



Cleaning Chemicals and Their Impact on Indoor Environments and Health

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In today's diverse market, cleaning product manufacturers are faced with the challenge of balancing two important goals: Creating effective cleaning products for a wide variety of applications that remove indoor pollutants such as dust, viruses, bacteria, particulates, endotoxins, allergens and mold, while not adding pollutants, such as volatile organic compounds (VOCs) and particulates, back into the indoor air. All of these indoor contaminants can make people sick, including triggering allergy and asthma attacks. In order to achieve these goals, manufacturers are trying to better understand how their products impact indoor air quality (IAQ) and health. Manufacturers are also under pressure to provide green products that meet today's market demands for effective, yet safe maintenance of schools, healthcare, commercial and residential environments. Consequently, they are striving to differentiate their products by earning third party impartial verification of their environmental performance.

This report takes a look at the health impacts associated with cleaning products and systems, especially chemical and particulate emissions that can be inhaled. It also discusses the importance of cleaning products in the green building movement and examines the various third party certification programs that are used to ensure products are safe for both the outdoor and indoor environments. In addition, the technology and testing protocols for measuring VOC emissions and for establishing the health risks associated with these emissions are highlighted.

Cleaning, Cleaning Products, IAQ: A Delicate Balancing Act

Cleaning is big business and is done at some level by nearly all adults, which means most people are exposed to cleaning chemicals for at least a portion of every day, with professional cleaning staff having significantly higher exposures for greater periods of time. For example, adults in the US spend an average of 20 to 30 minutes per day cleaning their homes (Wiley et al 1991). Results of activity pattern surveys of California adults found that 26 percent were near or used cleaning agents on the day on which they were surveyed and 31 percent reported that they were near or used scented air fresheners (Jenkins et al 1991). Three million people in the US are employed as janitors, cleaners, maids and housekeeping staff, which represent more than two percent of the working population (US Department of Labor 2001) (Nazaroff et al 2006).

At one end of the spectrum are a number of studies that have confirmed that dust control and deep cleaning are effective methods for reducing the level of viruses, bacteria, particulates, endotoxins, molds and allergens in indoor environments (Kildesø and Schneider 2000, University of Tennessee Center for Clean Products and Clean Technologies 2000 as reported in Culver et al 2002). With respect to cleaning products, some studies have explored the role of disinfectants in cleaning agents on limiting the spread of infectious disease (Bloomfield and Scott 1997, Josephson et al 1997, Rusin et al 1998). Only a few studies, however, have considered general cleaning efficacy (Schneider et al 1994, Franke et al 1997, Nilsen et al 2002) or the beneficial attributes of cleaning products (Olson et al 1994, Jerrim et al 2001, Jerrim et al 2002) (Nazaroff et al 2006).

At the other end of spectrum, results from a growing body of studies have demonstrated that the very products and processes that are used to keep indoor environments clean also may contribute to indoor pollution (Rumchv et al 2004; Shendell et al 2004; Zock et al 2001; Wolkoff

et al 1998) and health problems for building occupants. In many cases, VOC emissions from cleaning products and application processes, which building occupants can easily inhale, are the primary cause of concern.

A study published in the October 2007 issue of *American Journal of Respiratory and Critical Care Medicine* provides a good illustration. As a part of the follow up to the European Community Respiratory Health Survey in 10 countries, the researchers identified 3,503 persons who clean their homes and who were free of asthma at the beginning of survey. The results showed that 42 percent of the participants who used cleaning sprays at least weekly experienced asthma symptoms, such as wheezing, or were using asthma medication. The most commonly used products were glass-cleaning, furniture and air-refreshing sprays. The results also indicated that the incidence of physician-diagnosed asthma was higher among those who used the sprays at least four days per week. Cleaning products not applied in spray form were not associated with asthma. These results indicate that frequent use of common household cleaning sprays may be an important risk factor for developing asthma in adults (Zock, Plana, Jarvis et al 2007).

Impact of Cleaning Chemicals on Indoor Environments

What impact do chemical emissions from cleaning products and application processes have on indoor air and on building occupants? To answer these questions requires an understanding that indoor air is a very crowded and intricate place. It not only contains chemicals but also particles; viruses and bacteria; allergens and endotoxins; microscopic organisms such as dust mites; water vapor molecules (moisture); dust, and mold hyphae and spores to name a few examples. Among the most prevalent of all indoor air constituents are VOCs, with as many as 100 to 1,000 different VOCs in the air where people can easily inhale them. Some VOCs can cause eye, nose and throat irritation; cough; headache; general flu-like illnesses; skin irritation; and some can cause cancer. Others produce odors that may be objectionable.

Complicating matters is the potential for interactions of VOCs with other chemical compounds to form a third compound that also may be a threat. As a result, even though the concentrations of individual VOCs may be well below odor thresholds or known toxic levels, their occurrence in complex mixtures may lead to perceived poor IAQ or irritation among those exposed. Because these interactions and reactions among indoor air constituents are occurring constantly, purchasers and users of cleaning products often find it very difficult to manage IAQ and for manufacturers to create and verify that their products have no or low impact, particularly from VOCs.

Air Quality Sciences, Inc. (AQS) has tested the indoor air in hundreds of offices, schools and homes. The results of these studies have confirmed the potential for high levels of VOCs. They also have identified numerous VOCs associated with cleaning products and processes. Table 1 lists some common VOCs found in these indoor environments, along with the types of cleaning products in which they are found.

Table 1. Common VOCs in Indoor Environments

VOC	Types/Use of Products
1,4 dioxane	Spot removers
Acetaldehyde	Fragrance/disinfectants

Acetic acid esters	Surface cleaners
Acetone	Surface cleaners
Butoxyethanol	Surface cleaners
Butyl acetate	Surface cleaners/fragrances
C6 – C10substituted alkanes	All cleaners/polishers/waxes
Dichlorobenzene	Deodorizers
Dipropylene glycol	Surface cleaners
Ethanol	Disinfectants
Formaldehyde	Biocides
Isobutane	Aerosol cleaners
Isobutene	Aerosol cleaners
Isopropanol	Disinfectants
Limonene	Orange fragrance
Methoxyethanol	Surface cleaners
Methoxyethoxyl ethanol	Surface cleaners
Methyl methacrylate	Hard surface cleaner
Naphthalene	Disinfectants/moth repellants
Phenol	Disinfectants
Pinene	Pine fragrance
Propylene glycol	Surface cleaners/aerosols
Siloxanes	Waxes/polishes
Tetrachloroethylene	Dry cleaners
Trichloroethylene	Degreasers/spot removers

Within two hours of certain cleaning processes, the total VOC levels (TVOC) in these environments can increase significantly, ranging from 40 $\mu\text{g}/\text{m}^3$ to 25,000 $\mu\text{g}/\text{m}^3$ (micrograms per cubic meter), and reach levels higher than the acceptable value (500 $\mu\text{g}/\text{m}^3$ or 0.5 mg/m^3) for VOC emissions from cleaning products, established by the GREENGUARD Environmental Institute, an independent third party certification program for low-emitting products used in indoor environments (see *Certifying Green Cleaning Products* below). Numerous other studies have found that individual VOCs and mixtures of VOCs can lead to progressive eye, nose and throat irritation (Mølhave 2000, Otto 1990).

Researchers at the University of California, Berkeley, and Lawrence Berkeley National Laboratory have reported that common household cleaners and air fresheners may emit pollutants at levels that may lead to health risks. The investigators focused on products with ethylene-based glycol ethers, which are common, water-soluble solvents used in a variety of cleaning agents, latex paints and other products. The US Environmental Protection Agency's (US EPA) 1990 Clean Air Act Amendments classifies ethylene-based glycol ethers as hazardous air pollutants and by California's Air Resources Board as toxic air contaminants (Nazaroff et al 2006).

Other studies have shown that certain VOCs may react with ozone to produce a number of toxic compounds. For example, d-limonene and other terpene compounds, used in polishes, scented deodorizers, cigarettes, fabrics and fabric softeners, can readily react with low concentrations of ozone, brought in from the outdoors or produced by ionizing air cleaners. This reaction creates aldehydes and ultrafine particles, which can be irritating to building occupants (Sarwar et al 2002; Weschler and Shields 1999; Wolkoff et al 2000, Apte and Erdmann 2002). The results from another study demonstrated that a mopping agent containing terpene generated vast numbers of ultrafine particles in a reaction with ozone. The results also showed that 10 minutes of mopping with this agent influenced indoor particle concentration for more than 8 hours (Long et al 2000).

Researchers at the University of California also ran a series of experiments to determine the levels of chemical exposure people might have when using the cleaning products in a confined space. The tests were conducted in a 230-square-foot room with ventilation at an ordinary level, which provided approximately one air change every two hours. In some tests of terpene-containing products, ozone was introduced into the room at levels mimicking those that could occur in households or offices. The products were used in different ways, according to package directions: some at full-strength and others at various dilutions as recommended on their labels (Nazaroff et al 2006).

The tests produced various results, some reassuring and some raising concerns. The results that raise concern show that in several realistic use scenarios, building occupants could be exposed to potentially dangerous levels of toxic pollutants. For example:

- In cleaning a small, moderately well ventilated bathroom, the team found that a person who spends 15 minutes cleaning scale off of a shower stall could inhale three times the “acute one-hour exposure limit” for a particular glycol ether, as established by the California Office of Environmental Health Hazard Assessment.
- Under a multi-house cleaning scenario, a professional home cleaner, cleaning 4 houses a day, 5 days per week, 50 weeks per year, would take in about 80 µg per day of formaldehyde, double the guideline value set by California’s Proposition 65. In addition, the person’s intake of fine particulate matter during the hours spent cleaning would exceed the average federal guideline level for an entire year (Nazaroff et al 2006).

Recent epidemiologic studies have strengthened the evidence that people who work in domestic or industrial cleaning are at higher risk of developing asthma than professional employees in Europe and the United States. These studies took into account age and cigarette smoking, as environmental tobacco smoke is a significant risk factor for asthma. Increased risk of asthma has also been associated with some specific job tasks, such as cleaning windows and washing dishes (Jaakkola and Jaakkola 2006, Ramon 2007).

Poor IAQ in Schools Risks Health, Affects Learning and Productivity

Given the discussion above, it is not surprising that exposure to VOCs from cleaning products and other sources in offices and other business establishments can cause building occupants to feel uncomfortable, distracted or sick to the point that it interferes with their ability to do their work or reduces their motivation to work (Heerwagen et al). Missed work days or days with reduced activity can cost businesses billions of dollars in lost productivity (Dixon 1985, Fisk 2000, AAAAI 2005). Another major concern, however, is children’s exposure to VOCs from cleaning chemicals and other sources in schools. Children are at particular risk for health

problems from inhaling VOCs, because they breathe in more air with respect to their body mass than adults and thus have greater exposure to indoor environmental pollutants. Teachers and staff also are at risk from poor IAQ in schools.

According to the US EPA, 20 percent of the US population (55 million people) spends a significant amount of time each day public and private schools. The US EPA also estimates that 50 percent of the more than 120,000 schools in the US have IAQ problems. Other professional organizations and government agencies have reported similar findings in more than 20 years of monitoring conditions in schools. These findings are summarized in the National Research Council of the National Academies' interim report, *Review and Assessment of the Health and Productivity Benefits of Green Schools* (National Research Council 2006).

As a part of its review and assessment of the health and productivity benefits of green schools, the National Research Council also found "a robust body of evidence indicating that the health of children and adults can be affected by air quality in a school," and "a growing body of evidence [suggesting] that teacher productivity and student learning, as measured by absenteeism, may be affected by indoor air quality as well" (National Research Council 2006). The California Air Resources Board (CARB) reached a similar conclusion in its report to the California Legislature on the quality of indoor air in that state (CARB 2005).

Consequently, poor IAQ in schools places 10 percent (27.5 million people) of the US population at risk for health problems, such as coughing, eye irritation, headaches, asthma, allergies, and in rare cases Legionnaire's disease, carbon monoxide poisoning and cancer. Among those most at risk are the more than six million students who have asthma. Asthma can be life-threatening if not properly managed, and is the leading cause of school absenteeism and hospitalizations in children under the age of 15. Asthma accounts for an estimated 14 million lost school days and \$16 billion in annual health care expenditures for both children and adults. Asthma also tends to be seasonal, especially among children, with a noticeable spike in asthma-related emergency room visits and hospitalizations in September (Johnston et al 2006, Neidell 2004, AAFA 2005, AAAAI 2005).

For more information about risks to health, learning and productivity from poor IAQ in schools, please see the AQS research report *Reviewing and Refocusing on IAQ in Schools*, which is available from the AQS Aerias IAQ Resource Center at www.aerias.org.

Health, Environmental Protection at the Core of Green Cleaning

In large part, the significant health risks children face from exposure to cleaning products has spurred federal, state and local governments to require the creation of green cleaning programs and the use of green or environmentally preferred cleaning products, especially in schools. Although New York and Illinois are the only two states thus far to require green cleaning in schools by law, other states, such as California, Connecticut, Maine, Massachusetts, Minnesota, New Jersey, New York, Ohio, Oregon, Pennsylvania, Vermont and Washington, and cities, such as Chicago, Washington, DC; Seattle, Washington; and Santa Monica and San Francisco in California, also require the use of green cleaning and green cleaning products in state buildings and schools. In addition, the federal government requires the use of environmentally preferred cleaning products for its buildings. This list is by no means exhaustive, but offers a clear indication of the extent green cleaning and the use of green cleaning products are catching on in the US. In addition, the US Green Building Council (USGBC) (LEED) standard for existing buildings (LEED-EB) requires the use of green cleaning products to achieve credits for certification.

Although there is no set legal or regulatory definition as to what is “green” or “green cleaning,” the concept itself is straightforward. An overall green cleaning program applies a holistic approach to cleaning and focuses on cleaning effectively to create healthier buildings and reduce outdoor environmental impacts. Both factors must be considered in making decisions about green cleaning products and services. An effective green cleaning program also requires shared responsibility between manufacturers, distributors, cleaning personnel, building owners and managers, and building occupants, with the overall goal of getting everyone involved in caring for the buildings in which they live, work or go to school (Ashkin and Holly 2007). Even though the concept of green cleaning is straightforward, navigating through a myriad of often confusing marketing claims associated with green cleaning products is not. The following discussion reviews some of the issues.

Lack of Credibility, Availability, Upfront Costs. Part of the problem is that 5 to 10 years ago, green cleaning chemicals were either too expensive or did not work well. Further, unprincipled marketers promoted green cleaning products that were “little more than colored water,” which severely impacted the credibility of using environmentally friendly cleaning products. In response to marketplace demands, however, technology has improved and manufacturing volume has increased such that every major cleaning chemical manufacturer to some degree offers green cleaning products. As a result, green cleaning products are becoming more readily available and the purchase prices between these products and traditional cleaning products are beginning to level out (Ashkin and Holly 2007). See the discussion below on *Natural Does Not Necessarily Mean Effective or Safe* for more about possible hidden costs of using green cleaning products.

Lack of Clear Definitions. Another part of the problem is the lack of legal and regulatory definitions of green as well as the misuse and misunderstanding of the terms “natural,” “synthetic” and “artificial” to describe cleaning chemicals. The following offers clear definitions:

- **Natural:** Substances or chemicals that are produced or exist in nature. Products that carry the “natural label” generally fall into two categories: Those products that use natural materials to produce a product that would appear on its own without human intervention or those products that are made from natural ingredients but would not otherwise exist without human intervention.
- **Artificial:** Substances or chemicals that are made by humans. Artificial products can be made from natural ingredients, but require human action or intervention to be created.
- **Synthetic:** Substances or chemicals that require human intervention and are produced by a chemical synthesis, not by natural processes. Synthetic products are made from ingredients that do not occur in nature or if they do occur in nature that do not occur independently, meaning that a chemical process is required to separate the substance or chemical from its original source (DesJardins 2000).

Where making clear distinctions between these terms gets tricky is synthetic ingredients can be made from natural sources. Even though palm oil, palm kernel oil, inedible tallow and oleochemical surfactants are often called “natural” and petrochemical surfactants, such as linear alkylbenzene sulfonate (LAS), derived from crude oil, are referred to as “synthetic,” both crude oil and vegetable-based oils originate in nature, making all feedstocks technically “natural” (CLER 1996).

Natural or Green Does Not Necessarily Mean Effective or Safe. Many marketing claims have lead consumers to equate “natural” or “green” with safe and effective. When it comes to cleaning chemicals, this may not always be true. In some cases, natural (or green) chemicals used in cleaning products may not clean as effectively as the same amount of their synthetic counterparts. As a result, a greater amount or a more concentrated solution of a natural cleaner may have to be used to achieve the same level of cleaning as a conventional (synthetic) cleaner, which could raise the overall cost of using these products and may have a greater environmental impact as more or a stronger concentration of the product is washed into the outdoor environment. In addition, cleaning products with natural chemicals also can emit VOCs, and because more or a greater concentration of the product may need to be used to achieve the same level of cleaning as compared with cleaners with synthetic chemicals, more VOCs may be introduced into the indoor environment, thereby potentially causing greater risk of adverse health problems for building occupants.

For example, terpenes are a class of VOCs derived from plant oils and are widely used in cleaning products as solvents and to create pleasant fragrances. As noted, researchers at the University of California, Berkeley, and Lawrence Berkeley National Laboratory found that terpenes emitted from cleaning products can react rapidly with ozone, which may be brought into the indoor environment via the ventilation system or may be emitted from some types of air cleaners, photocopiers and printers. In this study, application of a pine-oil based cleaner produced an average concentration of 10 $\mu\text{g}/\text{m}^3$ to 1300 $\mu\text{g}/\text{m}^3$ for terpene hydrocarbons and terpene alcohols. Exposing these compounds to ozone, both in bench-scale chamber testing and simulated use, produced formaldehyde and hydroxyl radical, which in turn created an array of other indoor chemical reactions, including an aerosol of fine particles like those found in smog and haze, all of which raises the risk of health problems of those exposed (Nazaroff 2006).

Certifying Green Cleaning Products

To assist commercial users and consumers make more informed decisions and manufacturers create better products and application processes, several green cleaning standards from Green Seal, the Environmental Choice Program (ECP) and the GREENGUARD Environmental Institute have been developed. Both Green Seal and the ECP focus primarily on VOC content, while GREENGUARD Certification focuses exclusively on VOC emissions from cleaning products and their impact on human exposure (see the discussion below on *VOC Emissions Pollute; Not VOC Content* for more details).

GREENGUARD Certification requires that products undergo VOC emission performance testing for more than 2,000 individual VOCs. This difference is critical and is discussed in detail below (see the section on *VOC Emissions Pollute; Not VOC Content*). All individual VOCs detected must not exceed acceptable risk levels established by key global public health organizations and programs including the American Conference of Government Industrial Hygienists (ACGIH); the International Agency on Research of Cancer; National Toxicology Program; California’s Proposition 65 (CA Prop 65) and Section 1350 environmental requirements; and the US EPA.

Table 2 (see next page) contains the emissions testing criteria for GREENGUARD Certification on cleaning products, which applies specifically to general, glass, bathroom fixtures, floor, carpet and hard surface cleaners, institutional cleaning systems, and aerosol products. Once a product line has been certified, it may carry the GREENGUARD Indoor Air Quality Certified® mark and be listed in the GREENGUARD Product Guide. The GREENGUARD Certification Program requires annual re-certification. The GREENGUARD program does not encourage specially made low emitting products that have to be custom ordered. GREENGUARD Certified

Products are part of the manufacturers standard product offering and can be purchased in small quantities without additional cost. As a member in the consensus process, the GREENGUARD Environmental Institute is working with Green Seal as a partner in the development of any future revision of Green Seal's GS-37 Standard for Industrial and Institutional Cleaners. To learn more about the GREENGUARD Certification Program, visit www.greenguard.org.

Table 2. GREENGUARD Certification Criteria for Cleaning Products

	Short Term (Acute)	Long Term (Chronic)
TVOC (mg/m ³) ¹	≤5.0	≤0.22
Formaldehyde (ppm) ²	≤0.040	≤0.013
Carcinogens ³	NA	Less than the CA Prop 65 NSRL and the EPA IUR
Chronic non-cancer toxins ⁴	NA	Less than the ATSDR MRL, the CA CREL and the EPA RfC
Acute non-cancer toxins ⁵	Less than the ATSDR MRL and the CA AREL	NA
Developmental / reproductive toxins ⁶	Less than the CA Prop 65 MADL, the ATSDR MRL and the CA AREL	NA
Other individual VOCs	Less than the ACGIH STEL/C (or less than 1/10 TLV if no STEL/C)	Less than 1/100 ACGIH TLV and less than ½ CA CREL

NA = Not Applicable

1. Defined to be the total response of measured VOCs falling within the C6 – C16 range, with responses calibrated to a toluene surrogate.
2. Short-term level based on the ATSDR Acute Duration Minimal Risk Level (MRL). Long-term level based on ½ CAL-EPA 1-hour Reference Exposure Level (REL).
3. Compared with CA Prop 65 No Significant Risk Levels (NSRLs) and EPA Inhalation Unit Risk (IUR) (cancer potency factor). Excludes formaldehyde, which is covered by (2) above.
4. Compared with the EPA Reference Concentration (RfC), CA CREL and the ATSDR Intermediate or Chronic Duration MRL. Intermediate MRLs shall be used if a Chronic MRL is not available for that compound. Excludes Developmental and Reproductive endpoints (see Developmental / Reproductive Toxins).
5. Compared with ATSDR Acute Duration MRL and CA Acute Reference Exposure Level (AREL). Excludes Developmental and Reproductive endpoints which are covered by Developmental / Reproductive Toxins in (6) below.
6. Compared with CA Prop 65 Maximum Allowable Dose Levels (MADLs) for Chemicals Causing Reproductive Toxicity, CA ARELs and ATSDR MRLs for chemicals with Developmental or Reproductive endpoints.

VOC Emissions Pollute; Not VOC Content

When seeking to reduce VOC levels in indoor air, it is important to realize that many “low-VOC” products, even those certified as green or environmentally friendly, are rated by their VOC

content not by their VOC emissions. Measuring VOCs by weight or content (usually measured as grams per liter minus water) does not give a clear picture of how much of a particular VOC or the total amount of all VOCs (TVOC) from a product may be getting into the air. Nor does it give an accurate picture of how VOC emissions from a product will affect the total VOCs in the area in which it is being used. The only way to be sure a product does not emit high levels of VOCs is to actually measure VOC emissions (usually measured as micrograms per square meter per hour) through emissions test methods like those used in the GREENGUARD Certification program. It is the VOC emissions that contribute to indoor air pollution, not the VOC content.

This is especially critical with cleaning products as potential exposures are directly related to how a product is used. A product may have 10 percent VOCs by weight, which may be low enough to classify it as green or environmentally friendly. But, if that product is packaged as an aerosol, it will atomize the VOC particles during use, which increases the potential for exposure. Atomized particles are smaller and lighter, which means they can be inhaled more deeply into the lung, stay suspended longer in the air than larger, heavier particles, and can travel around an indoor environment easier via the heating, ventilating and air-conditioning system. If this same product is delivered using a trigger sprayer, coarse mist, stream or in a bucket, the risk for exposure diminishes as the particles become progressively larger and heavier and will fall to the ground more rapidly than smaller, lighter particles (Ashkin 2005).

Another critical consideration is some manufacturers may reformulate their products to become environmentally friendly by substituting longer-chained hydrocarbons to lower TVOCs in the short-term. Within families of organic compounds, such as acetates, ketones, alkylbenzenes and aldehydes, more carbon atoms usually translate into an increased odor and potential for irritation (Cometto-Muñiz and Cain 1992, Cometto-Muñiz et al 1998). Even though these larger molecules tend to have lower vapor pressures, they continue to emit VOCs over a longer period of time. As a result, focusing on short-term TVOC may have the undesired effect of making the quality of indoor air worse in the long run (Spengler et al 2000). In addition, some VOCs emitted by green products are not listed under the US EPA's definition of VOCs, because they do not contribute to ozone formation in outdoor air.

Going to the Next Level

Manufacturers, building owners, facility managers and commercial cleaning companies have made significant and commendable progress in recent years in their efforts to maintain healthier indoor environments through environmentally friendly cleaning products and deep cleaning processes. The cleaning industry, however, is responsible for minimizing exposures to VOCs emitted from its products. In addition, government mandates, market pressures from foreign competitors and a growing awareness of the connection between VOC emissions and adverse health impacts means it is no longer sufficient to just monitor VOC content.

To meet market demand and reduce product liability risks, product manufacturers will increasingly need to demonstrate their products' safety by testing and monitoring VOC emissions to ensure their products emit low levels of VOCs. In some cases, they may face the potential of reformulating those products that do not comply with acceptance limits.

The most reliable and scientifically proven way to test for VOC emissions and product performance is by using environmental chamber technology (ECT), which allows a product to produce emissions similar to the way the product would emit in a home, office or school. The collected data is then mathematically modeled to determine exposure concentrations produced by product application in many different indoor environments. The method also is scalable to

cleaning products used in the home in addition to products used in large industrial or institutional facilities, in conjunction with air sampling (Daggert et al 2007).

The method was recently evaluated in a study of cleaning products, tools and cleaning procedures with defined application processes, including the following:

- Glass cleaner, floor cleaner, toilet bowl cleaner and multi-surface cleaner
- Mop and microfiber mop pads and microfiber hard surface cleaning cloth
- Cleaning procedures and methodology, as specified by the manufacturer

The study was conducted in a simulated bathroom in a controlled environmental chamber. Two commercial grade toilets, a sink and counter surfaces, mirrors, and partitions were placed in the chamber. Prior to testing, background air samples were collected to provide a baseline. A trained technician then entered the chamber and with the door closed applied the chemicals, using tools and procedures consistent with how professional cleaning would be conducted in a school or office building (Daggert et al 2007).

Emission rates of aldehydes, TVOCs, individual VOCs and phthalates were measured over 48 hours, then modeled to provide airborne concentrations at 4, 8, 24, and 48 hours after product application. Chemicals detected were screened against federal and California lists for chronic and acute non-cancer toxins levels, developmental or reproductive toxin levels, and ACGIH short-term exposure limits. The results demonstrated that there were no carcinogens, chronic non-cancer toxicants, acute non-cancer toxicants, or developmental or reproductive toxicants identified in the 4 hour or 48 hour air samples. The chemicals identified in the air samples included aromatics, alcohols, aldehydes, alkanes, and glycol ethers. Airborne chemicals with threshold limit values (TLVs) were at least 1000-fold below the TLV. The results also showed that concentrations were greatest at 4 hours and not detectable at 48 hours (Daggert et al 2007).

The results of this study confirmed that this method offers significant advantages of realistic product application without the disadvantages of field studies where environmental parameters are difficult to control and measure. This method also allows manufacturers to evaluate and identify potential interactions between chemicals in their products formulations as well as assess the effects of tools and procedures on IAQ.

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