

**METHOD FOR MEASURING CHEMICAL AND PARTICLE EMISSIONS
FROM OFFICE EQUIPMENT (HARDCOPY DEVICES)
USING DYNAMIC ENVIRONMENTAL CHAMBERS**

Foreword

The GREENGUARD Environmental Institute (GEI) began certifying indoor products for low chemical and particle emissions in 2001. Testing procedures for the program were developed and applied by Air Quality Sciences, Inc (AQS) to cover a breadth of product types and building applications. The science of measuring product emissions developed from research conducted by the Environmental Protection Agency, Department of Energy, the Department of Housing and Urban Development, the Consumer Product Safety Commissions, California Department of Health Services, the state of Washington Department of General Administration, and additional national and international researchers. All testing procedures follow the general guidance of numerous ASTM standards including D-5116 and D-6670 for obtaining emissions data using small and large environmental chambers. Air Quality Sciences, Inc. was the first commercial facility worldwide, in 1989, to offer product testing and consulting services to manufacturers of products and end users

In 2001, Air Quality Sciences established the GREENGUARD Environmental Institute to 1) bring together performance based, field validated standards to define low emitting products and materials for the indoor environment; 2) provide a third party, non-industry and publicly available certification process for manufactured products; and 3) establish a public directory of certified products for architects, designers, specifiers, purchasers, and consumers. The GREENGUARD Environmental Institute, an ANSI National Standards Developer, sets standards and operates a publically available certification program, meeting the requirements of ISO Guide 65, for manufacturers of products.

The following Method incorporates the best-learned and available practices for testing and evaluating office equipment (hardcopy devices), including printers, multi-function machines, fax machines, and copiers. Elements of the Method include sample handling and shipment, sample preparation, product loadings and descriptions, analytical measurements, exposure modeling and allowable levels of chemical and particle emissions. Analytes include total volatile organic compounds (TVOC), individual VOCs, formaldehyde and other aldehydes, ozone and particles. All individual contaminants emitting from the products are measured as allowed by the Method, and each is required to meet defined allowable levels. AQS worked with the USEPA in 1995-1998 as part on its Environmental Technology verification program to assess indoor air emissions of office equipment and to develop emissions testing protocols for dry hardcopy equipment. This method includes the best practices developed in this EPA effort coupled with Germany's Blue Angel protocol. In 1996, AQS, using this method, became accredited by Germany's Federal Institute for Materials Research and Testing for providing acceptable data for the Blue Angel Eco Label Program for office equipment. This validation required proficiency verification and round robin testing to show that accurate and reproducible data could be obtained.

This test method follows is harmonized and validated with Germany's Blue Angel Environmental Label Program Requirements including Method RAL-UZ 122, ECMA 328, and ISO/IEC 28360. The Blue Angel Program is the most widely accepted, known, and proven standard for environmental attributes of machines including copiers, printers, and multifunctional machines. This method follows the procedures outlined in RAL-UZ 122, but also includes the option of obtaining emissions of formaldehyde, additional individual VOCs and particles defined as PM₁₀, as required for GREENGUARD certification and not currently required by Blue Angel method. Data measured from this method can be used to successfully meet the Blue Angel requirements and GREENGUARD certification requirements.

This document will be updated as new test protocols and standards become available according to the program requirements of Blue Angel and the GRENNGUARD Certification Program.

TABLE OF CONTENTS

SECTION 1	
BACKGROUND INFORMATION.....	1
1.0 Scope	2
1.1 Objectives and Use	3
1.2 References and Documents	3
1.3 Terminology.....	5
1.4 Definitions.....	5
1.5 Symbols.....	8
SECTION 2	
COLLECTION, PACKAGING, SHIPMENT, & DOCUMENTATION OF PRODUCT SAMPLES	9
2.0 Sample Collection.....	10
2.1 Representative Sample	10
2.2 Sample Preservation	10
2.3 Chain-of-Custody Documentation	10
2.4 Receipt of Samples by Laboratory	11
2.5 Rejection of Samples by Laboratory	11
2.6 Storage of Samples by Laboratory Prior to Following Testing.....	11
SECTION 3	
LABORATORY SAMPLE PREPARATION AND ANALYSES	12
3.0 Overview	13
3.1 Test Specimen Preparation	13
3.2 Environmental Chamber Testing	13
3.3 Environmental Chamber Performance Requirements.....	14
3.4 Chamber and Materials	14
3.5 Temperature and Humidity Control.....	15
3.6 Air Flow	15
3.7 Monitoring and Data Acquisition	15
3.8 Procedures.....	15
3.9 Air Sampling.....	16
3.10 Sampling Media	16
3.11 Chemical Analyses	17
3.12 Analytical Instruments.....	17
3.13 VOC Method.....	17
3.14 VVOC Method	19
3.15 Formaldehyde Method.....	19
3.16 Ozone Method.....	19
3.17 Dust Method	20
3.18 PM ₁₀ Method.....	21
3.19 Exposure Modeling.....	25
SECTION 4	
TARGET CHEMICALS AND MAXIMUM ALLOWABLE CONCENTRATIONS	27
4.0 Allowable Limits for GREENGUARD and Blue Angel Certification.....	28
SECTION 5	
REQUIRED ELEMENTS OF LABORATORY TEST REPORT	29

5.0 The Report of the Results Should Contain the Following Information 30
5.1 Certification of the Report with Date including Authorized Laboratory..... 30

SECTION 6

TABLES 31
Table 6.0 Sample Collection and Testing Chronology for Products 32
Table 6.1 Chamber Conditions for Test Period 32
Table 6.2 Parameters to be used for Calculation of VOC Concentrations in Offices 32

SECTION 7

VOC LISTS 33
7.1 Blue Angel Target List 34
7.2 Additional VOCs Frequently Identified in Printer Emissions 34

SECTION 1 BACKGROUND INFORMATION

1.0 Scope

Hardcopy devices may emit a variety of volatile chemicals, as well as ozone and particles, into the indoor air space of a building. The following methodology measures total volatile organic compounds (TVOC), individual volatile organic compounds (IVOCs), formaldehyde and other aldehydes, ozone, and particle emission levels from printers, multi-function machines, fax machines, and copiers using test conditions defined to simulate product use in a realistic commercial office, setting. The concentration of total or individual volatile organic chemical emissions, ozone and particle emissions is measured in a dynamic environmental chamber under specified test conditions. The observed chamber concentration is then converted by a mathematical calculation to an emission rate, a product specific variable, and then modeled to obtain room concentration estimates.

The test protocol follows the BAM RAL-UZ 122 Appendix 2 methodology used for Germany's Blue Angel Environmental Label Program. The Blue Angel Program is the most widely accepted, known, and proven standard for environmental attributes including copiers, printers, and multifunctional machines. The GREENGUARD method allows for additional measurements including formaldehyde, a range of IVOCs, and PM₁₀, which are not currently detailed in the Blue Angel Test Method.

The quantity of VOCs in the environmental chamber air is determined by gas chromatography/mass spectrometry. The methodology is generally applicable to volatile organic compounds with boiling points from 60°C to 290°C emitting from individual products. Emissions of selected aldehydes are measured using reverse-phase high-performance liquid chromatography (HPLC) with UV detection. Ozone is measured using a UV-absorbance based ozone analyzer. Total dust measurements are made by gravimetric analysis and PM₁₀ monitoring is performed using a 90° light scattering measurement to continuously determine airborne particle concentrations over time. Specialized analysis of chamber air samples may be conducted for other specific target chemicals as required for a specific product/project or standard requirements.

- 1.0.1 The methodology provides a standard means of reproducibly and accurately testing hardcopy devices under a realistic, yet highly controlled, atmosphere.
- 1.0.2 This protocol applies to any hardcopy device belonging to a product category generally used within an enclosed indoor environment.
- 1.0.3 This method establishes the procedures for product sample collection, emission testing and analysis, indoor air concentration modeling and associated documentation requirements.
- 1.0.4 This method also establishes performance criteria for specific chemicals of interest.
- 1.0.5 While this practice may list specific chemicals and associated maximum allowable concentrations, as required by criteria indoor air guidelines and specifications, it does not assess the human risk involved with use of hardcopy devices.
- 1.0.6 This practice does not purport to address safety concerns, if any, associated with the use of this practice. It is the responsibility of the user of this protocol to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1.1 Objectives and Use

1.1.1 Objectives

- 1.1.1.1 Measure VOCs, aldehydes, ozone, particles, and other potential air emissions from hardcopy devices.
- 1.1.1.2 Provide compound-specific data on VOCs to manufacturers for assessing product emissions and developing improved products for indoor environments.
- 1.1.1.3 Obtain emission data for use by the GREENGUARD Certification Program, Blue Angel and other government and private product specification programs.
- 1.1.1.4 Provide compound-specific data on VOC sources and assist in evaluating or certifying indoor air quality in buildings.
- 1.1.1.5 Provide emissions data for the development and use of models for prediction of indoor air concentrations of VOCs.
- 1.1.1.6 Identify irritants, odorants, and hazardous VOCs emitting from Hardcopy devices and their emission parameters to assist in risk evaluations.
- 1.1.1.7 Provide compound specific emission parameters for use in indoor exposure models.

1.1.2 Use

- 1.1.2.1 Intermediate (approximately 1 – 5 m³ volume) and large (< 5 m³) chamber evaluations are used to determine source emission rates and emission factors from hardcopy devices
- 1.1.2.2 Emission rates are used in indoor air quality models to predict indoor air concentrations of compounds emitted from the tested hardcopy device. The concentrations observed in the chambers are not to be directly used as a substitute for concentrations expected in full-scale indoor environments.
- 1.1.2.3 Emission factors are used to compare emission levels among products.
- 1.1.2.4 Measured emission rates and predicted indoor air concentrations or emission factors are used to determine compliance with criteria for certification programs including the GREENGUARD Certification Program and Blue Angel.

1.2 References and Documents

- ASTM D 5116*. Standard Guide for Small Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials / Products. *American Society for Testing and Materials, West Conshohocken, PA, 2006*.
- ASTM D 6670*. Standard Practice for Full-Scale Chamber Determination of Volatile Organic Emissions from Indoor Materials / Products. *American Society for Testing and Materials, West Conshohocken, PA, 2001*.
- ASTM D 5197*. Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Air (Active Sampler Methodology). *American Society for Testing and Materials, West Conshohocken, PA, 2003*.
- ASTM D 6196*. Practice for the Selection of Sorbents and Pumped Sampling / Thermal Desorption Analysis Procedures for Volatile Organic Compounds in Air. *American Society for Testing and Materials, West Conshohocken, PA, 2003*.
- ASTM D 6345*. Standard Guide for Selection of Methods for Active, Integrative Sampling of Volatile Organic Compounds in Air. *American Society for Testing and Materials, West Conshohocken, PA, 2001*.
- ASTM E 741*. Standard Test Method for Determining Air exchange in a Single Zone by Means of a Tracer Gas Dilution. *American Society for Testing and Materials, West Conshohocken, PA, 2001*
- USEPA Report 600/8-89/-074. Research Triangle Park, NC, 1989.
- ASHRAE Standard 55-2004. Thermal Environmental Conditions for Human Occupancy. ASHRAE, Atlanta, GA, 2004.

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BAM Federal Institute for Materials Research and Testing, Test Method For The Determination Of Emissions From Hardcopy Devices With Respect To Awarding The Environmental Label For Office Devices RAL-UZ 122 . Edition June, 2006.

CIE Document No. 15, Colorimetry, 2004.

ECMA International, ECMA-328 Standard, Determination of Chemical Emission Rates from Electronic Equipment, June, 2007.

ISO 554:1976. Standard atmospheres for conditioning and/or testing - specifications

ISO/IEC 28360: Information technology - Office equipment - determination of chemical emission rates from electronic equipment

ISO 16000-3: Indoor air - Part 3: Determination of formaldehyde and other carbonyl compounds – Active sampling method

ISO 16000-6: Indoor air – Part 6 Determination of VOC in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS/FID.

ISO 16000-9: Indoor air – Part 9 Determination of volatile organic compounds – Emission test chamber method.

ISO 16017-1: Indoor, ambient and workplace air -- Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography -- Part 1: Pumped sampling

ISO Guide 43-1:1997. Proficiency testing by interlaboratory comparisons – Part 1: Development and operation of proficiency testing schemes.

ISO Guide 43-2:1997. Proficiency testing by interlaboratory comparisons – Part 2: Selection and use of proficiency testing schemes by laboratory accreditation bodies.

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U.S. EPA. Air Quality Criteria for Particulate Matter (October 2004). U.S. Environmental Protection Agency, Washington, DC, EPA 600/P-99/002aF-bF, 2004.

1.3 Terminology

Acronyms and Abbreviations

ACH – Air exchanges per hour
ASTM – American Society for Testing and Materials
AQS – Air Quality Sciences, Inc.
BQL – Below quantifiable limit
COC – Chain of Custody
DL – Detection limit
DNPH – 2,4-Dinitrophenylhydrazine
ER – Emission Rate
EPA – U.S. Environmental Protection Agency
GC/MS – Gas chromatography/mass spectrometry
GEI – GREENGUARD Environmental Institute
HAP – Hazardous Air Pollutant
HPLC – High performance liquid chromatography
IAQ – Indoor Air Quality
ISO – International Organization for Standardization
IVOC – Individual volatile compounds
LOQ – Limit of quantitation, lower
MFC – Mass flow controller
MSDS – Material safety data sheet
NAAQS – National Ambient Air Quality Standards
Prop 65 – California Proposition 65
QL – Quantifiable limit
RH – Relative humidity in percent
TD/GC/MS – Thermal desorption GC/MS
TIC – Total ion-current chromatogram
TVOC – Total volatile organic compounds
VOC – Volatile organic compound
VVOC – Very Volatile Organic Compound

1.4 Definitions

Absolute Humidity (AH) - The amount of water vapor present in a unit volume of air; expressed as grams of water per grams of air.

Accuracy - The degree of conformity of a value generated by a specific procedure to the assumed or accepted true value; includes both precision and bias.

Air Exchange Rate (ACH) - The volume of purified inlet air, adjusted to standard

environmental conditions of 23°C and 50% RH, that enters the chamber environment in one hour divided by the volume of the chamber (typically expressed as hr^{-1}).

Air flow rate - Air volume entering the emission test chamber per unit time.

Air velocity - Air speed over the surface of the test specimen.

Aldehydes - Formaldehyde, acetaldehyde and other carbonyl compounds detectable by derivatization with DNPH and analysis by HPLC.

Background Concentrations – VOC, aldehyde, ozone, and particle concentrations in the emission test chamber in the absence of a product test specimen.

Chain-of-Custody - Document providing written evidence of transfer of a product sample, air sample, or another document from one organization to another organization or from one individual to another individual within the same organization. Document is signed and dated by each party involved in the transfer.

Concentration – Mass of VOC per unit air volume expressed at standardized conditions for temperature and humidity (i.e., 298K, 101.3 kPa)

Conditioning Phase – The period after loading the machine into the chamber prior to testing. for equilibration at 23°C and 50% RH for a minimum of 4 air exchanges. The machine is loaded with paper, and the power switch is switched “on” but the plug is not connected to the electrical supply.

Data Acquisition System – System used to monitor, acquire and store data defining the environmental conditions for an emission test.

Emission Rate (ER) – The rate of emission of a specific compound is defined as the total mass of an analyte emitted from the test device per unit time ($\mu\text{g/hr}$).

Humidity (H) – A measure of the amount of water vapor in the air.

Intermediate Environmental Chamber - A test apparatus consisting of an enclosed volume of between 1 and 5 m^3 with controlled environmental operational parameters used for the purpose of providing accurate and reproducible emission measurements from sources of indoor air pollutants.

Large Environmental Chamber - A test apparatus consisting of an enclosed volume of greater than 5 m^3 with controlled environmental operational parameters used for the purpose of providing accurate and reproducible emission measurements from sources of indoor air pollutants.

Loading - The physical act of placing the sample in the chamber, sealing the chamber door, and starting the test.

Loading Factor or Loading Ratio (L) - The ratio of the volume of the test specimen to the chamber volume (m^3/m^3).

Manufacturer's Identification Number - Unique product identifier from which a manufacturer is able to determine the product name, product category or subcategory, manufacturing location, date of manufacture, production line, and other pertinent identifying information for the product.

Mass Flow Controller - Electronic device based on principle of thermal conductivity used to control the flow rate of air entering the emission test chamber and the flow rate of air passing through a sampling device.

Normal Atmospheric Conditions – Standard atmospheric conditions of 23 ± 2 °C temperature and $50 \pm 5\%$ relative humidity.

Office Equipment (Hard Copy Device) – A category of equipment with printing function capabilities such as printers, copiers, fax machines and multi-function devices. Includes consumables such as paper and toner.

Operating Phase - The hardcopy device is printing/copying. The operating phase starts with the printing/copying of the first page and immediately follows the pre-operating phase without opening the test chamber.

Ozone - A molecule consisting of three oxygen atoms. Ground-level ozone is an air

pollutant with harmful effects on the respiratory systems of humans.

Ozone Half-Life – *The amount of time that elapses while the ozone concentration decreases to one half of the initial concentration.*

PM₁₀ - *Particles less than 10 micrometers in diameter.*

Post-Operating (Tailing) Phase – *The hardcopy device has completed the printing cycle; the post-operating (tailing) phase immediately follows the operating phase without opening the test chamber.*

Pre-Operating Phase – *The hardcopy device is plugged into the electrical supply; the pre-operating phase immediately follows the conditioning phase without opening the test chamber.*

Precision - *The degree of agreement of repeated measurements of the same property. The precision of a method is expressed quantitatively as the standard deviation computed from the results of a series of controlled determinations.*

Product – *the hardcopy device to be tested including its consumables (paper and toner/ink).*

Relative Humidity (RH) - *The ratio of the amount of water vapor actually present in the air to the greatest amount possible at the same temperature; expressed as percent saturation.*

Sampling Interval - *Time over which a single air sample is collected.*

Sampling Period – *Established time for collection of an air sample from the emission test chamber.*

Sorbent Tube – *Solid phase sampling device through which a sample of chamber exhaust air at controlled flow rate is passed to capture VOCs. Device typically contains Tenax-TA, or equivalent, as primary sorbent material, sometimes backed up by higher surface area sorbent material to quantitatively capture the most volatile VOCs.*

Test Protocol – *A defined process for operating hardcopy devices with specified settings, paper, toner/ink cartridges, and pre-operating, operating, and post-operating times in an environmental chamber.*

Total-ion-current Chromatogram – *Chromatographic representation of a GC/MS analysis produced as the sum of all of the scanned masses between m/z 35 – 350, or some other range.*

Total Volatile Organic Compounds (TVOC) - *The sum of those VOCs that elute between the retention times of n-hexane and n-hexadecane on a non-polar or equivalent capillary GC column. TVOC is estimated based on a toluene response factor.*

Temperature (T) - *Degree of hotness or coldness expressed in degrees Celsius.*

Ventilation Rate – *Same as air exchange rate*

Very Volatile Organic Compound (VVOC) - *Those nonpolar and moderately polar organic chemicals with boiling points below 60°C that are amenable to monitoring based on sorbent collection /thermal desorption/GC/MS analysis. The volatility range of chemicals amenable to the method will depend on the sorbent cartridges and thermal desorption chromatographic system used by the laboratory.*

Volatile Organic Compound (VOC) - *Those nonpolar and moderately polar organic chemicals with boiling points between 60°C and 290°C that are amenable to monitoring, based on sorbent collection /thermal desorption/GC/MS analysis. The volatility range of chemicals amenable to the method will depend on the sorbent cartridges and thermal desorption chromatographic system used by the laboratory.*

Zero Time – *The time establishing the beginning of an emission test or when a product is placed in a chamber and the door is sealed.*

1.5 Symbols

Symbol	Description	Units
A	Projected surface area	m ²
C	Chamber concentration of VOC	µg/m ³
C _P	Predicted exposure concentration	µg/m ³
ER	Emission rate	µg/hr
k	Rate constant	hr ⁻¹
L	Product loading factor	unit/m ³ (device volume/chamber volume)
N	Chamber air exchange rate	hr ⁻¹
N _e	Modeled air exchanges per hour	hr ⁻¹
SER	Product specific emission rate	µg/unit-hr
T	Time after start of test	hr or day
t	Time	hr
V	Volume	m ³

SECTION 2
COLLECTION, PACKAGING, SHIPMENT, &
DOCUMENTATION OF PRODUCT SAMPLES

2.0 Sample Collection

Guidelines are established for the collection, handling and documentation of hardcopy devices to ensure the products tested are reliable, representative, uncontaminated, and well preserved.

2.1 Representative Sample

2.1.1 Products selected or requested for testing are to be representative of similar products produced by the manufacturer. These products shall be treated no differently than similar products or components produced in the normal course of business and available in the marketplace. The hardcopy device may be a prototype or taken from the current production line. The manufacturer is responsible for ensuring that the prototype is identical to the latter serial product.

2.2 Sample Preservation

2.2.1 Product samples shall be packaged using the manufacturer's standard packaging materials.

2.2.2 After a check to ensure that the delivered contents are correct and undamaged, the product will be stored in the original packaging in an environmentally controlled indoor environment free of contamination with environmental control of 20° – 25°C and relative humidity no greater than 60% RH.

2.3 Chain of Custody Documentation

2.3.1 The manufacturer is responsible for the completion of the GREENGUARD, Blue Angel, or appropriate Product Documentation/Chain of Custody form. This form must be completed by the responsible manufacturer's employee/representative or by an independent third party pursuant to an agreement between the Licensee and the certifying agency. Each signatory shall retain a copy of this document.

2.3.2 The chain of custody form includes as a minimum the following information:

2.3.3 Manufacturer/Company Details – Name, Street Address, City, State/Province, Country, Zip/Postal Code

2.3.4 Contact Details – Contact Name, Title, Phone Number, Fax Number, Email Address

2.3.5 Sample Details – Sample ID, Manufacturer, Machine Name, Machine Type, Test Mode(s), Filter, Device No. (Serial No.), Toner/Cartridge Number(s), Paper Used (Type & Size), Date Manufactured

2.3.6 Shipping Details – Packed By, Shipping Date, Carrier, Airbill Number (Carrier and Airbill Number may be filled in by Laboratory upon receipt).

2.3.7 Ship to Laboratory – Name, Street Address, City, State/Province, Country, Zip/Postal Code, Phone Number, Fax Number

2.3.8 Laboratory Receiving Details – Received By, Received Date, Condition of Shipping Package, Condition of Sample, Assigned Laboratory Material Tracking Number

2.3.9 Signature Tracking Details – Relinquished By, Received By, Signature, Company, Date and Time

2.4 Receipt of Samples by Laboratory

- 2.4.1 Once the product sample is received by the laboratory, the packages will be checked against the shipping invoice to ensure all packages and components have been received.
- 2.4.2 The laboratory will visually inspect the shipping containers upon arrival to ensure they are intact and do not appear to have been contaminated during shipping.
- 2.4.3 The sample custodian shall note the condition of the package and container on the chain-of-custody form and sign and date the form.
- 2.4.4 If containers are damaged or missing, the laboratory will notify the manufacturer as soon as feasible.
- 2.4.5 If a package or container is significantly damaged or the other criteria are not met, the laboratory shall reject the sample as described in Section 2.5.
- 2.4.6 Valid samples are assigned a unique identifier and entered into an electronic data management system for sample and data tracking purposes.
- 2.4.7 The product is to remain in its original packaging (as received) until immediately prior to preparation for loading into the environmental chamber. It is to be stored in a normal indoor environment not expected to contaminate the product.

2.5 Rejection of Samples by Laboratory

- 2.5.1 The testing laboratory has the right to reject a product sample for testing due to, but not limited to, any of the following reasons:
- 2.5.2 Shipping package is severely damaged upon arrival.
- 2.5.3 Product container is damaged upon arrival so that integrity of the sample is compromised.
- 2.5.4 Chain of Custody form is missing or incomplete.
- 2.5.5 Product sample arrives with insufficient time to initiate testing within the required time frame.
- 2.5.6 When a product sample is rejected, the testing laboratory shall inform the manufacturer immediately and provide the reason for rejection.
- 2.5.7 The manufacturer has the right to collect a new sample and resubmit it for testing, subject to the conditions described within this practice. All costs for recollection and shipment shall be the responsibility of the manufacturer.

2.6 Storage of Samples by Laboratory Prior to and Following Testing

- 2.6.1 Before Testing: Samples are stored in original, sealed packaging in a controlled environment not expected to contaminate the sample. This environment must be free of chemical contamination and environmentally controlled at 20° - 25°C and not greater than 60% RH. Testing should take place as soon as possible, but no later than ten business days after receipt
- 2.6.2 After Testing: Following testing and report issuance, the product is stored until returned to the manufacturer. The yellow copy of the chain of custody form is returned or destroyed with the product.

SECTION 3
LABORATORY SAMPLE PREPARATION AND ANALYSIS

3.0 Overview

The test protocol follows the BAM RAL-UZ 122 Appendix 2 methodology used for Germany's Blue Angel Environmental Label Program. The Blue Angel Program is the most widely accepted, known, and proven standard for environmental attributes including copiers, printers, and multifunctional machines. This method allows for additional measurements including formaldehyde, additional Individual VOCs, and respirable particles (PM₁₀) which are not currently detailed in the Blue Angel method. Additional details on the testing methodology can be found in the referenced BAM RAL-UZ 122 Appendix 2.

3.1 Test Specimen Preparation

The hardcopy device is checked upon receipt to ensure all necessary paper trays, paper stackers, toner cartridges, and device drivers have been received.

Prior to testing, the printer is unpackaged, ink/toner cartridges installed, drivers loaded and all settings set to the manufacturer's default mode, and accessories assembled. The paper trays are loaded with DIN A4 format paper unless otherwise specified. The printer is then tested to ensure that the unit is operational, the printer prints from all installed trays, a minimum print time of 10 minutes can be achieved, and that the paper handling /output capacity is sufficient for the test. The unit is then operated for 2 full cycles (10 minutes x 2 cycles). Devices that cannot achieve the minimum print time are tested with their maximum possible print time. The device is also checked to ensure that the device can be operated in the chamber. The test page printout has 5% black surface coverage or 20% color (5% each of black, magenta, cyan, and yellow) surface coverage. From the printouts, the lightness (L*) and color values (L*, a*, b*) are determined. Power consumption in the pre-operating phase and operating phase is also determined.

3.2 Environmental Chamber Testing

3.2.1 Facilities

3.2.1.1 Chemical Emissions - A facility designed and operated to measure organic emissions and emission rates from office equipment (hardcopy devices) should contain environmental test chambers, sample storage areas, purification systems, monitoring and control systems, sample collection and analysis equipment, standards generation and calibration systems, data acquisition systems, and data modeling and reporting systems.

3.2.2 Equipment

3.2.2.1 Environmental Test Chamber Requirements - The chamber and analytical requirements are fully defined in the referenced BAM RAL-UZ 122 document and the "GREENGUARD Product Certification Program Laboratory Qualifications and Proficiency Requirements", based on the referenced ASTM documents D5116 for Small Scale Chamber Tests and D6670 for Full Scale Chamber Tests, and the referenced EPA ETV Large Chamber Test Protocol.

3.2.3 Chamber Sizes:

3.2.3.1 Intermediate (approximately 1 to less than 5 m³ volume) and large (greater than 5 m³) chamber evaluations are used to determine source emission rates from hardcopy devices.

3.2.3.2 The volume of the chamber needed for the hardcopy device is determined using the following equation:

$$0.01 < \frac{\text{Volume of Hardcopy Device}}{\text{Volume of Test Chamber}} < 0.25$$

3.3 Environmental Chamber Performance Requirements (The chamber requirements are fully defined in the referenced document “GREENGUARD Product Certification Program Laboratory Qualifications and Proficiency Requirements”) and in the referenced BAM RAL-UZ 122 document.

- 3.3.1 *Principle:* The principle of the test is to determine the specific emission rates of VOCs, ozone and particles emitted from hardcopy devices. The chamber test is conducted following the BAM RAL-UZ 122 methodology and the guidance of ASTM D 6670, “Standard Practice for Full-Scale Chamber Determination of Volatile Organic Emissions from Indoor Materials/Products”. The test is conducted in an environmental chamber at specified constant conditions of temperature, relative humidity, ventilation rate and product operating conditions. As the air in the chamber is fully mixed, VOC concentrations measured at the chamber exhaust are representative of air concentrations in the chamber. From the airflow rate into the chamber the print time and tailing time, and the VOC concentration, an emission rate is calculated using the equations in the BAM RAL-UZ 122 Appendix 2.
- 3.3.2 *Test Conditions:* The test is conducted at the conditions and within the limits specified in Table 6.2. Standard test conditions for chamber tests are 1 air exchange per hour (ACH) and inlet air conditions controlled at $23 \pm 2^\circ\text{C}$ and $50 \pm 5\%$ RH. Standard conditions for the purpose of calibrating flow measurement devices and calculating all flow rates are 23°C (298 K) and one atmosphere pressure (101.3 kPa). The chamber is ventilated optimally at 1 ± 0.05 air exchanges per hour.
- 3.3.3 *Clean air supply and flow control:* A clean air generator or high purity air is used to supply pressurized clean, dry air. The flow rate of the supply air to a chamber is regulated and monitored with electronic mass flow controllers (MFCs), or equivalent, with an accuracy of $\pm 2\%$ at 1 Lpm, or better, and capable of continuously maintaining the flow within $\pm 5\%$ of the specified value. MFCs are calibrated periodically according to the Laboratory’s quality assurance plan. At a minimum, flow measurement devices are calibrated on an annual basis against NIST traceable standards. At a minimum, the air exchange rate is monitored immediately before the product is placed in the chamber (at the same time background contamination checks are made) by accurately measuring the airflow into the chamber. The air exchange rate (h^{-1}) is then calculated as air flow (m^3/h) divided by chamber volume (m^3). The accuracy of this air exchange rate must be confirmed (with $\pm 10\%$ accuracy) using procedures similar to those presented in ASTM Method E741 for tracer gas application. Alternatively, ASTM Method E741 may be used as the primary method for determining the air exchange rate. The frequency of ACH verification is prescribed by the Laboratory’s quality assurance standards and should occur whenever flow changes are made to chamber air and at a minimum of twice per year, if conditions are not changed. Supply air contamination shall not exceed $10 \mu\text{g}/\text{m}^3$ for TVOC and $2 \mu\text{g}/\text{m}^3$ for any individual VOC.

3.4 Chamber and materials:

- 3.4.1 Environmental test chambers are constructed of inert, smooth, electropolished surfaces such as stainless steel.
- 3.4.2 All joints and openings are sealed. All seals are made of non-VOC emitting and non-VOC adsorbing/absorbing materials.
- 3.4.3 The air within the chamber is free of any obstructions or contamination such as humidifiers or refrigeration coils. Internally or externally mounted fans may be used to keep the chamber air well mixed if it can be demonstrated through the use of quality control samples that the fans do not contaminate the chamber air samples or irreversibly absorb/adsorb

- formaldehyde or representative VOCs (toluene and n-decane). The internal chamber air shall only come in contact with inert materials.
- 3.4.4 The surfaces and seals of the chamber are sufficiently chemically inert such that formaldehyde at the level of 0.005 ppm and representative VOCs at the level of 10 µg/m³ are not irreversibly retained on the interior surfaces.
- 3.4.5 Background concentrations in the empty chamber ventilated at 1.0 air exchanges per hour do not exceed 2 µg/m³ for any individual VOC or aldehyde, and 10 µg/m³ for TVOC or respirable particles.

3.5 Temperature and humidity control: The temperature of the chamber is maintained at 23 ± 2°C throughout the test period. All surfaces of the chamber are held at the same temperature so that the temperature inside the chamber is uniform. The humidity of the chamber air is maintained at 50 ± 5% RH. The humidity can be established by controlling the humidity of the inlet air. Water used in bubblers to saturate gas streams is free of organic solvents and contaminants (i.e., HPLC grade or equivalent). These conditions may vary slightly after loading the product into the test chamber and during the printing phase.

3.6 Air Flow: Optimal air exchange rate is 1.0 air changes per hour. The rate may be adjusted based on the size of the chamber:

Large Chamber (volume > 5 m ³)	1 ≤ ACH ≤ 2 ± 5%
Intermediate Chamber (> 1 and < 5 m ³)	1 ≤ ACH ≤ 5 ± 5%

The air velocity should be maintained at 0.1 – 0.3 m/s.

3.7 Monitoring and data acquisition: Instrumentation must be available to control and monitor the temperature and humidity with adequate accuracy, precision, and sensitivity to control these parameters and to document that the emission test is conducted within the control limits stated above. The measurements shall be made at the inlet air stream, inside the chamber or immediately at the chamber exhaust using electronic probes. The probes are calibrated periodically according to the laboratory's quality assurance plan. At a minimum, these probes are calibrated on an annual basis against NIST traceable standards.

3.8 Procedures

- 3.8.1 *Chamber cleaning and preparation:* Prior to the actual testing, clean chambers by wiping down the inner surfaces with deionized water. Soap or detergent is not recommended because of contamination and residue left on chamber materials. Chambers are then dried and purged at standard test conditions for a minimum of twelve hours, or 12 ACH's prior to use.
- 3.8.2 *Background measurement:* Prior to sample loading, collect chamber air background samples for VOC's, aldehydes, ozone and particles to determine the levels of TVOC, IVOCs and formaldehyde in the clean chamber. VOC and aldehyde samples are to be collected to provide lower quantitation limits of at least 2 µg/m³ for individual VOCs and aldehydes and 10 µg/m³ for TVOC.
- 3.8.3 *Chamber air leakage:* Air tightness is determined on an annual basis by capping the inlet and exhaust manifold and introducing a known concentration of a tracer gas such as SF₆ or CO. The concentration is monitored over a period of time. The ending concentration is within 3% of the initial concentration. Additionally, the air leakage of specific chambers can be determined periodically after loading a test specimen, if appropriate. This can be accomplished by measuring the flow rate at the chamber exhaust and comparing this to the supply airflow rate. The flow measurement device shall have low pressure drop. The

exhaust flow rate is within 10% of the inlet flow rate by this method.

3.9 Air Sampling

- 3.9.1 *Sampling schedule:* For standard certification tests, chamber air samples are collected for VOCs and formaldehyde prior to the conditioning phase, and during the pre-operating and operating plus post-operating phases or as otherwise dictated by the test program or specification requirements. Ozone and particles are monitored prior to the conditioning phase and during the operating plus post-operating phase.

Samples are collected at the following time points:

- 3.9.1.1 Blank value prior to loading the hardcopy device into the chamber
3.9.1.2 During the pre-operating phase with the hardcopy device loaded in the chamber
3.9.1.3 From the start of the operating phase and continuously through the post-operating phase until an air exchange has been completed during the post-operating phase.

3.10 Sampling Media

- 3.10.1 VOC sampling media for individual VOCs and TVOC consists of thermally desorbed, solid-phase sorption tubes containing Tenax-TA. Refer to ASTM documents D6196 and D 6345, and U.S. EPA Methods TO-1 and TO-17. The samplers are capable of quantitatively collecting VOCs with a broad range of functional groups and volatilities approximately within the volatility range of n-butane through n-octadecane, although TVOC is based on response from n-hexane through n-hexadecane (C₆ - C₁₆). Minimal losses of analytes (i.e., < 5%) due to breakthrough shall occur. This can be accomplished by the use of sampling tubes containing two or more sorbent materials in series, with the highest surface area material used as the backup to prevent the breakthrough of the most volatile compounds. Before use, samplers are conditioned by thermal desorption. Samplers taken from refrigerated storage are warmed to room temperature prior to use.
- 3.10.2 Sampling media for formaldehyde, acetaldehyde and other low molecular weight aldehydes consists of cartridges containing a solid support material (e.g., silica gel) treated with an acid solution of 2,4-dinitrophenylhydrazine (DNPH) as a derivatizing reagent. Refer to ASTM document D 5197 for guidance. Samplers are warmed to room temperature prior to use.
- 3.10.3 Dust samples are collected on 47 mm GF50 glass filters.
- 3.10.4 *Flow control:* Sampling flow rates are regulated with electronic mass flow controllers with an accuracy of ± 2 % full scale, or better, and capable of continuously maintaining the flow during sampling within ± 5 % of the specified value.
- 3.10.5 *Sampling procedures:* Air samples are collected directly from the chamber exhaust at the specified elapsed times. A short manifold with multiple ports and a maximum length of 4 in is used at the exhaust to allow simultaneous collection of multiple samples. No other tubing is allowed between the chamber exhaust and the sampler inlet. The DNPH cartridge is placed downstream of the VOC sorption tubes to reduce the chance of VOC sample contamination with residual acetone that may be present in the DNPH cartridge. The total sampling flow rate at any time does not exceed 75% of the inlet flow rate. The start and stop times and the sampling flow rates are recorded. A unique identification number is assigned to each air sample.
- 3.10.6 *Duplicate samples:* A fraction of the air samples are collected in duplicate. The fraction of duplicates is determined by the laboratory's quality assurance plan and recommended to be no less than 1 out of every 10 samples.
- 3.10.7 *Sample storage:* Following collection, air samples are sealed in clean airtight containers and stored at reduced temperature in a dedicated refrigerator or freezer. Samples are analyzed as soon as practical after collection. Use unexposed sample tubes as storage

blanks.

3.11 Chemical Analyses

3.11.1 *Principle:* Chamber air samples are analyzed using instrumental methods that are capable of identifying individual VOCs or aldehydes and quantifying them using multi-point calibrations prepared using pure standards. The methods provide sufficient sensitivity and accuracy to reliably quantify individual VOCs or aldehydes at concentrations of $2 \mu\text{g}/\text{m}^3$, or less.

3.12 Analytical Instruments

- 3.12.1 VOCs and TVOC: Sorbent tube samples for individual VOCs and TVOC are analyzed by thermal desorption GC/MS (TD-GC/MS). The thermal desorber desorption and inlet parameters are optimized to obtain quantitative recovery of range of VOCs expected. The GC column and oven temperature parameters are optimized for the analysis of volatiles. The MS is an electron impact instrument operated in the scanning mode over a mass range of at least m/z 35-350.
- 3.12.2 Formaldehyde, acetaldehyde and other low molecular weight aldehydes: Aldehyde samples are analyzed by HPLC equipped with a UV detector and an analytical column providing full resolution of the formaldehyde hydrazone derivative from unreacted DNPH in a sample.
- 3.12.3 Dust: An ultra microbalance is used for the gravimetric particle measurements.
- 3.12.4 PM_{10} : Respirable particles are measured using a laser photometer aerosol monitor set-up for the collection of particles less than 10 microns.
- 3.12.5 Ozone: A UV-absorbance based ozone analyzer or equivalent is used for ozone measurements.

3.13 VOC Method

- 3.13.1 The analytical methods for individual VOCs are based on ASTM D 6196, "Standard Practice for Selection of Sorbents, Sampling and Thermal Desorption Analysis Procedures for Volatile Organic Compounds in Air." Other relevant practices are EPA Methods TO17, "Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling Onto Sorbent Tubes" and TO-1, "Determination of Volatile Organic Compounds in Ambient Air Using Tenax Adsorption and Gas Chromatography/Mass Spectrometry (GC/MS)" or equivalent methods. Standards and chamber samples are analyzed using identical conditions.
- 3.13.2 TVOC measurements are made by adding all individual VOC responses obtained by the mass spectrometer between the elution times of n-hexane and n-hexadecane and calibrating the total mass relative to toluene.
- 3.13.3 *Identification of Individual VOCs*
- 3.13.3.1 The identification of an individual VOC by GC/MS is determined by comparing the chromatographic retention time and mass spectrum of the unknown to the corresponding parameters for the pure compound analyzed on the same instrument using identical methods. Matching retention times and mass spectra provide positive, confirmed identifications.
- 3.13.3.2 If no high quality match is obtained, the unknown spectrum is compared to spectra contained in the latest version of the NIST/USEPA/NIH mass spectral library. A trained analyst decides if the identification is likely based on the match quality and the reasonableness of the retention time. Compounds identified by this procedure are clearly indicated. If no highly probable match is obtained, the compound is labeled as an unknown.
- 3.13.4 *Analytical Calibrations*
- 3.13.4.1 Target VOCs of concern as identified in RAL UZ-122 or specified by a certification program are quantified by GC/MS based on multi-point calibrations prepared using pure

compounds. Specific target lists and expected VOCs are presented in Section 7. A minimum of four points are used. Target analytes are introduced onto sorbent tubes as gas or liquid standards and then analyzed using methods identical to those used for the analysis of chamber samples. Analyze calibration standards or perform full calibrations at least once every month or more frequently to ensure accuracy for the analyses.

3.13.5 Quantifiable Limit (QL)

3.13.5.1 A lower QL often is quantitatively defined as the analyte mass that produces a response that is 10 times higher than the instrumental noise level or is 10 times the standard deviation for repeated analyses of a low level standard. A lower QL that is higher than this absolute value may be defined based on practical considerations.

3.13.5.2 For TVOC, the lower QL is $10 \mu\text{g m}^{-3}$, or better.

3.13.5.3 The lower QL for VOCs appearing on list of chemicals of concern or allowable emission levels is $2 \mu\text{g m}^{-3}$, or better.

3.13.5.4 The lower QL for non- listed VOCs is $2 \mu\text{g m}^{-3}$, or better.

3.13.5.5 A QL verification sample is analyzed after each calibration. Target analytes are introduced onto sorbent tubes as gas or liquid standards at or below the level of quantitation and then analyzed using methods identical to those used for the analyses of chamber samples.

3.13.6 VOC Calculations

3.13.6.1 The VOC emission rate calculation during the pre-operating phase can be calculated using the following equations according to RAL-UZ 122 Appendix 2, Section 4.5:

$$SER_{PO} = C_{PO} * n * V \qquad C_{PO} = \frac{m_{VOCB}}{V_s}$$

SER_{PO} : Emission rate ($\mu\text{g/hr}$) during the pre-operating phase

C_{PO} : VOC concentration ($\mu\text{g/m}^3$) during the pre-operating phase

m_{VOCB} : Analyzed mass (μg) of VOC during the pre-operating phase

n : Air exchange rate (h^{-1}) during the pre-operating phase

V : Volume of test chamber (m^3)

V_s : Sample volume collected during the pre-operating phase (m^3)

3.13.6.2 The VOC emission rate calculation during the operating phase can be calculated using the following equation according to RAL-UZ 122 Appendix 2, Section 4.5:

$$SER_{OP} = \frac{\frac{m_{VOCOP}}{V_s} * n_{OP}^2 * V * t_G - SER_{PO} * n_{OP} * t_G}{n_{OP} * t_D - e^{-n_{OP}(t_G-t_D)} + e^{-n_{OP} * t_G}}$$

SER_{OP} : VOC emission rate ($\mu\text{g/h}\cdot\text{m}^3$) determined from the operating and post-operating phases

SER_{PO} : VOC emission rate ($\mu\text{g/h}\cdot\text{m}^3$) determined from the pre-operating phase

m_{VOCOP} : Analyzed mass (μg) of VOC during the operating and post-operating phases

n_{OP} :	Air exchange rate (h^{-1}) during the operating and post-operating phases
t_D :	Absolute printing/copying time (h)
t_G :	Total sampling time (h)
V :	Volume of test chamber (m^3)
V_S :	Sample volume (m^3) collected during the operating and post-operating phases

3.14 VVOC Method

3.14.1 VVOCs which are detected in VOC sampling using Tenax TA are to be quantified in the same way as VOCs and listed in the test report. VVOCs are not included in the TVOC value.

If very volatile solvents are contained in the inks of inkjet printers according to the manufacturer's information of material safety data sheet), it is of particular importance to prevent test results being falsified by "breakthrough". To prevent breakthrough, two Tenax tubes can be connected in a row.

3.15 Formaldehyde Method

3.15.1 The analytical method for formaldehyde is based on ASTM Standard D 5197, "Standard Test Method for Formaldehyde and other Carbonyl Compounds in Air (Active Sampler Methodology)". It is recognized that unsaturated low molecular weight aldehydes such as acrolein are not accurately determined by this method. Higher molecular weight aldehydes approximately beginning with butanal can be analyzed by the method for individual VOCs.

3.15.2 Aldehyde hydrazone derivatives analyzed by HPLC are identified by matching the chromatographic retention times of the unknowns with the retention times of derivatives of the pure compounds analyzed on the same instrument using identical methods.

3.15.3 Aldehydes analyzed by HPLC are quantified based on multi-point calibrations prepared from hydrazone derivatives of the pure compounds. Standards and samples are analyzed using identical methods. Analyze calibration standards or perform full calibrations at least once every month or more frequently to ensure accuracy for the analyses.

3.15.4 The emission rate calculation during the pre-operating and operating phases can be calculated using the same equations that are in Section 3.13.7 above.

3.15.5 A lower QL often is quantitatively defined as the analyte mass that produces a response that is 10 times higher than the instrumental noise level or is 10 times the standard deviation for repeated analyses of a low level standard. A lower QL that is higher than this absolute value may be defined based on practical considerations.

3.15.6 The lower QL for formaldehyde is $2 \mu\text{g m}^{-3}$, or better.

3.15.7 Emission rate calculations in the pre-operating and operating phase follow the same calculations as VOCs (3.13.6.1 and 3.13.6.2).

3.16 Ozone Method

3.16.1 The measurement of ozone is based on the flameless reaction between ozone and ethylene. The chemiluminescence produced can be measured photometrically. The quantifiable level for ozone is $10 \mu\text{g/m}^3$.

3.16.2 Ozone half-life can be determined from the decay curve in the post-operating phase. The ozone emission rate can be calculated using the following equations according to RAL-UZ 122 Appendix 2, Section 4.7:

$$SER_u = \frac{C_{max} * k' * V * p}{T * R} \qquad k' = \frac{\ln 2}{H}$$

SER_u : Ozone Emission rate ($\mu\text{g/hr}$)

C_{max} : Maximum ozone concentration ($\mu\text{g/m}^3$) during the first 10 minutes of the printing phase.

k' : Proportionality factor (min^{-1})

H : Ozone half-life under test conditions (min)

V : Chamber volume (m^3)

P : Air pressure (Pa)

T : Absolute Temperature (K)

R : Gas constant (339.8 Pa/K for ozone)

3.17 Dust Method

3.17.1 The dust emission rate is measured using the gravimetric method.

3.17.2 Air sampling is conducted from the beginning of the operating phase to the end of the post-operating phase. During this time, air is collected from the approximate center of the test chamber using a sampling pump and is drawn through glass fiber filter. The volume of air collected is recorded. The sample collection rate is less than 75% of the air exchange rate in the chamber. The absolute weight of dust (μg) is obtained by differential weighing of the filter. The dust concentration in the test chamber can be calculated from the emission rate. The quantifiable level for dust is 0.030 mg.

3.17.3 The glass fiber filters used for dust measurement must be stored in a conditioned room prior to being used for dust measurement and must be conditioned until the mass is constant. The conditions in the room are $23 \pm 2^\circ \text{C}$ and $50 \pm 5\%$ relative humidity. Prior to sample collection, at least one additional glass fiber filter, a reference filter, is weighed at the same time as the filters intended to be used for dust collection during the test. The reference filter remains in the conditioned room during sample collection. After sampling has been completed, the measuring filter must be returned to the conditioning room and reconditioned to a constant mass. The reference filter along with the measuring filter is reweighed. The mass difference between the first and second weighing of the reference filter is added to or subtracted from the gross mass of the measuring filter.

3.17.4 Dust concentration and emission rate can be calculated using the following equations according to RAL-UZ 122 Appendix 2, Section 4.8:

Determination of absolute dust weight on the measuring filter (moisture correction):

$$m_{St} = (m_{MF_{gross}} - m_{MF_{tare}}) + (m_{RF_1} - m_{RF_2})$$

m_{St} : Weighed mass of dust (μg)

$m_{MF_{gross}}$:	Mass of conditioned measuring filter after dust sampling (μg)
$m_{MF_{tare}}$:	Mass of conditioned measuring filter before dust sampling (μg)
m_{RF_1} :	Mass of conditioned reference filter weighed at the same time as the measuring filter before dust sampling (μg)
m_{RF_2} :	Mass of conditioned reference filter weighed at the same time as the measuring filter after dust sampling (μg)

Calculation of dust concentration and emission factor:

$$SER_{u_{St}} = \frac{m_{St} * n * V * t_G}{V_s * t_D} \quad c_{St} = \frac{m_{St}}{V_s}$$

c_{St} :	Dust concentration in test chamber ($\mu\text{g m}^{-3}$)
$SER_{u_{St}}$:	Dust emission rate ($\mu\text{g hr}^{-1}$)
m_{St} :	Weighed mass of dust (μg)
n :	Air exchange rate (h^{-1})
V :	Volume of test chamber (m^3)
V_s :	Volume of air sampled through filter (m^3)
t_G :	Total sampling time (min)
t_D :	total printing/copying time (min)
c_d :	Dust concentration in test chamber ($\mu\text{g m}^{-3}$)

3.18 PM_{10}

3.18.1 Respirable particles are measured using a laser photometer aerosol monitor set-up for the collection of particles less than 10 microns.

3.18.2 The quantifiable level for PM_{10} is $5 \mu\text{g}/\text{m}^3$. The determination of the emission rate for particles less than 10 microns in a well mixed environmental chamber can be calculated using the following equations:

A mass balance is done on the chamber, with the following assumptions:

- A the hardcopy device emits at a constant rate over a defined period of time;
- A the supply air to the chamber contains no measurable contaminants;
- A the sampled air is representative of a homogeneous concentration within the chamber; that is, the chamber is "well-mixed."

Let the time of operation of the hardcopy device be from t_{on} to t_{off} , and the sampling time span from t_{on} to t_F . The sampling interval is longer than the time over which the hardcopy device is emitting, and includes components of the concentration increase during the operation of the hardcopy device and the decay following the end of operation. The concentration change within the chamber is described by the equations:

For $t_{on} \leq t \leq t_{off}$: (A1)

$$\frac{dC_A(t)}{dt} = -NC_A(t) + \frac{E_U}{V}$$

For $t_{off} \leq t \leq t_F$: (A2)

$$\frac{dC_B(t)}{dt} = -NC_B(t)$$

$C_A(t)$ = chamber concentration over time unit is operating

$C_B(t)$ = chamber concentration after unit stops operating

N = air exchange rate in the chamber (air changes per hour)

E_U = emission rate of the powered unit (mass per time)

V = volume of chamber.

Equations (A1) and (A2) are first order ordinary differential equations. The boundary conditions are:

$$C_A(t_{on}) = 0$$

$$C_B(t_{off}) = C_A(t_{off}).$$

The solutions to (A1) and (A2), assuming $t_{on} = 0$ are:

$$C_A(t) = \frac{E_U}{Q} (1 - e^{-Nt})$$

(A3)

and

(A4)

$$C_B(t) = \frac{E_U}{Q} (e^{Nt_{off}} - 1) e^{-Nt}$$

Q is defined as volumetric flow rate of air through the chamber, or $N \cdot V$.

The average concentration in the chamber over the sampling interval 0 to t_{off} is defined by the equation:

$$\bar{C} = \frac{1}{t_F} \left[\int_0^{t_{off}} C_A(t) dt + \int_{t_{off}}^{t_F} C_B(t) dt \right]$$

(A5)

The respective integrals may be determined from the solutions (A3) and (A4) to be:

$$\int_0^{t_{off}} C_A(t) dt = \frac{E_U}{Q} \left(t_{off} + \frac{1}{N} e^{-Nt_{off}} - \frac{1}{N} \right)$$

(A6)

$$\int_{t_{off}}^{t_F} C_B(t) dt = \frac{E_U}{Q} (e^{Nt_{off}} - 1) \left[\frac{1}{N} e^{-Nt_{off}} - \frac{1}{N} e^{-Nt_F} \right]$$

(A7)

The predicted emission factor over time is based on the derivation provided in equations A1 through A7. However, in order to account for deposition of particles, an additional rate term (k) is included:

$$C_A(t) = \frac{E_U}{(Q + Vk)} (1 - e^{-(N+k)t})$$

(B1)

and

$$C_B(t) = \frac{E_U}{(Q + Vk)} (e^{(N+k)t_{off}} - 1) e^{-(N+k)t}$$

(B2)

The known parameters in these equations include t_{off} , Q , and N . C_A and C_B are measured during continuous sampling. The continuously sampled data are compared by a least squares error method to the predicted concentrations based on (B1) and (B2). The error is minimized by a root finding method or trial and error substitution of values for E_U , k , and for a delay factor t_{delay} . This delay factor accounts for the time delay associated with sampling methodology, unrelated to the increase in chamber concentration due to mixing during the continuous generation of emissions during operation of the unit. E_U is determined as the value providing the minimum least squares error for a time delay factor consistent with the measured data. Graphical analysis determines the reasonability of the values E_U , k , and t_{delay} . The reasonability of k can further be assessed by calculating the deposition velocity:

(B3)

$$V_d = \frac{kV}{A}$$

V_d = deposition velocity (length per time)

k = deposition rate (inverse time)

A = Area of chamber floor

V = volume of chamber

3.19 Exposure Modeling

3.19.1 The emission rates of individual VOCs, TVOC, formaldehyde, dust, respirable particles and ozone can be used in an exposure model to determine potential air concentrations of the pollutants.

3.19.2 Determination of Predicted Exposure Concentrations

The emission rate data for the individual compounds identified during chamber testing is combined with expected use conditions to determine a predicted exposure concentration. The assumption is made that the space within which the equipment is placed is well-mixed.

The space within which the hard copy devices are utilized is assumed to be 32 m³, with an air exchange rate of 0.72 air exchanges per hour (ACH). Concentrations of the different pollutants compounds emitted by the hard copy device are calculated based on the measured operating + post-operating phase emission rates. For each pollutant, the predicted exposure concentration is calculated using the following equations:

$$C_{st} = \frac{E}{N \cdot V} \quad (1)$$

C_{st} : the predicted exposure concentration (µg/m³) of a given compound in the workspace

E : the operating + post-operating phase emission rate (µg /hr)

N : the air exchange rate (hr⁻¹) in the workspace, assumed to be 0.72 ACH

V : the volume (m³) of the workspace, assumed to be 32 m³

3.19.3 GREENGUARD Certification testing calculated exposure concentrations are used to determine compliance with the standard based on acceptable Blue Angel emission rates.

3.19.4 Office - Office ventilation rates are based on the ASHRAE 62.1-2004 ventilation standard for acceptable indoor air quality. The office ventilation rate is based on the ASHRAE parameters of 5 CFM per person and 0.06 CFM/ft² for office spaces in commercial buildings. These parameters are applied to the GREENGUARD office size (32 m³) for a single occupant, which results in a ventilation rate of 0.72 ACH.

3.19.5 Conversion to ppm

3.19.5.1 For formaldehyde, the conversion from $\mu\text{g}/\text{m}^3$ to ppm is obtained by use of the partial molar volume of formaldehyde via the following formula:

$$\text{ppm} = [(\mu\text{g}/\text{m}^3) \times (24.45 \text{ m}^3/\text{mol})] / [(\text{gram molecular weight of formaldehyde}) \times (1000)]$$

3.19.5.2 The model measurements are made with the following assumptions: air within open office areas of the building is well-mixed at the breathing level zone of the occupied space; environmental conditions are maintained at 50% relative humidity and 23°C (73°F); there are no additional sources of these pollutants; and there are no sinks or potential re-emitting sources within the space for these pollutants.

SECTION 4
TARGET CHEMICALS AND MAXIMUM ALLOWABLE
CONCENTRATIONS

4.0 Allowable Limits for GREENGUARD and Blue Angel Certification

Blue Angel and GREENGUARD requirements are based on the emission rate (mg/hr) and predicted air concentrations (mg/m³) during the print/copy phase of operation:

<i>Monochrome</i>		
Blue Angel & GREENGUARD Acceptable IAQ Criteria		
Emitted Substance	Emission Rate [mg/h]	Room Concentration [mg/m³]
TVOC ^{2,3}	10	≤ 0.4
Benzene ²	0.05	≤ 0.002
Styrene ²	1	≤ 0.04
Ozone ²	1.5	≤ 0.06
Total Dust ³	4	≤ 0.16
Additional criteria for GREENGUARD certification		
Formaldehyde	1.2	≤ 0.05
Individual VOCs ¹	---	≤ 0.1 TLV
Respirable Particles (PM ₁₀) ⁴	---	≤ 0.15 mg/m ³
Listing of measured carcinogens and reproductive toxins as identified by California Proposition 65, the U.S. National Toxicology Program (NTP), and the International Agency on Research on Cancer (IARC) must be provided.		
Any pollutant regulated as a primary or secondary outdoor air pollutant must meet a concentration that will not generate an air concentration greater than that promulgated by the National Ambient Air Quality Standard (U.S. EPA, Code of Federal Regulations, Title 40, Part 50).		

<i>Color</i>		
Blue Angel & GREENGUARD Acceptable IAQ Criteria		
Emitted Substance	Emission Rate [mg/h]	Room Concentration [mg/m³]
TVOC ^{2,3}	18	≤ 0.8
Benzene ²	0.05	≤ 0.002
Styrene ²	1.8	≤ 0.08
Ozone ²	3	≤ 0.13
Total Dust ³	4	≤ 0.16
Additional criteria for GREENGUARD certification		
Formaldehyde	1.2	≤ 0.05
Individual VOCs ¹	---	≤ 0.1 TLV
Respirable Particles (PM ₁₀) ⁴	---	≤ 0.15 mg/m ³
Listing of measured carcinogens and reproductive toxins as identified by California Proposition 65, the U.S. National Toxicology Program (NTP), and the International Agency on Research on Cancer (IARC) must be provided.		
Any pollutant regulated as a primary or secondary outdoor air pollutant must meet a concentration that will not generate an air concentration greater than that promulgated by the National Ambient Air Quality Standard (U.S. EPA, Code of Federal Regulations, Title 40, Part 50).		

¹ Any VOC not listed must produce an air concentration level no greater than ¹/₁₀ the Threshold Limit Value (TLV) industrial work place standard (Reference: American Conference of Government Industrial Hygienists, 6500 Glenway, Building D-7, Cincinnati, Ohio 45211-4438).

² Styrene, benzene, ozone, total VOCs and total dust levels correspond to the German Blue Angel Environmental Label (BAM) program requirements for emissions from hard copy devices.

³ Defined to be the total response of measured VOCs falling within the C₆ – C₁₆ range. Responses calibrated to authentic standards, for a target list defined by BAM. Other VOCs quantified relative to toluene.

⁴ Respirable particles are based on the National Air Quality Ambient Standard 24-hour average, promulgated January, 2007. Results based on an 8-hour average.

**SECTION 5
REQUIRED ELEMENTS OF THE LABORATORY TEST
REPORT**

5.0 The Report of the Test Results Should Contain the Following Information:

5.0.1 *Laboratory identification:* Name, address, phone number and other contact information for the laboratory.

- Manufacturer,
- Product description, indication if tabletop/floor-mounted device, device number, print or copy speed according to manufacturer information, toner description, and description of paper used,
- Date of manufacture,
- Date of delivery,
- Type of packaging,
- Storage prior to measurement,
- Test date/time period,
- Lightness or color value of the printouts,
- Test conditions (type and size of chamber, temperature, relative humidity, air exchange rate or air flow rate),
- Duration of printing job,
- Print speed during testing,
- Number of pages printed,
- Time and interval of air sampling, volume and flow rate of air sampling for VOC, ozone and dust,
- Name, CAS-No. and concentration of identified VOCs, as well as concentration of unidentified VOCs in pre-operating phase and printing phase, and calculated emission rates. Benzene and styrene have to be separately listed in every case.
- The TVOC value calculated as the sum of the concentrations of all identified and unidentified substances, additionally the TVOC value calculated based on the response factor of toluene,
- Information on VVOCs, if detected,
- Ozone half-life of empty chamber and from the post-operating phase,
- Ozone concentration and calculated ozone emission rate during printing,
- Dust mass measured gravimetrically and dust emission rate calculated from it,
- Detection limits of VOC-, dust- and ozone emission rates,
- Disruptions and deviations from test algorithm,
- Summary of the results by the testing institute with respect to environment label criteria (if necessary, indication that the determined emission characteristic is only valid in connection with the tested toner type),
- Signature under the summary which must once more include the exact device description

5.0.2 *Chamber methodology:* Referenced methods/practices followed to operate chambers; description of the chamber used, how air flows through the chamber, supply air contaminant levels (either in report or readily available upon request).

5.0.3 *Data analysis procedures:* Analytical methods used to determine measured chamber concentrations and to derive emission factors from measured chamber concentrations; methodology and parameters used to calculate room concentrations from the emission factors including the assumed product area, room volume, and ventilation rate and ventilated volume fraction.

5.0.3.1 Provide estimated concentrations for modeled building scenarios for all pollutants of concern.

5.1 Certification of the Report with date including authorized laboratory.

5.1.1 Report any additional facts, which may have influenced the test results. These may include, but are not limited to, the following:

5.1.1.1 Any deviations of laboratory parameters from specified values

5.1.1.2 Any other relevant observations.

SECTION 6 TABLES

Table 6.0 Sample collection and testing chronology for products

Event	Schedule
<i>Office Equipment (Hard Copy Devices)</i>	
Manufacturing date	Date product comes off of final manufacture line
Shipment to laboratory	Within 24 hours of sample collection
Arrival at laboratory	Not to exceed 7 days from shipment date
Commence laboratory testing	Not to exceed 10 business days after arrival and product acceptance at laboratory

Table 6.1 Chamber conditions for test period

Parameter	Symbol	Units	Value
Chamber volume	V	m ³	1.0 – 26
Loading factor**	L	m ³ /m ³	0.01 – 0/25
Air exchange rate	a	hr ⁻¹	1.0 ± 0.05
Temperature	T	°C	23 ± 2
Relative humidity	RH	%	50 ± 5

Table 6.2 Parameters to be used for calculation of VOC concentrations in offices

Parameter	GG Office Model
Room Length	10 ft
Room Width	14 ft
Room Height	8 ft
Room Volume	32 m ³
Air exchange Rate	0.72 hr ⁻¹

SECTION 7 VOC LISTS

**7.1 Blue Angel VOC Target List
(VOCs which must be specifically calibrated with authentic standards)**

Acetophenone
 n-Alkanes (C₁₀ - C₁₆)
 Benzaldehyde
 Benzene
 BHT (2.6-di-tert.-butyl-4-methylphenol)
 Ethylbenzene
 Ethylhexanol
 Unsaturated aldehydes (C₆ - C₁₀)
 n-Butanol
 n-Propylbenzene
 Phenol
 Propyleneglycol
 Siloxane (e.g. D3-D6)
 Styrene
 Toluene
 Trimethylbenzenes
 Xylenes

7.2 Additional VOCs Frequently Identified in Printer Emissions

Name	CAS Number
3-Isopropoxy-1,1,1,7,7,7-hexamethyl-3,5,5-tris(trimethylsiloxy)tetrasiloxane	71579-69-6
Benzothiazole	95-16-9
Benzene, 1-methylethyl (Cumene)	98-82-8
Octanal	124-13-0
Allylbenzene	300-57-2
n-Butyl ether	142-96-1
Isobornyl propionate	2756-56-1
2-Propanol, 1-methoxy-	107-98-2
Pentasiloxane, dodecamethyl	141-63-9
Benzenemethanol, à,à-dimethyl-	617-94-7
Ethanol, 2-(2-ethoxyethoxy) (Diethylene glycol monoethyl ether)	111-90-0
Limonene (Dipentene; 1-Methyl-4-(1-methylethyl)cyclohexene)	138-86-3
2-Pentanone, 4-methyl (Methyl isobutyl ketone, MIBK)	108-10-1
Ethanol, 2-butoxy	111-76-2
Acetone	67-64-1
2-Propanol, 1-ethoxy	1569-02-4

Longifolene	475-20-7
à-Methylstyrene (iso-Propenylbenzene; (1-Methylethenyl)benzene)	98-83-9
1-Octanol	111-87-5
2-Propanol, 1,1'-[(1-methyl-1,2-ethanediyl)bis(oxy)]bis	1638-16-0
Benzene, (3,3-dimethylbutyl)	17314-92-0
Benzene, 1-ethyl-4-methyl (4-Ethyltoluene)	622-96-8
Butyl acrylate (2-Propenoic Acid, butyl ester)	141-32-2
2-Propanol, 2-methyl	75-65-0
Naphthalene	91-20-3
2-Propenoic acid, 2-ethylhexyl ester (Octyl acrylate)	103-11-7
Butyl propionate	590-01-2
Benzene, 1-ethyl-3-methyl	620-14-4
2-Furanmethanol	98-00-0
Tetrasiloxane, decamethyl	141-62-8
2-Propenoic acid, 2-methyl-, 2-hydroxyethyl ester	868-77-9
2,2,4-Trimethyl-1,3-pentanediol monoisobutyrate	77-68-9
Ethanol, 2-(2-butoxyethoxy)	112-34-5
Pinene, à (2,6,6-Trimethyl-bicyclo[3.1.1]hept-2-ene)	80-56-8
Acetic acid, 2-ethylhexyl ester	103-09-3
Silanol, trimethyl	1066-40-6
Cyclopropylbenzene	873-49-4
Indane	496-11-7
2-Pyrrolidinone, 1-methyl	872-50-4

Attachment 1
BAM RAL UZ-122
Appendix 2