyde, and ozone. Sources of these include electronic and heating processes, inks and toners, papers and transparencies, plastics, and cleaning solvents. Manufacturers are proactively designing for the environment, including indoor air quality as an important part of their product stewardship, and eco-criteria are available for acceptable levels of airborne contaminants released by operating equipment. This paper will review current international programs addressing allowable emissions from imaging devices (including Blue Angel, Greenguard, and the State of California), test procedures, and representative emissions data from print devices.

Eco-criteria are based on the performance of operating office equipment and acceptable contributions of certain contaminants. Acceptable emission levels of reparable particles, formaldehyde, styrene, benzene, and other VOCs 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 contaminant release. These data can be used in building 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.

Discussion

Volatile organic compounds (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 can result in headaches, mucous membrane irritation, and dryness of the throat, eyes, and nose [1, 2, and 3]. 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. 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 for copiers and printers [4]. Certain other voluntary criteria programs have been developed in the Unites States including the GREENGUARD certification program, and the IEEE 1680 standard for imaging equipment [5, 6].

Comparisons 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. GREENGUARD also requires a complete listing of measured carcinogens and reproductive toxins and also requires that any pollutants meet any air concentrations covered by the United States National Ambient Air Quality Standard. Criteria for ultrafine particles are expected from Blue Angel in 2012.

Table 1. Acceptable Indoor Air Quality Criteria for Monochrome Imaging Devices

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 study of over 400 different imaging devices. Studies were 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. This data and the measurement technologies can be used by manufacturers to understand the IAQ impact of their products, benchmark their products, evaluate health hazards, and evaluate source reduction through supply chain management.

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 [7]. 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 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.

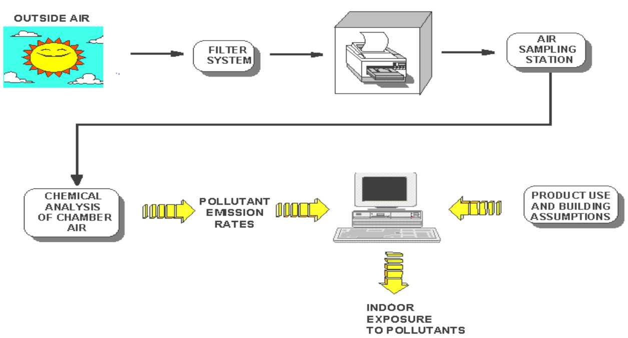

Figure 1. A flow chart of the environmental chamber testing methodology

Analytical Measurements

For VOC analysis, an integrated chamber air sample was collected on Tenax® sorbent tubes following the guidelines of EPA Method IP-1B [8]. 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 $\mu g/m^3$ 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 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. Ultrafine particles were measured with a condensation particle counter and mobility particle sizer. Particle sizes from 7-300 nm were included.

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 various print devices are presented in Table 2. Emission rates are expressed as milligram (mg) of contaminant emitted per hour of equipment operation. Background total VOC (TVOC) emissions were measured from imaging devices 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.

Table 2. Summary of Emission Rate (ER) Data for Imaging Devices

Average Contaminant ER, mg/hr (Range of Values)			
TVOC	Total Particles	Ozone	Ultrafine particles
26.4 (1.2-130)	0.9 (<0.02-5.5)	0.8 (<0.02-6.5)	$3.1x10^{11}$(±1 hr) ($0.6x10^{9}$-$4.3x10^{13}$)

Over 700 different VOCs have been detected and measured. Those VOCs that were found in 50% of the print device studies are listed in Table 3. The top 20 most frequently measured VOCs along with their potential health hazard characteristics are listed in Table 4.

Table 3. Primary VOC Emissions from Office Equipment.

Nonyl aldehyde (Nonanal)	Ethanol, 2-(2-butoxyethoxy)	Formamide, N,N-dimethyl
Decanal	Hexanoic acid, 2-ethyl	Phthalic anhydride (1,3-Isobenzofuran dione)
Cyclotrisiloxane, hexamethyl	Acetic acid, 2-ethylhexyl ester	Benzene, 1,4-dichloro
Benzaldehyde	Ethanol, 2-butoxy	Phenol, 3-methyl
Cyclohexasiloxane, dodecamethyl	2-Propenoic acid, 2-ethylhexyl ester (Octyl acrylate)	1,2-Ethanediol (Ethylene glycol)
Benzothiazole	Longifolene	Benzene
Pentadecane	Styrene	Hexane
Cyclotetrasiloxane, octamethyl	Benzene, 1-methylethyl (Cumene)	Acetate, vinyl (Acetic acid ethenyl ester)
Hexanal	1,2-Propanediol (Propylene glycol)	1,4-Dioxane
3-Isopropoxy-1,1,1,7,7,7-hexamethyl-3,5,5-tris(trimethylsiloxy)tetrasiloxane	Ethanol, 2-(2-ethoxyethoxy) (Diethylene glycol monoethyl ether)	Ethanol, 2-ethoxy-, acetate (2-Ethoxyethyl acetate)
Octanal	Hexadecane (Cetane)	Ethene, 1,1,2-trichloro (Trichloroethylene)
1-Butanol (N-Butyl alcohol)	Pentasiloxane, dodecamethyl	Valproic Acid
2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	Limonene (Dipentene; 1-Methyl-4-(1-methylethyl)cyclohexene)	2-Hexanone
Undecane	Naphthalene	Ethanol, 2-ethoxy
2-Pyrrolidinone, 1-methyl	Benzene, ethyl	Phenol, 4-methyl
Cyclopentasiloxane, decamethyl	Xylene (para and/or meta)	Propane, 2-ethoxy
Toluene (Methylbenzene)	2-Propanol (Isopropanol)	1,3-Benzenediamine, 4-methyl-
Decane	Xylene, ortho	Benzenamine, 2-methoxy-
2-Propanol, 1-methoxy-	Phenol	Ethene, 1,1,2,2-tetrachloro (Tetrachloroethylene)
Benzenemethanol, à,à-dimethyl-	2-Cyclohexen-1-one, 3,5,5-trimethyl-	Oxirane, ethyl
Tetradecane	Benzene, chloro	
Dodecane	Triethylamine (N,N-Diethylethanamine)	

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:

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

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) (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:

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

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 (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:

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

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 5. 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. Other VOCs fall on potential hazard lists as indicated in Table 4 and should be assessed for their health impact based on expected human dose.

Table 4. Frequently Found VOCs from Imaging Devices

Compound	Odorant	Potential Carcinogen[9]	Re-productive[9]	Long-term Health Impact[10]
Nonyl aldehyde (Nonanal)	x			
Decanal	x			
Cyclotrisiloxane, hexamethyl				
Benzaldehyde	x			
Cyclohexasiloxane, dodecamethyl				
Cyclotetrasiloxane, octamethyl				
2-Pyrrolidinone, 1-methyl		x		
Toluene(Methylbenzene)	x		x	x
2-Propanol, 1-methoxy	x			x
Ethanol, 2-(2-butoxyethoxy)	x			x
Hexanoic acid, 2-ethyl		x		
Sytrene	x			x
Pentasiloxane, dodecamethyl				
Naphthalene	x	x		x
Benzene, ethyl	x	x		x
Xylene (para and/or meta)	x			x
2-Pyrrolidinone				
Acetophenone (Ethanone, 1-phenyl)	x			
Xylene, ortho	x			x
2-propanol, 1-(2 methoxypropoxy)				

Table 5. Typical Contaminant Exposure Concentrations from Imaging Equipment for Room Occupant, mg/m³

Contaminant	mg/m³
TVOC	0.24
Particles	0.01
Ozone	0.01

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Biography

Marilyn S. Black, Ph.D.

Dr. Marilyn S. Black, founder and Chief Scientist of UL Air Quality Sciences, Inc. and founder of the GREENGUARD Certification Program, is a leading expert in characterizing indoor air pollutants and their sources, with more than 25 years of experience. She has directed numerous research studies involving indoor air pollution and human health effects. Dr. Black holds Ph.D., M.S. and B.S. degrees in chemistry and applications in environmental health.