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Chemical Emissions of Residential Materials and Products: Review of Available Information

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DISCLAIMER

PREFACE

This report is prepared in the context of a larger program whose mission is to advance understanding of ventilation and indoor air quality in U.S. homes. A specific objective of this program is to develop the scientific basis – through controlled experiments, monitoring and analysis – for health risk-based ventilation standards.

Appropriate and adequate ventilation is a basic element of a healthy home. Ventilation provides outdoor air and in the process removes indoor odors and contaminants including potentially unhealthful chemicals emitted by indoor materials, products and activities. Ventilation traditionally was assured to occur via infiltration of outdoor air through cracks and other leakage pathways in the residential building envelope. As building air tightness is improved for energy efficiency, infiltration can be reduced to inadequate levels. This has lead to the development of standards requiring mechanical ventilation. Though nominally intended to ensure acceptable indoor air quality, the standards are not explicitly tied to health risk or pollutant exposure targets. LBNL is currently designing analyses to assess the impact of varying ventilation standards on pollutant concentrations, health risks and energy use.

These analyses require information on sources of chemical pollutant emissions, ideally including emission rates and the impact of ventilation on emissions. Some information can be obtained from recent studies that report measurements of various air contaminants and their concentrations in U.S. residences. Another way to obtain this information is the bottom-up approach of collecting and evaluating emissions data from construction and interior materials and common household products.

This review contributes to the latter approach by summarizing available information on chemical emissions from new residential products and materials. We review information from the scientific literature and public sources to identify and discuss the databases that provide information on new or low-emission materials and products. The review focuses on the primary chemical or volatile organic compound (VOC) emissions from interior surface materials, furnishings, and some regularly used household products; all of these emissions are amenable to ventilation. Though it is an important and related topic, this review does not consider secondary pollutants that result from reactions of ozone and unsaturated organics bound to or emitted from material surfaces. Semi-volatile organic compounds (SVOCs) have been largely excluded from this review because ventilation generally is not an effective way to control SVOC exposures. Nevertheless, health concerns about exposures to SVOCs emitted from selected materials warrant some discussion.

EXECUTIVE SUMMARY

Chemical emissions from construction materials, interior surfaces, and household products are a major source of indoor air contaminants. Emissions characteristics of building materials have been extensively reported. Several large-scale studies have also been conducted in existing homes to quantify contaminant concentrations; in some cases, information was simultaneously collected about potential contaminant sources. In recent years, awareness of health risks associated with hazardous indoor air contaminants has triggered a growing public health concern. However, health-based standards or guidelines to ensure good indoor air quality, and regulations to control the production of potentially hazardous materials are still lacking in the U.S. To fill this void, various organizations—including government agencies, professional societies, and industry associations—have developed guidelines, standards, and rating schemes for ventilation, material emissions, and related areas.

As new homes are built and existing homes are retrofitted to reduce infiltration air exchange, accumulation and exposure of occupants to indoor air pollutants is becoming an even greater concern. To address this concern, home labeling schemes have been introduced by state and federal regulators. These schemes include use of low-emission materials as a standard criterion. In parallel, certification systems for low-emission materials have been introduced by various organizations including commercial entities. However, there is currently no consensus among these labeling and certification systems on the criteria or performance levels that define low emissions. Emissions data from new materials and products are not consistently available, and databases for U.S. products are either not updated or incomplete. A comprehensive understanding of emissions characteristics of new materials and products, including how emissions may change over time, is needed.

This report aims to provide an overview of the current state of information available from various resources on chemical emissions from residential construction and surface materials. Our review also covers some household products. In describing the state-of-the-art information, this review focuses on: (1) the characterization of emissions from recently developed materials and products, (2) the identification of new target contaminants with hazardous properties for evaluation in new homes, and (3) recent and current activities related to source control to reduce chemical emissions from materials. Information was compiled from peer-reviewed journal articles, technical reports from government institutions and organizations, on-line databases, web pages, and software data libraries.

Several major home labeling programs are currently available in the U.S. The U.S. Environmental Protection Agency (EPA) launched the Indoor airPLUS home labeling program in 2009, a significant milestone in the effort to assist homebuyers in identifying residences with good indoor air quality. The program recognizes new homes equipped with a comprehensive set of Indoor Air Quality (IAQ) features, which includes use of low-emission materials and coatings. Other major programs are the Leadership in Energy and Environmental Design (LEED) rating for Homes from the U.S. Green Building Council and the National Green Building Standard (NGBS) from the National Association of Home Builders (NAHB).

Various organizations and testing laboratories certify low-emission materials. In California, testing methods and performance criteria are based on California Department of Public Health Standard Method (Section 01350), "Standard Method for the Testing and Evaluation of Volatile

Organic Chemical Emissions from Indoor Sources Using Environmental Chambers." The standard is gaining nationwide acceptance as the benchmark. It was first established for commercial buildings such as offices and schools; a section for new single-family residences was added later. Scientific Certification Systems (SCS) and the GREENGUARD Environmental Institute (GEI) are two major certification organizations in the U.S. with substantial databases on low-emission materials and household products.

Lists of certified low-emission materials or products are also compiled by other organizations. The information is generally available through their websites. These include the Low Emitting Materials Table from the Collaborative for High Performance School (CHPS) developed in partnership with the EPA (a report on emissions characteristics of new materials and their older counterparts using California Specification 01350 is available through the CHPS program), the LEED Green Building Rating Systems, and the Pharos Project materials rating system from the Healthy Building Network (HBN).

The information and level of detail provided by each organization varies greatly, from a simple materials and products list (with links to manufacturer websites) to a searchable database with summaries of chemical constituents and total emissions. Information on emissions characteristics, such as emission rates and measured concentrations, is generally not available because of non-disclosure agreements between the certification bodies and product manufacturers. At best, the available information allows for identification of new target compounds of concern based on toxicity and frequency of occurrence within a material or product category.

In Europe, efforts to characterize low-emission materials have resulted in more than 10 labeling systems for various materials and products categories, each based on different testing methods and threshold values. The following are examples of these labeling systems: the EU flower, EMICODE, M1 classification, Blue Angel, Ecolabel, and Nordic Swan. As part of the European Commission policy-making process, there have been active efforts to harmonize indoor materials labeling schemes during the past five years, as recommended in European Collaborative Action (ECA) Report no. 24. As is the case in the U.S., European certification and rating systems do not report detailed chemical emissions data for new materials and products.

The few existing databases that include detailed emissions data for residential materials and products are not up to date. For example, EPA compiled measured emissions from indoor sources based on 72 references through May 1999, which was later named the Sources of Indoor Air Emissions (SIAE) database. The database includes 8,490 emission rates representing 78 types and 17 categories of materials. To date, this is still the most comprehensive database compiled from published articles, but an updated version is urgently needed. More recently, the France Research Agency (FRA) funded the development of an indoor air pollutant emissions database called PANDORA. This database includes occupant activities and home products categories. It also differentiates materials and products according to study location, for example residence, office, and hospital. A five-year European project called Prioritization of Building Materials as Indoor Pollution Sources (BUMA) was completed in 2009. A main deliverable of this project is a comprehensive database containing up-to-date data on chemical emissions from construction products and other building materials used in Europe. One of the main objectives of this database is to identify a list of prioritized building materials with respect to hazardous compounds emission factors and relevant exposure levels. The database currently has information for more than 400 construction products and materials. In Canada, the National Research Council (CNRC) incorporated into the IA-QUEST software package emissions data for 245 contaminants and 50 types of materials. The U.S. National Institute of Standards and Technology (NIST) combined databases from EPA, CNRC and other publications into the indoor air quality model called CONTAM. The emissions data library for each material can be retrieved with CONTAM software.

Information about materials and products composition is needed to support the assessment of emissions, resulting exposures, and associated acute and chronic health effects. The U.S. Department of Health & Human Services (HHS) has compiled a comprehensive list of household products including surface finishing materials. HHS's website includes chemical compositions based on material safety data sheets (MSDSs) and product labeling, acute and chronic health effects and safety ratings, manufacturer data, and handling and disposal information. HBN's Pharos Project has taken a similar approach in developing their database but with a different rating/scoring scheme. Ratings are based on health impacts of VOCs, materials renewability, and toxic properties of each substance. At the moment, the Pharos Project database does not include household products, and, because the rating scheme is based on certifications and voluntary participation, emissions data are not available.

In the past, most emissions databases used information published in peer-reviewed journals as their main source of information. However, journal publications on materials emissions have decreased substantially during the past five years, and data on residential materials are even more deficient. This review cites studies conducted from 2001-2010 and compares the chemicals reported in those studies to existing databases to identify compounds of interest for exposure assessment.

This report highlights key results from emissions studies of flooring systems including polyvinyl chloride (PVC), carpet with backing, and wood-based flooring during the publication years 2001-2010. Newly installed PVC flooring emits aromatic hydrocarbons more than other groups of chemical compounds; however, one year after installation of flooring, aliphatic hydrocarbons dominate emissions. Several phthalates of health concern were also detected from flooring materials, for example, DEHP and DBP, which are listed as Hazardous Air Pollutants (HAPs) by EPA. Diisocyanate – a HAP and toxic contaminant – was detected in carpet with polyurethane foam backing. EPA has recently cautioned against Methylene diphenyl diisocyanate (MDI) exposure during the application of spray polyurethane foam insulation. Some of the risks of diisocyanate exposure include work-related asthma and sensitization. Because of its large production volume and high detection in emissions from various materials, Texanol has been suggested as a chemical that should be reviewed more carefully for toxicity and exposure assessment.

Water-based paints were reported on more than any other type of surface finishing during the past 10 years. Emission factors from wet surfaces depend greatly on the sorbent properties of the underlying material. One study found that ethylene glycol concentrations remained 15-20 times higher than the detection limit three months after the application of various types of wet-based paints. For solvent-based paints, 2-butanonoxime has been identified as a VOC of concern because of its carcinogenic properties; for water-based paints, formaldehyde and acetaldehyde exposures have been considered cause for concerns because of the chronic health risks associated with both compounds. Potential hazards associated with chemical emissions from paint were summarized by EPA in a 2001 report.

TABLE OF CONTENTS

1. INTRODUCTION

Most people spend the majority of their time indoors, commonly in the home. Young children, socially isolated seniors, caregivers, and individuals who work from home offices are among those who spend the vast majority of their time at home whereas school-age children and working adults typically spend 12-16 hours at home each day. Given how much time people spend at home, achieving and maintaining good indoor air quality in residences is, without a doubt, a key priority. An important step toward this goal is to use building materials that do not emit hazardous quantities of chemical contaminants into the air. As awareness of exposure risks has increased, interest in chemical emissions from building materials and consumer products has grown over the past decade.

This report lists and discusses resources that provide various types of archival and more recent information on emissions from residential materials and household products with a focus on low-emission materials. We address the level of detail and key information provided in these resources. Our search and review process aimed to address the following key topics: (1) the characterization of emissions from new materials and products, (2) the identification of new target contaminants with potentially hazardous properties, and (3) the evaluation of source control as a control mechanism.

This review was carried out by researchers in the Environmental Energy Technologies Division of Lawrence Berkeley National Laboratory (LBNL) as part of a multi-phase research study on ventilation, indoor air quality and energy in new U.S. homes. This study's goal is to provide key directives for improving the indoor air quality and energy performance of the U.S. housing stock. The current report complements a hazard assessment that compared existing data on pollutant concentrations in homes to health-based concentration standards (Logue et al., 2010). The outcome of that study was a list of compounds that are present at hazardous levels either commonly or in a non-negligible set of circumstances. The current report is intended to aid identification of additional chemicals of concern and factors that influence emissions.

Our preliminary search reveals that databases on emissions from materials and products are neither comprehensive nor up to date. Furthermore, most databases assume products and materials are universally applied in both commercial and residential environments. Although this may be true for a select list of materials or products, it may not be the case for other materials or products that are designed, manufactured, or treated according to functional and economic requirements for offices, retails, schools, hospitals, and residences.

We begin this report by discussing the ongoing initiatives for reducing indoor pollutant levels in residences. These initiatives encompass materials testing guidelines, exposure limits, labeling, and certification systems. A common by-product of these initiatives is a database of materials and products certified or approved under the relevant label or guideline. These databases include the newest materials and products because manufacturers only submit the latest ones most likely to pass or produce the best test results due to the high costs associated with third-party testing. This means that the information available from the databases better represents the materials and products available in the market today. However, there are several limitations associated with these databases. These limitations are discussed in this report, and recommendations are offered for improving and synchronizing databases.

This report also highlights several databases compiled in the past that are still commonly used as sources of information. Some exist as materials libraries in indoor air quality simulation programs. Original research articles from peer-reviewed journals prior to the year 2000 are often cited as the main resources of these databases. We conducted a systematic search from the same scientific sources and identified reports on materials and products emission testing between 2001 and 2010. This report compiles the results from this search and summarizes the chemical emissions from various materials and product categories; as part of this process, we note several chemicals that have recently been identified as likely or possible contaminants of concern.

2. SCOPE

Residential materials considered in this review are building materials applied or fixed within the enclosure of a home. This includes surface materials that significantly contribute to the chemical constituents in the indoor environment, such as, but not limited to, wallboard, plasters, paints, and, most importantly, floor coverings. Structural materials within walls and external surfaces are not included.

A myriad of household products are used in homes, ranging from liquid point sources such as glue and nail polish to aerosolized sources such as air freshener and hair spray and to large-surface-area applications such as floor cleaner, disinfectant, and floor and furniture polish. This review focuses only on the chemical emissions data related to aerosolized mixtures and interior-surface-application products. Logically, these would have greatest potential to be significant pollutant sources in homes.

This review primarily focuses on volatile organic compounds (VOCs) released from chemical ingredients used in residential materials and household products. Inclusion of semi-volatile organic compounds (SVOCs) is beyond the scope of this review because their emissions are not typically controlled with ventilation (Weschler and Nazaroff, 2008), but we give some attention to SVOCs where they make up a significant portion of emissions from specific sources. Because one of the objectives of this review is to highlight potential new target compounds for future field studies, total volatile organic compound (TVOC) data are considered less important and are not discussed in detail. We do not include the sensory evaluation of chemical emissions in this review because the information pertaining to materials or products used in the U.S. is largely unavailable. Information on the sensory evaluation aspects of materials or products emissions has been mostly generated in the European region.

The following describes the main scope and limitations of this review:

- ☐ For website resources, we considered only information provided by government institutions, certified laboratories, recognized certification systems, and major organizations on new, low-emission or eco-friendly materials and products. We highlight the data fields from each database. It is not our intention to produce a comprehensive database of materials and products emissions from these resources.

- ☐ This review provides information regarding data availability, differences in the use of testing methods, data analysis, and benchmarking guidelines related to testing of materials for pollutant emissions characteristics.

- ☐ Reviewed scientific publications on materials and products emissions may include those from non-residential settings. Many publications do not include details about the source or application of the tested materials or products because of conflicting interests or non-disclosure agreements. By contrast, information on manufacturers and the application of their materials or products is mostly available from the certification system databases as part of marketing tools.
- ☐ This review only considers publications with emissions data for flooring, wall, and finishing materials and some household products between 2001 and 2010. However, review articles dating from before this period are discussed.
- ☐ The following particular hazards are not covered: lead, radon, asbestos, tobacco smoke, pesticides, and particulate matter.
- ☐ This review focuses on primary emissions and does not include a review of secondary emissions associated with indoor chemistry.

3. HOME LABELING AND GREEN HOME STANDARDS

Controlling emissions of unwanted chemical substances through selection of low-emission materials or products is an important step toward good indoor air quality in homes. This requires participation of builders, which implies the need to balance between higher initial costs and long-term marketing benefits. Government institutions and certification bodies recognize this issue.[1] The home labeling program is one of the main efforts to address the issue; this program includes low-emission materials as one of its requirements, which makes materials testing and rating schemes important to manufacturers. Both home labeling and materials certification can be viewed as the umbrella programs in the progress towards achieving healthy homes.

3.1. Home labeling program

3.1.1. U.S. Environmental Protection Agency Indoor airPLUS

In 2009, EPA launched the Indoor airPLUS home labeling scheme with the intention of helping builders meet the growing preference for homes with good indoor air quality. Currently, Indoor airPLUS is the only national specialty label that addresses the issues related to home indoor air quality in the U.S. The reporting process for airPLUS has recently been integrated with the ENERGY STAR home energy efficiency rating system. Indoor airPLUS has also been adopted by the U.S. Green Building Council; it merits “green” points for indoor air quality under the council’s Leadership in Energy and Environmental Design (LEED) for Homes program. The LEED rating system says:

LEED for Homes will treat certification under Indoor airPLUS as equivalent to certification under the Indoor Air Package: EQ 1 earned with Indoor airPLUS is worth 13 points.

[1] http://www.epa.gov/indoorairplus/video/transcript_homebuyer_concerns.txt

Projects registered after June 23, 2009 must use Indoor airPLUS to earn EQ 1. (EQ 01-03).

To attain the Indoor airPLUS label, a home must meet technical specifications for the following: moisture control systems; heating, ventilating, and air-conditioning (HVAC) systems; combustion-venting systems; radon-resistant construction; pest control and low-emission building materials. The requirements checklist comprises 37 items to be verified by the contractor and a third-party rater. The following items are directly related to materials VOC emissions and common pollutants such as formaldehyde:

- Certified low-formaldehyde pressed wood materials used (i.e. plywood, OSB, MDB, cabinetry) (Section no. 6.1)
- Certified low VOC or no VOC interior paints and finishes used (Section no. 6.2)
- Carpet adhesives that qualify for [Carpet and Rug Institutes] CRI Green label plus or Green label (Section no. 6.3)

Other airPLUS items related to the ventilation system that potentially affect emissions from materials and indoor VOC concentrations are as follows:

- Whole-house ventilation system installed to meet [American Society of Heating, Refrigerating, and Air Conditioning Engineers] ASHRAE 62.2 requirements (Section no. 4.5)
- Local exhaust ventilation to outdoors installed for baths, kitchen, clothes dryers, central vacuum system, etc. (Section no. 4.6)
- Central forced-air HVAC system(s) have minimum MERV 8 filter, no filter bypass, and no ozone generators (Section no. 4.7)

The Indoor airPLUS program currently does not include active documentation of the emission characteristics in the certified homes, which may be available through third-party evaluator.

3.1.2. U.S. Green Building Council Leadership in Energy and Environmental Design (LEED) for Homes

LEED for Homes is a consensus-developed, third-party-verified rating system that provides a basis for quantifying the benefits of high-performance green homes.[2] LEED-certified homes are designed and constructed based on guidelines for eight categories: site selection, water efficiency, materials and resources, energy and atmosphere, indoor environmental quality, location and linkages, awareness and education, and innovation.[3]

As mentioned in Section 3.1.1, LEED has recently incorporated the Indoor airPLUS program as the label for obtaining LEED points for Indoor Environmental Quality equivalent to LEED certification under the Indoor Air Package: EQ1 (13 points).

[2] www.usgbc.org

[3] U.S. Green Building Council (2010) Leed for Homes Rating System (http://www.leed.us/ShowFile.aspx?DocumentID=3638)

Beyond EQ1, LEED for Homes specifies other requirements that affect emissions characteristics in homes. For example, under the Energy and Atmosphere (EA) category, a section on air infiltration specifies reduction of home leakage (EA2). The Materials and Resources (MR) category describes measures for efficient use of framing materials and application of environmentally preferable products (low emission, recycled and locally produced). The Indoor Environmental Quality (EQ) category maps out two major pathways to achieving good indoor air quality. By adopting Indoor airPLUS, home builders have the option to follow a simplified checklist to obtain minimum EQ points. Outdoor air ventilation, local exhaust, air filtering and distribution, and contaminant control are all part of the EQ requirements and determine the home emissions characteristics.

Another important aspect of LEED for Homes is that the rating is adjusted for home size. This adjustment is meant to account for changes in materials and energy consumption relative to the home size over the home's lifecycle. A 100% increase in home size results in a 40% to 90% increase in materials usage, depending on the home design. To adjust for this, a curve model is introduced so that it is easier for smaller homes to reach LEED for Homes certification than it is for larger homes. This implies that home builders are required to exert greater effort in materials selection and control of indoor concentrations in larger homes.

To facilitate communication among home owners, consultants, and builders with regard to understanding the LEED for Homes program and promoting green features for homes, the U.S. Green Building Council has set up a website: http://greenhomeguide.com/ (still in beta version) that provides many resources related to currently available low-emission materials.

3.1.3. National Association of Home Builders (NAHB) National Green Building Standard™ (NGBS)

This first residential green building rating system to receive American National Standards Institute (ANSI) approval, NAHB-ICC-700-2008, was the result of a partnership between National Association of Home Builders (NAHB) and the International Code Council (ICC) in 2007 to establish a nationally recognizable standard definition for green homes, covering single and multi-family homes, residential retrofitting, and site development projects.

Similar to LEED for Homes, the NAHB standard uses a point-based rating and includes a section on indoor environmental quality. NAHB performed a study to compare the costs and technical requirements for compliance to NGBS and LEED.[4] For obtaining the first level of compliance to LEED for Homes, the costs are approximately three times as high as for meeting the NGBS. Higher overhead and programmatic costs are also associated with LEED certification, such as for registration, verification, and certification.

NGBS Scoring for New Construction, released in July 2010,[5] provides a complete checklist of the point-based scoring system. Standards that must be met to for low-emissions certification for wood-based products, carpets, hard-surface flooring, wall

[4] NAHB Research Center (2008) Green Home Building Rating Systems – A Sample Comparison

[5] http://www.nahbgreen.org/ScoringTool.aspx

coverings, architectural coatings, sealants and adhesives, cabinets, and insulation materials are specified in detail, including the accruable points. Other measures that may affect indoor pollutant concentrations include ventilation strategies, filtration, moisture control, and point exhaust systems. NAHB refers to various testing and certification systems for the materials selection process and does not maintain databases of materials used in the certified construction.

3.2. Local program ratings

An October 31, 2008 article published on the *New York Times* website reported that some home builders are concerned about the costs and paperwork involved in getting LEED for Homes certification.[6] Alternative rating systems such as the NGBS and state-based certifications are preferred for cost effectiveness. Already, the NAHB research center partners with Home Builders Associations from 28 states and offers local educational opportunities for builders and home owners about NGBS.[7] We conducted a search of local home rating systems for various states across the U.S. The credits awarded for applying low-emission materials vary from one rating system to another, indicating that new "green" homes in different states may have different levels of indoor pollutant loading. The following are state-level green home programs:

- Arizona (Scottsdale): Green Building Program
  (http://www.scottsdaleaz.gov/greenbuilding/)
- California: Built It Green's GreenPoint Rated
  (http://www.builditgreen.org/greenpoint-rated-new-home/)
- Chicago: Green Homes Program
  (http://www.cityofchicago.org/city/en/depts/doe/provdrs/green/svcs/)
- Colorado: Built Green
  (http://www.builtgreen.org/programs/homes.htm)
- Minnesota: GreenStar
  (http://www.mngreenstar.org/about-minnesota-greenstar/)
- North Carolina: HealthBuilt Homes Program
  (http://healthybuilthomes.org/builders_and_developers.cfm)
- Virginia (Arlington): Green Home Choice Program
  (http://www.arlingtonva.us/departments/environmentalservices/epo/environmentalservicesepogreenhomechoice)
- Washington: Built Green
  (http://www.builtgreenwashington.org/56/programs-overview.html)
- Wisconsin: Green Built Home
  (http://wi-ei.org/greenbuilt/index.php?category_id=3981)

4. TESTING STANDARDS AND CERTIFICATION SYSTEMS FOR MATERIALS AND PRODUCTS

Controlling the source of pollution is the most effective and commonly recommended method to limit harmful effects of indoor pollutants on residents. Guidelines, home ratings, and regulations, as discussed in previous sections, are utilized to ensure that materials or products that

[6] http://green.blogs.nytimes.com/2008/10/31/green-home-rating-systems/
[7] http://www.nahbgreen.org/WhoIsGreen/findlocalgreenprogram.aspx

off-gas potentially hazardous pollutants are either limited or not permitted in the home environment. These efforts must be accompanied by control over use of hazardous substances in the manufacturing process, improved methods of emissions characterization, and better understanding of the health effects associated with exposures.

Certification systems and testing companies offer various professional services to test and certify materials or products. Services offered include measurements of VOCs and other target pollutants, evaluation of material or product contents, rating of materials or products, reports, and certification. Certified products, particularly in the U.S., are not tested based on sensory assessments or benchmarked against health data and ecological standards. Chemical interactions, which produce reactive compounds or irritants, and presence of SVOCs, VVOC (very volatile organic compounds), and potentially hazardous chemicals require special investigation and are generally beyond the scope of U.S.-based certification systems.

4.1. California Department of Public Health Standard Method (Section 01350) (Standard Method for The Testing and Evaluation of Volatile Organic Chemical Emissions from Indoor Sources Using Environmental Chambers Version 1.1)[8]

Currently, California Department of Public Health Standard Method (Section 01350) is the only health-based standard method widely accepted in the U.S. for building materials and products testing and certification. This standard addresses sampling and test methods, exposure modeling based on material or product application, and benchmarking of exposure limits against the California Environmental Protection Agency (Cal-EPA) Office of Environmental Health Hazard Assessment (OEHHA) list of chemicals with established Chronic Reference Exposure Levels (CREL). The specified test method, sample analysis technique, and model estimation were developed based on ASTM, ANSI, ISO, EPA, and ASHRAE standards. Because of growing concerns over residential exposure risks, the latest revised version of the standard (2010) includes an exposure modeling section for a new single-family residence.

Since the earlier version of the standard was issued in 2004, numerous materials have been tested for low-emission certification based on the standard. However, the test information on materials emissions remains with the certified test laboratories. Because of confidentiality agreements with manufacturers, detailed emissions test results are not disclosed to the public. Other sources of information are manufacturers and certification programs. The later usually maintain publicly accessible materials and products catalogues with limited information.

The standard broadly categorized test specimens into two categories: 1) dry products (applicable to flooring and wall materials, including: vinyl composition tile; resilient floor tile; linoleum sheet or tile; parquet flooring; laminated flooring; carpet roll or tile; wall covering; textile-based covering; insulation batt, roll, or foam, etc.); and 2) containerized products (including paints, adhesives, sealants, coatings, and other wet products). Unlike other testing and specification standards, this standard allows for testing of most types of building materials as well as household products because of its broad categories and

[8] http://www.cal-iaq.org/VOC/CDPH-IAQ_StandardMethod_V1_1_2010.pdf

applications to various types of building environments, i.e. office, school, residence, and others.

This standard defines the maximum allowable concentrations for target contaminants under sections 4.2.1 for volatile organic compounds and 4.2.2 for formaldehyde. The standard states, "to ensure indoor air concentrations are within allowable limits, each individual product category is capped at no more than one-half of the CREL for each chemical in a building type" and "to determine acceptability of the emission results, the estimated building VOC concentrations are compared to one-half their corresponding CREL values." For formaldehyde, the standard stipulates that "the allowable limit for emissions of formaldehyde corresponds to an indoor air concentration not to exceed the full CREL of 9 [microgram per square meter] $\mu g/m^3$ commencing January 1st, 2012. Until that date, one-half of 33 $\mu g/m^3$ will continue to be used as the allowable concentration limit." The list of target compounds and their one-half CREL values is shown in Table 1.

Table 1. Target CREL VOC and their maximum allowable concentrations

No.	Compound Name	Allowable Conc. ($\mu g/m^3$)
1	Acetaldehyde	70
2	Benzene	30
3	Carbon disulfide	400
4	Carbon tetrachloride	20
5	Chlorobenzene	500
6	Chloroform	150
7	Dichlorobenzene (1,4-)	400
8	Dichloroethylene (1,1)	35
9	Dimethylformamide (N,N-)	40
10	Dioxane (1,4-)	1500
11	Epichlorohydrin	1.5
12	Ethylbenzene	1000
13	Ethylene glycol	200
14	Ethylene glycol monoethyl ether	35
15	Ethylene glycol monoethyl ether acetate	150
16	Ethylene glycol monomethyl ether	30
17	Ethylene glycol monomethyl ether acetate	45
18	Formaldehyde	16.5
19	Hexane (n-)	3500
20	Isophorone	1000
21	Isopropanol	3500
22	Methyl chloroform	500
23	Methylene chloride	200
24	Methyl *t*-butyl ether	4000
25	Naphthalene	4.5
26	Phenol	100
27	Propylene glycol monomethyl ether	3500
28	Styrene	450
29	Tetrachloroethylene	17.5
30	Toluene	150
31	Trichloroethylene	300
32	Vinyl acetate	100
33-35	Xylenes (m-, o-, p-xylene combined)	350

4.2. ASTM Committee D22.05 on Indoor Air

ASTM D22.05 currently maintains 34 active standards on topics related to materials, products and activity-related emissions; air cleaning and filtration performance; and personal exposures in various environmental settings. Several ASTM standards on materials testing have been adopted in the California Department of Public Health Standard Method (Section 01350). The main purpose of these standards is to establish consensus on test methods or measurement practices; therefore, they do not specify or attempt to regulate concentration limits for pollutants or emissions characteristics of tested materials or products. Thus, it is beyond the scope of this review to discuss these standards.

Of note, there is currently ongoing Work Item no. 28325 under ASTM D22.05, which aims to establish the method for estimating inhalation exposures in low-rise residences as the result of VOC emissions from new building products, furnishings, and consumer products. Based on the short description provided, it appears that the new proposed standard is likely to adopt the scenario-based approach used by the California Green Building Specification Section 01350. The proposed standard will contain standardized scenarios that include information on building sizes and configurations, occupancies, interior space characteristics, surface materials loading, use of consumer products, quantity of furnishings, and air change rates for new or existing residences that represent single-family homes and low-rise multifamily apartments. This information will be used as input parameters to facilitate estimation of VOC inhalation exposure concentrations by means of indoor air quality modeling and to compare the impacts of materials, furnishings, and consumer products. Similar to the California Green Building Specification Section 01350, this standard practice will be useful and will likely influence manufacturers, product certification and home labeling systems, and residents and home buyers. It is envisioned that a by-product of this standard will be a comprehensive database of materials and products specific to the residential setting, with corresponding emissions data.

4.3. Materials emissions testing and labeling

This section reviews resources from various certification and labeling systems in the U.S. that provide accessible databases related to emissions behavior. We describe the information provided in each database. Testing and certification systems that do not provide a database of certified manufacturers and products are excluded from this review.

4.3.1. Scientific Certification Systems (SCS)[9]

One of SCS's many programs is the Green Products Certification program. Under its Indoor Air Quality section, SCS includes five certifications that are directly related to materials emissions. The first is calCOMPliant,™ which certifies compliance with California Code of Regulations title 17, sections 93120-93120.12, "Airborne Toxic Control Measure to Reduce Formaldehyde Emissions from Composite Wood Products." The regulation is applicable to plywood, particle board, medium-density fiberboard, and other finished wood products.

[9] http://www.scscertified.com/gbc/index.php

FloorScore® is an indoor air quality certification of the Resilient Floor Covering Institute (RFCI) conducted under the auspices of SCS Environmental Certification Program SCS-EC10.2-2007 on Indoor Air Quality Performance. Target VOCs are evaluated based on the health-based emission requirements of California Department of Public Health Standard Method (Section 01350). Certified products also qualify for the LEED-NC (v. 2.2) EQ 4.3 credit.

Indoor Advantage™ is a certification for furniture systems based on a testing standard for low-emission office furniture systems and seating (ANSI/BIFMA X7.1), developed by the Business and Institutional Furniture Manufacturer's Association (BIFMA). Certified furniture systems qualify for the LEED EQ 4.5 credit.

SCS Indoor Advantage™ Gold certification is awarded to building materials that meet VOC emission requirements of California Green Building Specification, Section 01350 and meet SCS-EC10.2-2007, Indoor Air Quality Performance criteria. Certifiable materials include adhesives and sealants, paints and coatings, composite wood and agri-fiber products, and furniture and seating. This certification meets the LEED EQ requirement for each corresponding type of material. SCS Indoor Advantage™ Gold is also a prerequisite for SCS Formaldehyde-Free Certification.[10]

The SCS website provides a complete directory of SCS-certified products, including manufacturer listings and certifications (printable) for each product.[11] A database search can be executed using the following fields/ menus:

1) Product categorization, which includes a three-step search: product category (list of all product main categories), product sub-category (expanded list of categories), and product types (specific types, names, or key materials)
2) Manufacturer's name (list of all manufacturers with one or more SCS-certified products; automatic short listing through product categorization selections)
3) Certification program (list of all certifications provided by SCS)
4) Conformance to standards (list of five reference standards including the California Department of Public Health Standard Method (Section 01350), ANSI/BIFMA furniture emissions standard, and LEED EQ 4.3 flooring system criteria)

Figure 1 shows the search page and a sample result from the SCS website. The main search results display information on a product's commercial name, type, and manufacturer. Standards compliance and certifications are also included. There is, however, no information on contents or chemical emissions of the tested building materials or products. A simple search of the database as of July 2010 reveals that it includes 670 flooring materials, 459 furniture products, 45 paints and coatings, 14 wall systems and finishes, and 74 other building and construction products that are currently available in the market and certified by SCS as low-emission products.

4.3.2. GREENGUARD Environmental Institute (GEI)[12]

[10] Formaldehyde Free is a program to confirm no added formaldehyde in a product and non-detectable formaldehyde emissions. Confirmation is through 1) authorized statements of compliance by product manufacturers and suppliers of components used in the manufacturing process, 2) MSDSs, and 3) laboratory tests and conformance to standards.

[11] http://www.scscertified.com/products/

[12] http://www.greenguard.org/en/newGG/new_certificationPrograms.aspx

GEI is a third-party certification provider for indoor air quality issues such as chemical emissions and mold growth. Manufacturers can choose from three types of low-emission product certification: GREENGUARD Indoor Air Quality Certified,® GREENGUARD Children & Schools℠ Certified, and GREENGUARD Premier℠ Certified.

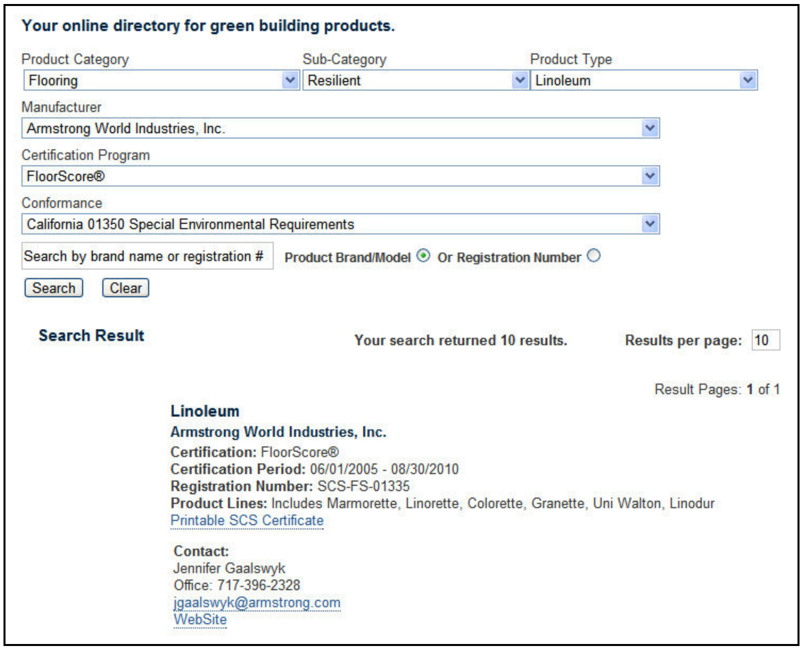


Figure 1. Search page and sample of information available from SCS certification system

These three programs evaluate chemical emissions from building materials, furniture, furnishings, finishes, cleaning products, and electronics and consumer products. Moreover, GREENGUARD Children & Schools℠ Certified items have to comply with the California Green Buildings Specification Section 01350 requirements. GREENGUARD Premier℠ Certification is a newly developed health-based certification program that takes into consideration both acute and chronic health effects. This new program is most stringent of the three certifications and includes evaluations for lead and phthalates. Similar to the approach taken by California Department of Public Health Standard Method (Section 01350), this program assesses chemical exposures to tested products based on their application in various indoor environments, such as residences, schools, health care settings, and offices.

GEI tests products using established performance-based standards for test methods and frequency and product sampling and handling, as well as specifications of allowable emissions levels, toxicity limits, and acceptance. The main standard used is called the "Standard Method for Measuring and Evaluating Chemical Emissions from Building Materials, Finishes and Furnishings Using Dynamic Environmental Chambers." GEI certification also includes calculation of emission factors and personal exposure levels based on product usage, application processes, and room parameters such as ventilation and volume.

GEI Product Guide lists all the certified building materials and indoor products through a searchable on-line materials database (Figure 2).[13] The four main search categories are product category (27), manufacturer (327), internationally recognized sustainable credits (22), and certification type (2). Search results provide manufacturer information, product commercial name and description, certification status and validity period, and printable certificate. The certificate describes the reference standard, evaluation criteria, and allowable limits. No chemical emissions data are provided in the on-line search results or the downloadable product certificate. A search based on major product categories shows that the database currently has active certification for 827 flooring materials and finishes, 865 wall surface materials, 4,036 furniture products, 101 paints and coatings, 242 adhesives and sealants, 110 construction materials, 14 cabinetry systems, and 23 cleaning products. Table 2 shows a partial list of materials and products from the GEI database.

4.3.3. Collaborative for High Performance Schools (CHPS)[14]

CHPS was founded by California's major utilities in 1999[15] to address energy efficiency in schools and later expanded to include aspects of school design, construction, and operation. CHPS provides free resources to address energy efficiency, water usage, materials selection and application, health and learning performance, building performance mandates (thermal, acoustic, and visual), and operations in schools. Relevant to this review is the database of High Performance Products that CHPS developed in partnership with the EPA and CalRecycle. This database – currently available in beta version – contains CHPS's low-emission materials list and some additional information, such as recycled content, rapidly renewable material content, and organically grown material content, of products.

The CHPS products database is simpler to search than the SCS and GEI databases. The CHPS database has eight materials categories, each followed by a set of sub-categories. Upon selecting the category, the user can narrow the search by selecting the attribute of interest. In our case, this is "Low Emitting Material." Products can also be searched using CSI number or keywords. The search output provides information on product descriptions, manufacturer and contacts, attribute(s) and validity period, and a link to download the laboratory test certificate for compliance with the California Department of Public Health Standard Method (Section 01350). This standard is the only reference standard that CHPS recognizes for determining what materials qualify as low-emission. The CHPS database is smaller than the SCS and GEI databases and does not provide chemical emissions data.

Related to the CHPS certification program is an independent study conducted by the California Department of Health Services (DHS) in 2001-2003. Funded by the California Integrated Waste Management Board (CIWMB), the three-phase study was conducted to measure emissions from standard materials and to compare them with emissions from

[13] http://www.greenguard.org/en/QuickSearch.aspx
[14] http://www.chps.net/overview/overviewHealthProductivity.htm
[15] http://www.chps.net/dev/Drupal/node/164

alternative counterparts, to investigate the applicability of California Department of Public Health Standard Method (Section 01350), and to identify new chemicals of concern. A total of 77 standard and alternative materials were tested for the following 11 categories: ceiling panels, carpets, fiberboard, gypsum boards, paints, particle board, plastic laminates, resilient flooring, wall panels, thermal insulation, and wall base. Detailed emissions data for all the tested materials can be found in the study report (appendixes B-M).[16] The study concluded that emissions from standard and alternative materials were not markedly different and that emission criteria were exceeded in both, mostly for only one of the target chemicals. The chemicals whose emissions most consistently exceeded standards were naphthalene, formaldehyde, and acetaldehyde. To be considered candidate chemicals with potential health hazards that could be added to the CREL list are caprolactam (from nylon-based carpets) and 2-butoxyethanol (from resilient flooring).

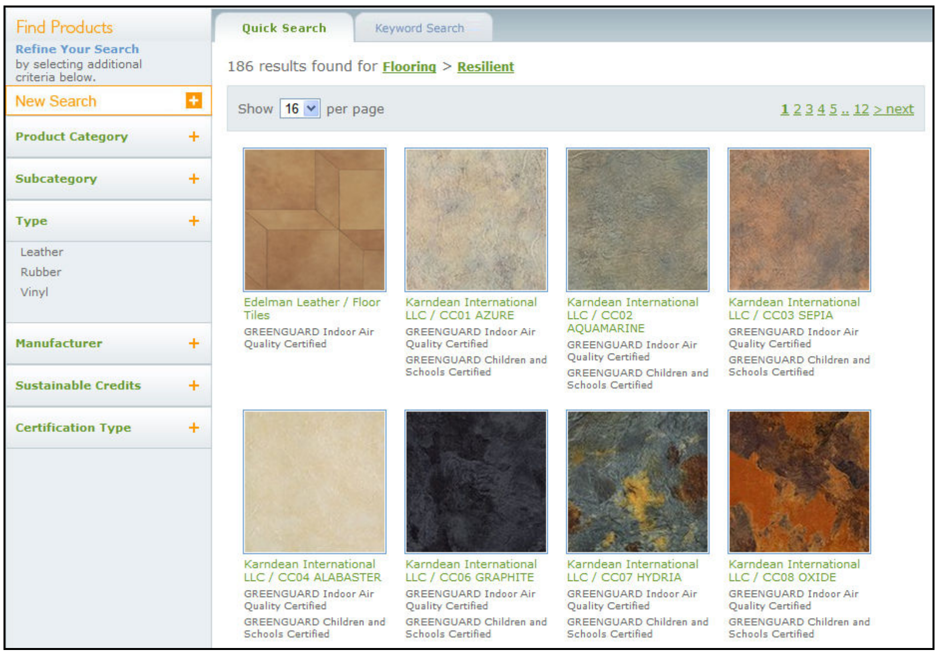


Figure 2. Search page and sample of information available from GEI certification system

4.3.4. Carpet and Rug Institute (CRI)

CRI's Green Label and Green Label Plus are internationally recognized low emissions labels for carpet, carpet backings, cushions, and adhesives. CRI-certified carpet and related products are tested according to the method in the California Department of Public Health Standard Method (Section 01350) and several additional protocols, including sample validation (chain of custody), annual product testing for chemicals of concern, reproducible protocol, and oversight by a Scientific Review Board.

[16] California Integrated Waste Management Board (2003). Building Material Emissions Study. Sacramento, California.

Table 2. Partial list of materials database provided by GEI online search

Category	Material contents	Types/ uses	Sizes (associated with tests)	Certified manufacturers
Wood flooring	Natural wood	Engineered: red oak, hickory, maple, teak, pecan	½"x3", ½"x4.5", ½"x5"	Anderson Hardwood Floors
	OSB	Engineered pressed wood	Customized	Huber Engineered Woods, Norbord Inc
	Cork, hybrid cork (linoleum, wood, leather), surface coating, binder	Cork parquet, vinyl tile, floating floor	Customized	Amorim Revestimentos SA, Global Market Partners Inc, Granorte LDA, USFloors Inc, Wicanders Cork Oak Flooring
Resilient flooring	Polyvinyl chloride, glass fiber, polyester, cork, plasticizers, stabilizers, fillers, flame retardant	Tile or plank	12"x12" tile, 4"x36" or 6"x36" planks	Karndean International LLC, Lonseal
	Polyolefins (polyethylene and polypropylene), ethylene vinyl acetate, fillers, pigments, acrylic polyurethane, flame retardants	Sheets	Customized	Amtico
	Linoleum-cement (linseed-oil, resin, accelerator), cork or wood flour, fillers, pigments	Sheets	Customized	Armstrong World Industries Inc, Forbo Linoleum, Harris-Tarkett
	Natural rubber, styrene-butadiene rubber, fillers, accelerator, pigments, antioxidants	Single layer or multiple layers, heavy-duty, electrically conductive	Customized	Mondo America Inc, Nora Systems Inc
Laminate flooring	Particle board, fiber board, melamine and phenol resins	Mat or glossy finishes, tile, plank	Customized	Faus group, Kaindl Flooring Gmbh, Shaw Industries Inc, Shnier, Wilsonart Flooring
Tile flooring	Granite, marble, limestone, porcelain	Mat, glossy, or textured finishes, tile	Various sizes/ shapes	Florida Tile, GranitiFiandre, Iris US, Dolce Italia, Mediterranea, StonePeak Ceramics
Bamboo flooring	Bamboo, aluminium oxide finish		5/8" thick	Shaw Industries Inc
Carpet flooring	*Main system:* Polyamide, polypropylene & polyester, synthetic latex, adhesive, pigments dye; *Treatment:* fluorine (fiber carpet), pyrethroid and permethrin (wool carpet)	Cut pile, woven, loop pile		Shaw Industries Inc
Gypsum ceiling and wall board or drywall	Calcium sulfate dehydrate, calcium carbonate, cellulose, quartz, fiber glass; *Surface treatment:* Premixed vinyl-based, sand-setting compound, polystyrene	Regular, laminate, veneer, fireguard, moisture resistance	½", ¼",3/8", 5/8" thick	Gold Bond Gypsum Board, EcoRock Drywall, American Gypsum Board, CertainTeed Gypsum, National Gypsum Company
Cement board	Portland cement, aggregate, glass	Moisture protection	Customized	National Gypsum Company
Adhesive/ sealants	Epoxy, neoprene, polychloroprene, acrylic urethane, polyurethane	Fast bonding, pressure sensitive, wood bond/ filler, drywall adhesive, adhesive sealant, surfacing adhesive, structural/ cons. adhesive	-	3M Company, Abatron, Henkel Corporation, ITW Plexus, ITW TACC, Wilsonart Adhesives

Table 2. Partial list of materials database provided by GEI online search (continued)

Category	Material contents	Types/ uses	Sizes (associated with tests)	Certified manufacturers
Floor finish/ maintenance	Acrylic urethane	Hard surface, wood surface, sealer, filler, cleaner	-	Bona
Insulation	Glass fiber, resin, polystyrene, polyurethane, polyethylene foam, organic bond agent, flame retardants	Textile-type, EPS, spray foam, sill plate	-	ANCO Products Inc, BASF, BioBased Insulation LLC, CertainTeed Corporation, Demilec (USA) LLC, Guardian Fiberglass, Owens Corning
Paints and coatings	Acrylic latex, solvent, color pigments, resin, collagen, anti-microbial agent, plasticizers	Eggshell, Flat/ Mate, Gloss Primer	-	AkzoNobel, Benjamin Moore, Eco-Trend Corp, Sherwin-Williams Company, Valspar
	Varnish		-	
Wall finish and surfaces	Textile, wall paper, non PVC substrate (ECORE), polyester cotton, resin	Surface layer	54" wide, 21 oz. ply	KnollTextiles, Maharam, Luxe Surfaces, Colour & Design, DeNovo, Koroseal, LANARK Wallcovering
	Polymethyl methacrylate, alabaster resin, polyethylene, ecoresin, fiberglass	Plastic, poured or pressed glass	Customized	3form Inc, Panolam Industries International Inc
	Laminate	Various types of finishes	Customized	Abet Laminati, Formica Corporation
	Melamine	Customized shapes and applications	Customized	Arclin Surfaces Inc
	Vinyl	Sheets	21 oz. ply	InPro Corporation, Koroseal
Window covering	Textile (micro-woven), wood, metal	Blinds	Customized	Ferrari SA, Hunter Douglas, Turnils, Vertilux Limited
	PVC glass fiber, vinyl coated glass fiber	Mobile shading device, blinds	Customized	Helioscreen, Hunter Douglas, Phifer Inc
Bedding materials	Textile, cotton padding, latex foam, wool, natural rubber, adhesives	Mattress	Standard sizes	Lifekind Inc, Organic Mattresses Inc
Cabinetry	Wood, waterborne finishes	Panels, modular	Customized	Executive Cabinetry LLC, Teknion
	Coated metal	Panels, customized	Customized	Dwyer Products

Testing for Green Label Plus examines 13 target compounds independently, for 24-hour and 14-day emissions for carpet products, and 15 target compounds for adhesive products. The target pollutants are: 1) *Carpet*: acetaldehyde, benzene, caprolactam, 2-ethylhexanoic acid, formaldehyde, 1-methyl-2-pyrrolidinone, naphthalene, nonanal, octanal, 4-phenylcyclohexene, styrene, toluene, and vinyl acetate; 2) *Adhesive*: acetaldehyde, benzothiazole, 2-ethyl-1-hexanol, formaldehyde, isooctylacrylate, methylbiphenyl, 1-methyl-2 pyrrolidinone, naphthalene, phenol, 4-phenylcyclohexene, styrene, toluene, vinyl acetate, vinyl cyclohexene, and xylenes (m-,o-,p-). Emissions criteria for the individual pollutants can be downloaded from the CRI website.[17]

The CRI on-line database provides information for all certified carpets (Green Label Plus), adhesives (Green Label Plus), and carpet cushions (Green Label). Carpet products can be shortlisted by selecting one of the nine product types or a specific manufacturer. Information from the database includes CRI label identification number, product type, a brief description of the product, a downloadable certificate, and a link to the manufacturer's website. Like other databases, this on-line database does not include emissions data.

4.3.5. Environmentally-preferable products certification

Green Seal™ and EcoLogo℠ are certification systems which mostly focus on the ecological aspects of building materials and household products. Green Seal™ has 36 environmental standards, including four new standards in the development, for certification of a wide variety of items. These include household products (tissue paper, plastic bag and wrapper, newsprint, cleaner, and personal care products, etc.), surface application products (paint and coating, floor care and finish, etc.) and building material and appliance (window, electronic, fluorescent lamp, etc.). Green Seal™ standards do not specifically address the issue of chemical emissions. However, for some products, Green Seal™ standard has added the health-specific requirements as established by existing guidelines or standards, which include VOC emissions limit. For example, the Green Seal™ Standard for Paints and Coatings (GS-11) include the evaluation of a list of 25 prohibited chemicals listed as Hazardous Air Pollutants, carcinogens, mutagens and reproductive toxins. Green Seal™ online database provides a list of certified products by five categories.[18] The product database provides name of manufacturer, commercial name of product and the Green Seal™ standard used for certification.

EcoLogo℠ program certifies a wide array of products similar to Green Seal™. The program has a series of stringent standards, which were "designed so that only the top 20% of products available on the market can achieve certification." The program standards address the entire lifecycle of the product and require testing or audit by a third-party laboratory. In some standards, control of VOC contents is required. For

[17] http://www.carpet-rug.org/commercial-customers/green-building-and-the-environment/green-label-plus/carpet-and-adhesive.cfm
[18] http://www.greenseal.org/findaproduct/index.cfm

example, the standard for architectural coatings (CCD-047) specifies that sealants and caulking compounds must not be formulated with formaldehyde, ethylene glycols, phthalates, and aromatic compounds, to name a few. The EcoLogo^{CM} standards are available online and are searchable by product category. The database of EcoLogo^{CM} certified products only include product name, limited description of the product (e.g. size, weight) and name of manufacturer.[19]

4.3.6. European databases of certified materials and products

In Europe, there have been major efforts to identify low-emission materials.[20] This subsection gives an overview of European initiative. During the past 10 years, building materials and products emissions and labeling have been handled at the national level in many European countries, and great progress has been made. In 2003-2005, as part of the European Collaborative Action mandate for the "Urban Air, Indoor Environment and Human Exposure" program, the Joint Research Centre of the European Commission conducted a detail inventory and review of 11 major labels in seven countries. A leading country in this field, Germany, has five internationally recognized labeling schemes for materials and products. France, Finland, Denmark, Portugal, Austria, and Sweden each have national labeling schemes. As part of the European Commission policy-making process, there have been active efforts to harmonize the indoor material labeling schemes during the past five years, as recommended in European Collaborative Action (ECA) Report no. 24 (2005).[21] The standard methods adopted or developed for these labels are comparable to those applied in the US. The only significant difference lies in the use of sensory evaluation data, which is not required in the U.S. Databases of certified items are mostly in the national languages and are not available in English. Available information from the databases resembles what is found in their U.S. counterparts.

Links to the available databases are provided below:

- Emicode (Germany): http://www.emicode-produkte.de/
- Natureplus (Germany): http://www.natureplus.org/en/products/
- Blue Angel (Germany): http://www.blauer-engel.de/en/
- M1 (Finland): http://www.rts.fi/list_of_M1_classified_products.htm
- Austrian Eco-Label (Austria): http://www.umweltzeichen.at/cms/home/produkte.html
- Scandinavian Trade Standards (Sweden): http://www.golvbranschen.se/vara-medlemmar

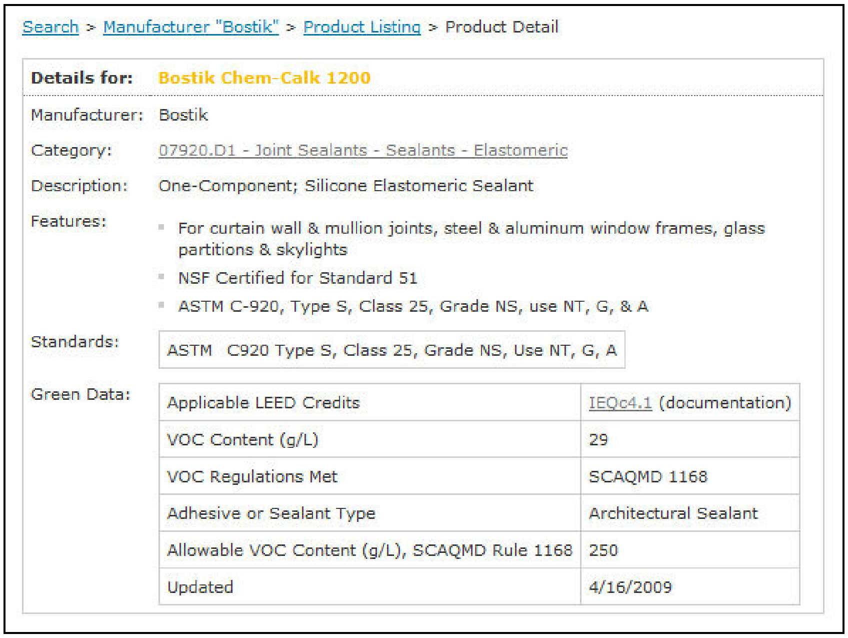
5. MATERIALS AND PRODUCTS DATABASE FROM NON-CERTIFICATION ORGANIZATION OR INSTITUTION

5.1. Non-certification institution or organization

[19] http://www.ecologo.org/en/greenproducts/consumers/
[20] http://www.label-online.de/
[21] http://www.inive.org/medias/ECA/ECA_Report24.pdf

5.1.1. BuildSite[22]

Buildsite aims to provide contractors and suppliers with technical information and resources related to green building materials for LEED certification. This comprehensive database can be browsed by manufacturer, master format category, ASTM, or LEED credit. The database consists of thousands of products from 396 manufacturers, some of which include green data on their products. Figure 3 shows an example of database details for a selected material. Other information available through the database includes product data, MSDS, LEED certification, complete laboratory reports (including VOC emissions data), warranty documents, comparison charts, as well as brochures and catalogues. Lists of low-emission materials can be easily extracted from the database by selecting LEED credit as the main search term.



Search > Manufacturer "Bostik" > Product Listing > Product Detail

Details for: Bostik Chem-Calk 1200

Manufacturer: Bostik

Category: 07920.D1 - Joint Sealants - Sealants - Elastomeric

Description: One-Component; Silicone Elastomeric Sealant

Features:
- For curtain wall & mullion joints, steel & aluminum window frames, glass partitions & skylights
- NSF Certified for Standard 51
- ASTM C-920, Type S, Class 25, Grade NS, use NT, G, & A

Standards: ASTM C920 Type S, Class 25, Grade NS, Use NT, G, A

Green Data:

Applicable LEED Credits	IEQc4.1 (documentation)
VOC Content (g/L)	29
VOC Regulations Met	SCAQMD 1168
Adhesive or Sealant Type	Architectural Sealant
Allowable VOC Content (g/L), SCAQMD Rule 1168	250
Updated	4/16/2009

Figure 3. Sample of information available from BuildSite

5.1.2. U.S. Department of Health and Human Services' (HHS) Household Products Database[23]

More than 10,000 consumer products and brands available from 2001-2010 are listed in the HHS database, which is largely based on MSDSs and product labels. Information available for each product includes chemical composition, manufacturer information, acute and chronic health effects, and other toxicological data from the National Library of Medicine. Chemical data for each product are not verified through laboratory tests, however, and the database does not specifically focus on low-emission products.

5.1.3. HBN Pharos Project[24]

22 http://www.buildsite.com/query/list/manufacturer
23 http://householdproducts.nlm.nih.gov/index.htm
24 http://www.healthybuilding.net/about/index.html

The Pharos Project is flagship project of HBN, an organization founded by a group of national environmental health professionals in 2000. Its objective is to define a consumer-driven vision of green building materials and establish an evaluation method that is consistent with principles of environmental health and justice. As stated on the website, the outcome of the project is not a certification system. It is a web-based tool that provides information and scoring, based on critical health and environmental data, about manufacturing, use, and life-cycle impacts of building materials. The database, which is currently under development, comprises two interconnected data libraries, the building product library and the chemical and material library. Figure 4 shows a product search results page from the Pharos Project website. The results show a score for each of the five HBN evaluation categories. The main results page also provides information about manufacturer cooperation in providing data and access and the content of materials, including flags for chemicals with significant health risks. The main page is linked to detailed explanations for each evaluation category. For example, the VOC category page describes the VOC score and the list of certification(s) awarded to the material.

The strengths of the database are its multi-pronged rating system, its requirement for environmental performance, and its accessibility. The major drawback is the level of manufacturer participation and commitment needed to make this database more comprehensive and reliable.

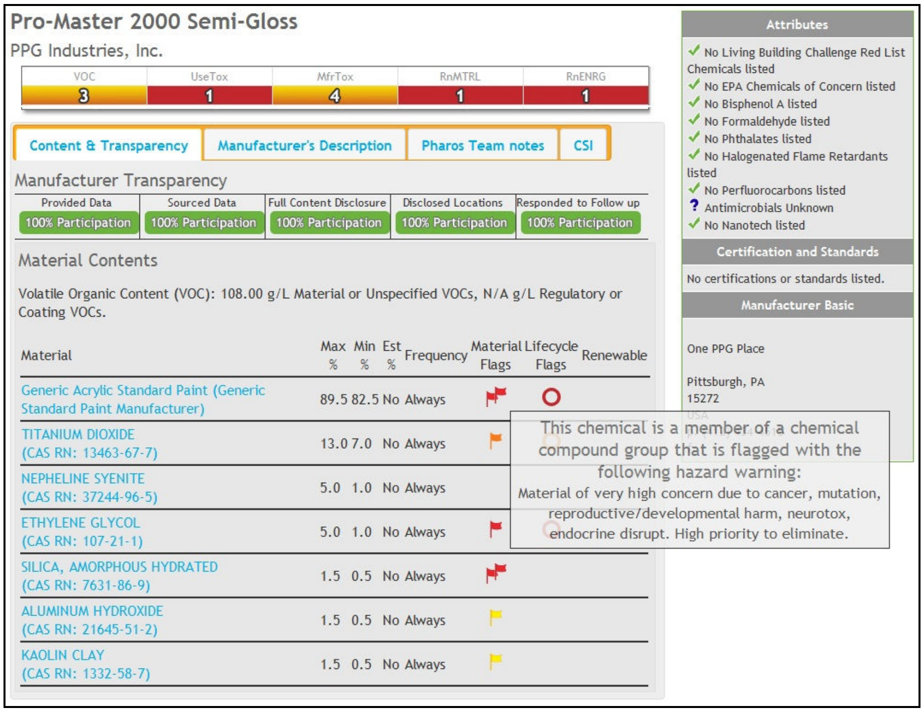


Figure 4. Sample of information available from Pharos Project database

5.2. Databases developed based on peer-reviewed publications or research projects

5.2.1. EPA Source of Indoor Air Emissions (SIAE) database

For the EPA SIAE database, source emission rates from 78 types of materials in 17 source categories were collected from 72 references (including conference papers) reviewed through May 1999. In total, the database – available in Excel format – includes 8,500 data records. Each record contains information about source classification, test conditions, material contents, and emission factors and characteristics, if available. Of note, manufacturer data and the material's name are not available because this information is not commonly included in a journal publication. Although the database appears outdated, it is still one of the most comprehensive lists based on peer-reviewed publications. A partial list of this database is being used as input data source in the CONTAM air flow and pollutant transport modeling software of the National Institute of Standards and Technology (NIST).

5.2.2. Canada National Research Council (CNRC) materials emission database

The CNRC database was developed by the Institute for Research in Construction. They measured 69 building materials commonly used in Canada and 152 contaminants, resulting in a total of more than 2,300 data records. Each data record contains 70-80 data fields, including manufacturer information, emissions testing conditions, material contents, and emission factors and characteristics. The database is accessible through NRC's IA-QUEST indoor air quality model, which is available for download from their website.[25]

5.2.3. European Union Building Materials (BUMA) database

As part of the European initiative for healthy buildings, the European Commission of Health and Consumer Protection funded a five-year program called Prioritization of BUilding MAterials (BUMA) as Indoor Pollution Sources. The objectives are to form a comprehensive database with updated emissions data for construction products and building materials; to classify and prioritize, by compound, emission factors and exposure levels; to develop exposure models; and to produce guidelines as part of a policy-making process.

The BUMA database[26] is continuously updated and currently contains more than 400 materials and products. The BUMA project also includes data validation through field studies and laboratory testing. Formaldehyde, acetaldehyde, acetone, and limonene were identified as pollutants of concern in consideration of their emission sources.

5.2.4. France PANDORA database[27]

The PANDORA database is a product of the REGENAIR project, which is partly funded by the French Research Agency (ANR). The database aims "to compile the available data regarding the emission rates of both gaseous and particulate pollutants in

[25] http://irc.nrc-cnrc.gc.ca/ie/iaq/iaquest_e.html
[26] www.buma-project.eu
[27] http://leptiab.univ-larochelle.fr/PANDORA.html

a systematic way into a unique database to provide useful information for IAQ modelers."

The database search is carried out, using PANDORA software, by either product or chemical compound. The database consists of three major categories: materials, cleaning products and air fresheners, and occupants and occupant activities. Each category is further divided into subcategories containing materials or products lists. Information for each material includes a description of the material, its location of use, its country of origin, references, a list of pollutants, and emission models and factors. A notable difference between this database and others is the inclusion of location of use of the materials, i.e. residential, office, school, etc.

6. EMISSIONS DATA FROM PEER-REVIEWED PUBLICATIONS AND TECHNICAL REPORTS

During the past 10 years, research on chemical emissions phenomena has substantially transformed. Advancements in sampling techniques as well as analytical methods and technologies have generated new level of in-depth research on emissions from materials and products. The subsection below discusses the data available in recent publications. In this report, we focus on studies reported during the period of 2001-2010. Review papers from earlier periods are discussed briefly in terms of emissions data availability and identified pollutant(s) of concern. We summarize results from published investigations of individual building materials and household products, including short- and long- term emissions of primary pollutants, that is, the free (non-bound) VOCs emitted from the material or product. Degradation of materials and chemical reactions leading to secondary emissions are beyond the scope of this review.

Studies reporting only TVOC data are summarized in this review with only limited discussion because our focus is on individual VOC emission data and source identification. Although SVOC studies are not a focus of this review, we reference some results showing SVOCs as a substantial fraction of emissions from the investigated materials or products. We also discuss and compare a few studies describing the application of low-emission materials.

6.1. Review articles and reports

6.1.1. Wet products

Brown et al. (1994) reviewed past studies on materials emissions. They reported that emissions from "wet" materials, such as paints and adhesives, contributed most significantly to VOC levels measured indoors. The review also showed that emissions related to wet products in new buildings increased the TVOC concentrations by an order of magnitude. Norback et al. (1995) reviewed and compared emissions from various paints. Use of water-based paints as reported to reduce VOC emissions and, correspondingly, the exposures to painters, by a factor of 100 when compared to use of solvent-based paints. An EPA review of VOC emissions from paints found that TVOC emissions from solvent-based paints were about 2,000 milligrams per square meter (mg/m^3), and the level measured in water-based paints was much lower at 40 mg/m^3 (Chang, 2001). The main VOCs of concern in solvent-based paints were xylene and 2-

butanonoxime, with measured levels that approached the threshold for neurological and toxic effects. Chronic exposures to xylene and 2-butanonoxime were associated with central nervous system effects and cancer, respectively. Formaldehyde and acetaldehyde emissions were found in some water-based paints. Acetaldehyde presented a concern for cancer risk with risk estimates of 10^{-4} and formaldehyde with a risk of 10^{-6}, based on lifetime exposure assessment.

Yu and Crump (1998) reviewed the emissions data from dry (24 types) and wet (56) polymeric materials testing conducted in the United Kingdom Building Research Establishment (BRE). As mentioned before, water-based paints emitted far fewer VOCs than oil-based paints. The total emission rate was 4.7 $mg/m^2/h$ for water-based compared to 5,220 $mg/m^2/h$ for oil-based. They also reported that Texanol® continued to be released from emulsion paints, and decane and undecane from gloss paint and wood varnish two years after application. A complete listing of VOCs, total emissions, and source of materials content was included in their review; however, emissions data from each individual compound were not available.

Adhesives are commonly applied to large indoor surface areas in conjunction with floor covering materials. As with most wet products, adhesives emit a vast array of organic compounds. A review of VOC emissions by Yu and Crump (2002) found that glycols and glycol ethers were most commonly detected from adhesives used in conjunction with carpet, vinyl, and parquet.

A recent review published by HBN (2009) on high-performance paint coatings calls for attention to the use of bisphenol A (BPA) as a chemical component in epoxy resins that are used in paints, sealers, coatings, adhesives, binders, and additives.[28] Higher BPA levels have been significantly associated with heart disease, diabetes, and abnormally high levels of certain liver enzymes (Lang et al., 2008). Early exposure to BPA has also been linked to increased risk of cancer (Newbold et al., 2009), which triggered major health concerns over the use of this substance in baby products.[29] Other adverse effects associated with BPA are related to brain development (Leranth et al., 2008), the prostate gland (Ho et al., 2006), and the reproductive system (Adewale et al., 2009, Mendiola et al., 2010). A BPA variant, bisphenol A diglycidyl ether (BADGE), is commonly used in paints, which could be inhaled from by those who are close by during application or absorbed through skin.

Household products – in particular liquid-based applications – have been the center of much attention because of the high personal exposure risks associated with chemical constituents released in the air as primary pollutants as well as the formation of secondary pollutants. Nazaroff and Weschler (2004) reviewed studies on emissions, exposures, and health effects of cleaning products and air fresheners from 1982-2003. The review explored the likely significance of pollutant exposures in homes, emphasizing both primary and secondary emissions, and studied the causal links between use of a product and inhalation exposure. The paper presents a summary table of reported volatile compounds emitted from cleaning products with no significant risk level (NSRL), chronic exposure reference level (ChREL), or both. There were 21 chemical compounds that posed some health risk from exposure. The authors highlighted that not all chemicals

[28] http://www.healthybuilding.net/healthcare/2009-07-17_BPA_memo_FINAL.pdf

[29] http://www.newscientist.com/article/dn14739-plastic-bottle-chemical-linked-to-heart-disease.html

of concern were represented by the established exposure guidelines. As an example, 4-nonylphenol and nonylphenol ethoxylates – potential hormonal disruptors – were detected in widely used disinfectant cleaners and spot removers.

6.1.2. Dry products

Formaldehyde emissions from wood-based materials are an established indoor air concern (Salthammer et al., 2010). Formaldehyde is used as a synthetic polymeric resin or binder. Many standards have been developed to control formaldehyde content in these materials. Some alternative materials have also been proposed and used. A report by HBN (2008),[30] showed that the formaldehyde level had declined in alternative resins for particle board, medium-density fiberboard (MDF), and wheat board but that emissions had not been eliminated. For example, modified urea formaldehyde continues to emit formaldehyde for long periods of time, and phenol formaldehyde and methylene diphenyl diisocyanate (MDI) both raise exposure concerns during their production stage.

The most common emissions from natural woods building products are acetic acid, formic acid, and formaldehyde, according to a review of emissions data for European and Australian woods and wood panels (Bradley and Thickett, 1998). The review concluded that zero-formaldehyde MDF exhibits higher emissions of organic acids than conventional MDF. Organic acids are known to degrade other materials and are of special concern to cultural items made of bronze, limestone, or glass.

Germany's AgBB Institute published a technical report (2006) on dangerous substances from flooring materials.[31] Textile-based, resilient, and rigid floorings were reviewed and tested. Lists of materials used and the potential release of dangerous substances from each type of flooring (35 categories) were detailed in Annex 4 of the report. The summary of their recommendation on content-based pollutants of concern to be excluded from new generations of flooring products is partially reproduced as follows:

- All flooring types: pentachlorophenol and formaldehyde
- Resilient flooring: polybrominated diphenyl ethers
- Textile-based flooring: pesticides in natural fibers
- Polyvinyl chloride (PVC) flooring: plasticizers [di(2-ethylhexyl) phthalate (DEHP), dibutyl phthalate (DBP), butyl benzyl phthalate (BBP)], cadmium stabilizers
- Rubber-based flooring: nitrosatable substances

A review of resilient flooring materials and their hazard potential was carried out by the Health Care Research Collaboration (HCRC, 2009).[32] Although this review is about health care facilities, the resilient flooring types discussed in the report are not uncommon in residential settings. Figure 5 reproduces the summary table of this review. Of all materials, PVC flooring has the most pervasive presence of unavoidable persistent bioaccumulative toxicants (PBT) in its life cycle. Three of the most commonly added phthalates with known toxic effects are BBP, DEHP, and di-n-hexyl phthalate (DnHP). The

[30] http://www.healthybuilding.net/healthcare/2008-04-10_alt_resin_binders_particleboard.pdf
[31] http://www.umweltbundesamt.de/building-products/archive/AgBB-Evaluation-Scheme2010.pdf
[32] http://www.healthybuilding.net/docs/HBN-ResilientFlooring&ChemicalHazards-Report.pdf

presence of unavoidable carcinogenic contents in styrene butadine rubber (SBR) flooring also raises serious concern. One area of concern is the addition of flame retardants in the highly flammable SBR materials. Polybrominated diphenyl ethers (PBDE), a halogenated flame retardant, has been linked to serious health consequences such as reproductive and nervous system problems, immune suppression, and cancer (Siddiqi et al., 2003). Polyolefin flooring (based on Stratica product) seems to offer the most improvement over PVC in terms of hazard risks. In this floor type, only ethylene presents a potential health risk as a carcinogen and neurotoxicant. Linoleum flooring has the greatest potential for improvement by eliminating the use of pesticides in growing flax feedstock for the production process. Nevertheless, the types of linoleum flooring on the market today still release several high-concern VOCs including acetaldehyde and formaldehyde. In addition to phthalate in PVC, PVC flooring emits three major volatile compounds: tridecane, phenol and TXIB, according to Yu and Crump (1997). TXIB is least volatile and thus tend to adhere to surfaces and may be re-emitted to the air long after the material is installed.

6.2. Published materials or product investigation and testing results

6.2.1. Application of low-emission materials

Guo et al. (2003) demonstrated the positive impacts of using low-emission materials in a newly constructed house. In this study, materials were carefully selected based on emission values from chamber tests. Subsequent investigations and measurements in the house after a three-month flush-out period showed that emissions from paints were the likely main source of the VOCs detected in the house. The performance of low-emission materials was broadly based on TVOC results. The papers states, “the total VOCs concentrations measured in the house range from non-detectable to 43 µg/m^3” and ”these values were much lower than the published values (0.48-31.7 mg/m^3).”

Primary and secondary emissions data for the application of a “green” oil-based paint on wood material were reported by Toftum et al. (2008). The main ingredients of the paint were orange oil, sunflower stand oil, castor stand oil, linseed oil, and mineral pigments. Compared to pine wood and oriented strand board (OSB), the painted beech emitted the lowest concentrations of terpenoids – the only target group of compounds – with exception of limonene, carvone, and linalool. Limonene was detected at relatively high concentration and was a source of concern because of its reactions with ozone. Kim (2008) tested the application of “green” adhesive produced from cashew nut shell to reduce the emissions of VOCs and formaldehyde. Formaldehyde emissions and xylene concentrations were reduced.

6.2.2. Recent publications on emissions from materials or products

Table 3 summarizes the studies reporting emissions behavior from various building materials and household products during the period 2001-2010. The information is sorted according to three major categories – flooring materials, surface finishes and wall materials, and household products – each of which is followed by the source reference, material or product type(s), and details related to study parameters and data availability. We identified the pollutants of concerns based on discussions provided in the articles. However, in a few cases, pollutants of concern were inferred from reported data that showed very high concentrations or emissions. Subsequently, we screened various exposure and toxicity guidelines for the identified pollutants. These guidelines were OEHHA's Acute and Chronic Reference Exposure Levels (AcREL and ChREL), OEHHA's Toxic Air Contaminants (TAC), EPA's Hazardous Air Pollutants (HAP), the ChREL contaminants adopted by the California Green Building Specification Section 01350, and the priority compounds defined in a recent review by researchers at the Lawrence Berkeley National Laboratory (Logue et al., 2010).

	Chemicals	PVC	SBR	Stratica	Linoleum	Hazards
Persistent PBT s*	Dioxins					POP, PBT, carcinogen, endocrine
	Polychlorinated biphenyls (PCBs)					POP, PBT, carcinogen, developmental neuro, endocrine & aquatic
	Hexachlorobenzene (HCB)					POP, PBT, carcinogen, neurotoxicant, developmental & aquatic
	Cadmium					PBT, carcinogen, developmental & reproductive & aquatic
	Mercury	Opt	Opt			PBT, developmental neuro & endocrine
	Lead	Opt	Opt			PBT, carcinogen, reproductive, developmental neuro & endocrine
	Chlorinated paraffins & decaBDE	Opt	Opt			PBT, carcinogen & endocrine
	Polycyclic aromatic compounds	Intl	Opt			POP, PBT, carcinogen
	Trifluran & other PBT pesticides					PBT, carcinogen
Contents- User exposures	Lead, cadmium, paraffins & decaBDE					see Persistent exposures
	Butyl benzyl phthalate (BBP or BzBP)	Opt				Developmental & reproductive, endocrine & aquatic
	Di(2-ethylhexyl phthalate (DEHP)	Opt				Developmental, reproductive & endocrine
	Di-n-hexyl phthalate (DnHP)	Opt				Reproductive
	Tributyltin	Opt				endocrine
	Antimony trioxide	Opt	Opt			Carcinogen
	Styrene		Int			Carcinogen (possible), endocrine, neuro
	Toluene, acetaldehyde and other VOCs	Opt+	Opt	Opt	Opt	Carcinogens, developmental & neuro
	Pigments (titanium dioxide & carbon black)	Opt	Opt	Opt	Opt	Carcinogen through inhalation
-Feedstocks & intermediary chemicals or emissions Additional manufacturing exposures**	Ethylene dichloride (EDC)	Intl				Carcinogen
	Vinyl chlorine monomer (VCM)	Intl				Carcinogen & neuro
	Chlorine gas	Intl				Aquatic & acute
	1,1,1-trichloroethane	Int				neurotoxicant and ozone depletor
	Acrylic acid	?				acute
	Vinyl acetate	Opt		Opt		Carcinogen (suspected)
	Mercury	Opt	Opt			PBT, developmental & neuro
	Ethylene	Int	Int	Int		Neuro & may metabolize to ethylene oxide (carcinogen & reproductive)
	1,3, butadiene		Int			Carcinogen, reproductive & developmental
	Acrylonitrile		Opt			Carcinogen & neuro
	Dimethylformamide		Opt			Reproductive & developmental
	Dithiocarbamates		Opt			Endocrine, neuro
	Ethylbenzene		Int			Carcinogen
	Benzene		Int		Opt	Carcinogen, developmental & mutagen
	Formaldehyde			Opt	Opt	Carcinogen
	Epichlorohydrin				Opt	Carcinogen, reproductive, mutagen
	Bromoxynil, Trichlorfon, Mancozeb & other pesticides				Opt	Carcinogens, developmental toxicants, neuros & endocrines
Fill colors in the table reflect the concern level in Table 1						
Black = Very High Concern		Red = High Concern			Orange = Moderate Concern	

* In addition to the chemicals listed, all three of the petrochemical plastics (PVC, SBR & polyolefin) share common PBT releases from the extraction and refining process of the petrochemical raw materials

** Manufacturing exposures also include all of the exposures from the persistent PBT & user exposure categories

Int =integral – fundamental unavoidable part of the base material, not likely to be designed out of the chemical process without significant redesign.

Opt=Optional variation on additives or manufacture process that is relatively more possible to avoid by selection or redesign.

+ Note that materials engineering can reduce, but not likely totally eliminate VOC emissions from any of these flooring types.

Figure 5. Hazard exposure assessments for chemical constituents of flooring materials
(Reproduced from HCRC technical report, 2009[33])

[33] Health Care Research Collaborative (2009) Resilient Flooring & Chemical Hazards (see foot note 30 for free online access to report)

Most studies tested newly procured materials or fresh applications of products. Although most databases from certification systems included the contents or formulas of the test materials or products, the published articles have failed to provide detailed information of this kind. In addition, there was no consistent use among the studies of particular lists of target pollutants. Studies measuring primary pollutants (VOCs, aldehydes) reported the list of detected or targeted VOCs and their concentrations and/or emission factors. A few household products studies did not include emissions data were, presumably because data sets were large. A very limited number of studies included SVOC measurements. Similarly, phthalates and secondary organic emissions were only investigated in a few studies. Most reports included the environmental test conditions (temperature, relative humidity, air velocity); however, effects of these parameters on emissions behavior were only investigated in a small number of studies.

The identified pollutants – based on highest concentration, emission factors, or frequency of occurrence among the samples – encompass various classes/ categories of chemical compounds: aromatic hydrocarbons (xylene, naphthalene, 4-phenylcyclohexene), terpenes (α-pinene, limonene), alcohol (Texanol, methanol, ethanol, isopropyl alcohol, 2-ethylhexanol), aldehyde (formaldehyde, acetaldehyde, benzaldehyde, hexanal), ketone (acetone), acid (acetic acid), ester (TXIB), glycol (2-butoxyethanol, ethanol 2-phenoxy, 2,2-butoxyethoxy-ethanol), aromatic diisocyanate (toluene diisocyanate), phthalate (DEHP, DBP), and halogenated flame retardants (TCPP, PBDE). Other major pollutants such as the aldehydes (formaldehyde) and aromatics (xylene) have been extensively discussed in various publications. Thus, the following section of this review only discusses some of the less-established contaminants.

The main pathway by which many of these pollutants have negative impacts on residents in homes is when they become airborne. Ingestion through eating or drinking toxic contents as well as diffusion through the skin are rare and critical only when children are considered. TXIB, a plasticizer used in PVC material, could contribute to odor in the range of parts-per-billion, but it causes irritation only at parts-per-million concentrations (Cain et al., 2005). There is currently no evidence of effects in humans from TXIB exposure through inhalation or skin contact. However, a screening study in animals has found that TXIB could cause developmental and reproductive toxicity.[34]

Use of phthalates in PVC materials has been subject to much attention during the past five years. Both DEHP and DBP are listed as HAPs by EPA. DEHP is a commonly used phthalate in the production of polymer products. DEHP, also known as bis (2-ethylhexyl) phthalate, exhibits low toxicity from acute (short-term) and chronic (long-term) exposures. When ingested, DEHP may cause gastrointestinal problems distress in humans.[35] No information is available on the chronic, reproductive, developmental, or carcinogenic effects of DEHP in humans. EPA currently lists it as a probable carcinogen. More recently, the EU conducted a risk assessment of DEHP exposures and concluded that DEHP poses no general risk to human health; the review nevertheless cautioned against exposing children to DEHP. This has led to regulations, introduced in January 2007, stipulating that DEHP is no longer permitted in toys and childcare articles within the EU. Dibutyl phthalate (DBP) is a commonly used plasticizer in adhesives. Use of DBP in children's items has been banned

[34] http://www.cpsc.gov/about/cpsia/docs/EastmanTXIB11282007.pdf

[35] http://www.epa.gov/ttn/atw/hlthef/eth-phth.html

since 1999 in the EU and since 2008 in the U.S. Also an irritant to the skin and mucous membrane, DBP has an established toxicity level in humans for ingestion; no information is available for inhalation risk.[36] Exposure risks of 2-ethylhexanol and ethanol 2-phenoxy are not specified in any of the exposure standards. However, a clinical toxicology review has reported that both compounds may cause central nervous symptoms such as headache, ataxia, delirium, and gastrointestinal distress if ingested.[37] There is no established toxic limit for humans as only animal studies have been conducted.

Emissions of toluene 2,4 diisocyanate – a highly reactive compound – are detected in carpet with polyurethane foam backing. This compound is also widely used in the manufacture of flexible and rigid foam, fibers, coatings such as paints and varnishes, and insulation foam. EPA and OEHHA list this chemical as a hazardous and toxic pollutant. OEHHA's Reference Exposure Level stipulates 0.07 $\mu g/m^3$ limit for inhalation exposure because of its known effects on the human respiratory system as asthma causative agent. More recently, EPA has cautioned against exposure to a variant of diisocyanate, 4,4-Methylenediphenyl Diisocyanate (MDI), which is commonly used in spray polyurethane foam insulation. Acute effects of MDI exposure include sensitization, asthma, dermatitis, and eczema.[38]

Other contaminants of potential concern from carpet emissions are 4-phenylcyclohexene (4-PCH) and 2,2-butoxyethoxy-ethanol (2,2-BEE). 4-PCH is considered to be a common VOC emitted from carpets backed by SBR latex. CRI lists it a target compound for their Green Label Plus certification. 4-PCH is currently not regulated because of lack of evidence supporting the link between health effects and exposures. However, as a major odorant emitted from new carpets, 4-PCH may be linked to adverse health effects (Hawkins et al., 1992) and has been considered a major contributor to poor perceptions of indoor air quality (Schleibinger et al., 2001). The National Institute of Environmental Health Sciences (2002) conducted a toxicological review of animal studies; this review indicated concerns for possible neurotoxic and genotoxic effects. 2,2-BEE has been classified as an irritant to the eyes by the European Commission (Commission Directive 67-548-EEC). There are no toxicity data for human exposure, and this chemical is not regulated in the U.S.

Produced in large volume every year, TMPD-MIB (2,2,4-trimethyl-1,3-pentanediol monoisobutyrate) – also known commercially as Texanol®) – is a versatile phthalate used in resin production and commonly added to latex-based paints to increase durability, adhesion, and resistance to water spotting. There are currently no established exposure limits for Texanol and very limited toxicity information available for humans and animals. Information on Texanol is mostly supplied by the manufacturer.

Table 4 shows expanded data/ information from some publications. The additional information provided in this table includes test methods, materials age, concentration or emissions data, and other environmental parameters. This table is essentially a sample of summary information available from published peer-reviewed articles, which is clearly superior to on-line databases from certification testing systems as far as the extent of emissions behavior data. However, scientific publications generally refrain from including

[36] http://www.osha.gov/SLTC/healthguidelines/dibutylphthalate/recognition.html
[37] http://environment.gov.ab.ca/info/library/6675.pdf
[38] http://www.epa.gov/ttn/atw/hlthef/methyl-d.html

any information pertaining to manufacturer or the manufacturing process of the tested products. Furthermore, publications reveal very limited or no information related to materials or products contents/ formula.

Sampling and testing methods in most studies were relatively standardized although the same cannot be said of the quality control in each of the different laboratories producing the analytical results and reports. Tests were performed for new materials or product applications, and repeated measurements were conducted at a specified subsequent time, e.g., 1, 3, 12 month(s) after application. Flooring materials were usually sampled between one day and three months after application, including the adhesives testing. In some cases such as evaluation of long-term emissions from PVC materials, tests were conducted up to one year after installation. Wet products were sampled from several hours to several days from their application. Nevertheless, although sampling and analytical standards were used in most studies, there were no consensus on sampling duration and frequency.

All research publications specified environmental testing conditions in detail, particularly when interaction effects could impact the results. Some studies also stated compliance with standard methods. Concentrations data or emission factors for individual compounds were usually supplied in the form of summary tables, which were based on either detected or targeted compounds and sorted according to chemical classes. In a few reports, particularly those with a long list of tested products, the authors opted to report and discuss only TVOC levels. Testing of household products generally included numerous items, making it impractical to report emissions for each product. For this type of study, the level of details was reduced; results were summarized by compound group or for selected VOCs of interest.

Table 3. Summary of data available from peer-reviewed publications on identified pollutants of concern

Material/ product category [flooring (F), surface/wall (S), household (H)]	Reference	Material/ product type	Materials desc.	Material content	Target pollutants	VOC list	VOC data [concentration (C), emission rate (E)]	TVOC	Aldehyde	SVOC/ VVOC	Phthalates	SOA	Temperature effect	Relative humidity effect	Identified pollutants of concerns by concentration (C), emission (E), frequency (F)	AcREL	ChREL	HAP	TAC	CAL SPEC 01350	LBL PRIORITY LIST
F	Kim (2010)	Wood	New	■	■	■	C, E	■	■	□	□	□	□	□	Xylene (C)	●	●	●	●	●	○
F	Yrieix et al (2010)	Particle board	New	□	■	■	C	□	■	□	□	□	□	□	Hexanal (C)	○	○	○	○	○	○
															Alpha-pinene (C)	○	○	○	○	○	○
F	Lin et al (2009)	Wood	New	□	■	■	C,E	□	□	□	□	□	■	■	-						
F	Kagi et al (2009)	Wood	Used	□	□	■	E	□	■	□	□	■	■	□	DEHP (E)	○	○	●	○	○	○
F	Chino et al (2009)	PVC, adhesive	New	■	■	■	E	□	□	□	■	■	□	□	2-ethylhexanol (E)	○	○	○	○	○	○
F	Jarnstrom et al (2007, 2008)	PVC, adhesive	Used	□	□	■	E	■	■	□	■	□	□	□	Ethanol 2-phenoxy (E)	○	○	○	○	○	○
															2-ethylhexanol (F)	○	○	○	○	○	○
															TXIB (F)	○	○	○	○	○	○
F	Katsoyiannis et al (2008)	Carpet	New	■	□	■	C, E	■	■	□	□	□	□	□	4-phenylcyclohexene (C)	○	○	○	○	○	○
															2,2-butoxyethoxy-ethanol (C)	○	○	○	○	○	○
F	Clausen et al (2007)	PVC	Used	■	■	□	C	□	□	□	■	□	□	□	DEHP (C)	○	○	●	○	○	○
F	Makowski et al (2005)	OSB	New	■	■	C	C	■	■	□	□	□	□	□	Formaldehyde (C)	●	●	●	●	●	●
F	Afshari et al (2004)	PVC, polyolefine	New	■	□	□	C	□	□	□	■	□	□	□	DBP (C)	○	○	●	○	○	○
F	Wilke et al (2004)	PVC	New	□	■	■	C	□	□	□	□	□	□	□	TXIB (C)	○	○	○	○	○	○
															2,2-butoxyethoxy-ethanol (C)	○	○	○	○	○	○
		Linoleum	New	□	■	■	C	□	□	□	□	□	□	□	Acetic acid (C)	○	○	○	○	○	○
		Carpet	New	□	■	■	C	□	□	□	□	□	□	□	Toluene 2,4 diisocyanate (C)	○	●	●	●	○	○
F	Guo et al (2004)	Carpet, polypropylene	New	■	□	□		■	□	□	□	□	□	□	-						
F	Hugo et al (2004)	Carpet, polyurethane foam	New	■	■	□	C	□	□	□	□	□	□	□	Toluene 2,4 diisocyanate (C)	○	●	●	●	○	○
F	Hodgson et al (2002)	Plywood	Used	□	□	■	C	□	■	□	□	□	□	□	Alpha-pinene (C)	○	○	○	○	○	○
F	Wiglusz et al (2002)	Laminate w/ particle board or HDF	New	□	□	□	□	■	■	□	□	□	■	□	-						
F	Rucksthul (2001)	Concrete and additives	New	■	□	■	C	□	■	□	□	□	□	□	Naphthalene (C)	○	●	●	●	●	●
															Polyethelene glycol (C)	○	○	○	○	○	○
F, S	Toftum et al (2008)	Wood, paint	New	■	■	■	C	□	□	□	□	■	□	□	-						
S	Auvinen et al (2008)	Photocatalytic paint	New	■	■	■	C	■	■	□	□	■	□	□	Formaldehyde (C)	●	●	●	●	●	●
															Acetaldehyde (C)	●	●	●	●	●	●
															Acetone (C)	○	○	○	○	○	○
S	Lin et al (2007)	Paint w/ alumn., gyps., conc.	New	■	■	■	C, E	□	□	□	□	□	□	□	TMPD-MIB (C, E)	○	○	○	○	○	○
S	Koivula et al (2005)	Insulation	New	■	□	■	□	■	□	□	□	□	□	■	-						
S	Kwok et al (2003)	Finishes, varnish	New	■	□	■	□	■	□	□	□	□	□	□	-						
S	Yu et al (2002)	Gypsum board	New	□	□	■	C	□	■	□	□	□	□	□	Formaldehyde (C)	●	●	●	●	●	●
H	Steinmann et al (2010)	Freshener, detergent	New	■	□	■	C	□	■	□	□	□	□	□	Acetone (C)	○	○	○	○	○	○
															Acetaldehyde (C)	●	●	●	●	●	●
															Benzaldehyde (C)	○	○	○	○	○	○
H	Fauser et al (2008)	Solvents	New	□	■	■	E	□	■	□	□	□	□	□	Methanol (E)	●	●	●	●	○	○
															Isopropylalcohol (E)	○	○	○	○	○	○
H	Coleman et al (2008)	Degreaser, freshener, cleaner	New	□	□	□	□	□	□	□	□	■	□	■	-						
H	Kwon et al (2007)	Cleaner, deodorizer, misc	New	□	□	■	□	■	□	□	□	□	□	□	Acetone (F)	○	○	○	○	○	○
															Limonene (F)	○	○	○	○	○	○
															Ethanol (F)	○	○	○	○	○	○
H	Destaillats et al (2006)	Cleaner, freshener	New	■	■	■	□	□	■	□	□	■	□	□	Acetic acid (%)	○	○	○	○	○	○
															Acetone (%)	○	○	○	○	○	○
H	Singer et al (2006)	Degreaser, cleaner, freshener	New	□	□	■	C	□	■	■	□	■	□	□	Limonene (C)	○	○	○	○	○	○
															Benzyl acetate (C)	○	○	○	○	○	○
H	Wensing et al (2005)	Plastic additive (flame retardant)	New	□	□	□	C	□	□	■	■	□	□	□	DEHP (C)	○	○	●	●	○	○
H	Kemmlein et al (2003)	Insulation, electronics (flame retardant)	New	■	■	□	□	□	□	■	□	□	■	□	TCPP (E)	○	○	○	○	○	○
															PBDE (E)	○	○	○	○	○	○
H	Zhu et al (2001)	Cleaner, paint, misc	New	□	□	■	C, E	□	□	□	□	□	□	□	2-butoxyethanol (C, E)	○	○	○	○	○	○

Note: ■ some information is available; □ not measured or data not available; ● compound listed; ○ compound not listed

Table 4. Expanded emission data and other information from peer-reviewed publications on building materials and products

Material classification	Materials/ components	Age of materials/ duration of use	Sample treatment/ techniques/ location	Median/GM emission data (µg/m²/ h)			Air exchange data	Other env. data/ effects	Ref.
				TVOC	Compounds/ VOC group/ VOCs	Aldehydes			
Floor system	PVC with Adhesive	1, 6, 12 mth(s)	FLEC, Active sampling on Tenax TA, field	<930 (1 mth) <350 (6 mths) <200 (12 mths)	12 mths: Acid 9, Alcohol 13, Aliphatic hydrocarbon 20, Aromatic hydrocarbon 12, Cycloalkane 0, Ester 15, Glycol 20, Ketone 6, Terpene 2	12 mths: Aldehyde 14, Formaldehyde 7	Not available	0, 6 mths: some effects of Rh and T, 12 mths: no effects	Jarnstrom et al 2007
	PVC (17% (w/w) plastisizer)	12 mths	FLEC, Active sampling on Tenax TA, lab	Not measured	Phthalate ester (DEHP) <1 µg/m³	Not measured	Not available	No effects of Rh	Clausen et al 2007
	PVC only (6 types)	1, 2 mths	FLEC, Active sampling on Tenax TA, lab	11-430	Acid 1-22, Alcohol 1-42, Aliphatic hydrocarbon 1-53, Aromatic hydrocarbon 1-131, Cycloalkane 1-25, Ester 1-17, Glycol 1-13, Ketone 2-10, Terpene 1-6	Not measured	Not available	None	Jarnstrom et al 2008
	PVC	472 days	FLEC, CLIMPAQ	Not measured	Phthalate ester (DEHP) <1 µg/m³	Not measured	Not available	Dust layer increased emission rate	Clausen et al 2004
	PVC, polyole-fine	6, 35, 62, 105, 150 days + 100 days (PVC only)	FLEC, CLIMPAQ	Not measured	PVC: DEHP 1 µg/m³; polyolefine: DBP 22 µg/m³	Not measured	Data available for CLIMPAQ measurement	No effects of ventilation rates	Afshari et al 2004
	PVC (5 types) on concrete, primer, screed, ahesives	1, 28 days	FLEC, CLIMPAQ	PVCs: 100-1,000; adhesives: 900-10,000	PVCs: TXIB 670 Diethylene glycol butyl ether 290 N-methyl pyrrolidone 31 2-ethyl-1-hexanol 13 Ethyl hexanoic acid 75 Phenol 46	Not reported	Data available for CLIMPAQ measurement	Adhesive: Lower VOCs emission rates but higher SVOCs in 28 days	Wilke et al 2004

Table 4. Expanded emission data and other information from peer-reviewed publications on building materials and products (continued)

Material classification	Materials/ components	Age of materials/ duration of use	Sample treatment/ techniques/ location	Median/GM emission data (µg/m² /h) TVOC	Compounds/ VOC group/ VOCs	Aldehydes	Air exchange data	Other env. data/ effects	Ref.
	Linoleum (3 types) on concrete, primer, screed, adhesives	1, 28 days	FLEC, CLIMPAQ	Not reported	Acetic acid 130 Hexanoic acid 28 Hexanal 28 Propylene glycol ether 7 Nonanal 5 Decanal 5	Not reported	Data available for CLIMPAQ measurement	None	Wilke et al 2004
	Carpet with backing (4 types)	1, 3 days	20lt (glass), 280lt (SS), 450lt (glass) and 30m³ (SS), Tenax TA	65-200 µg/m³	Benzene0-4.6µg/m³ Toluene 0-8.6µg/m³ 4-PCH 15-140µg/m³ 2-2-BEE 11-320µg/m³ Ethylbenzene Xylenes Styrene Ketone Acetone	Formaldehyde 14-24 µg/m³ Acetaldehyde 3.1-14 µg/m³	0.5 h^{-1}	None	Katsoyiannis et al 2008
	Carpet (2 types) on concrete, primer, screed, adhesive	1, 28 days	FLEC, CLIMPAQ	Not reported	4PCH 23, n-tridecane 5 Acetic acid 4100 Caprolactam 120 n-tetradecane 18 n-heptadecane 6 BHT 1 Ethylene glycol 25 1,2-propylene glycol 50 2-ethyl-1-hexanol 29 TXIB 7 n-hexadecane 7 Benzothiazole 2 Cyclohexanol 2	Not reported	Data available for CLIMPAQ measurement	None	Wilke et al 2004
	Carpet with polyurethane foam backing	3 days	Chamber (details were not given)	Not reported	Toluene 2,4-diisocyanate (TDI) 1.5 µg/m³	Not measured	Not available	None	Hugo et al 2004
	OSB made of Scots pine and bonded with pMDI	1 day – 2 mths	Active sampling, Tenax TA (sample conditioned)	Not reported	1 day: Terpenes 8567 13 days: Terpenes 3586 59 days: Terpenes 246 (VOC data available)	1 day: Aldehyde 66 13 days: Aldehyde647 59 days: Aldehyde 435	3.1 h^{-1}	None	Makowski et al 2005

Table 4. Expanded emission data and other information from peer-reviewed publications on building materials and products (continued)

Material classification	Materials/ components	Age of materials/ duration of use	Sample treatment/ techniques/ location	Median/GM emission data (μg/m² /h)			Air exchange data	Other env. data/ effects	Ref.
				TVOC	Compounds/ VOC group/ VOCs	Aldehydes			
	Particle board made of pine and bonded with UF resin	3, 28 days	Active sampling, ISO 16000-6, ISO 16000-3	3 days: 218.1 μg/m³ 28 days: 120.3 μg/m³	3 days (μg/m³): Alpha-pinene 50.3 Beta-pinene 9.4 Pentanal 14.2 Hexanal 65.5 28 days (μg/m³): Alpha-pinene 32.3 Beta-pinene 5.9 Pentanal 7.2 Hexanal 38.6	3 days (μg/m³): Formaldehyde 61.0 Acetaldehyde 14.5 28 days (μg/m³): Formaldehyde 57.6 Acetaldehyde 5.5	0.5-4.7 h^{-1}	None	Yrieix et al 2010
	Plywood (subfloor)	3 mths	Active sampling, Chrompack and Carbosieve S-III	Not reported	Alpha-pinene 278 Beta-pinene 69 d-limonene 113 Pentanal 28 Hexanal 169 Heptanal 4 2-Heptenal 5 Octanal 8 2-Octenal 12 Nonanal 22	Formaldehyde 11 Acetaldehyde 19	Not available	None	Hodgson et al 2002
	Water-based adhesive (8 types)	1, 28 days	FLEC, CLIMPAQ	Not reported	2-ethyl-1-hexanol 45 Hexanal 19 1-butanol 14 α-pinene 1.3	Not reported	Data available for CLIMPAQ measurement	None	Wilke et al 2004
	Adhesive for PVC (4 types)	1, 2 mths	FLEC, Active sampling on Tenax TA, lab	500-12,000	Acid 17-873, Alcohol 32-2463, Aliphatic hydrocarbon 1-5, Aromatic hydrocarbon 6-16, Cycloalkane 1-17, Ester 2-7206, Glycol 129-9084, Ketone 1-21, Terpene 1-48	Not measured	Not available	None	Jarnstrom et al 2008

Table 4. Expanded emission data and other information from peer-reviewed publications on building materials and products (continued)

Material classification	Materials/ components	Age of materials/ duration of use	Sample treatment/ techniques/ location	Median/GM emission data (µg/m² /h) TVOC	Compounds/ VOC group/ VOCs	Aldehydes	Air exchange data	Other env. data/ effects	Ref.
Wall system	Gypsum board	Not reported	Small chamber test	6-160	Alkanes, toluene, xylenes, trimethylbenzenes, 1-butanol, hexanal	Formaldehyde	Not available	None	Yu and Crump 2002
	Latex paints on gypsum board, aluminium, concrete (without primer)	New application – 100 hrs	Small chamber test, active sampling, Tenax TA	Not measured	TMPD-MIB 5-100 hrs (mg/g/h): Aluminium 22-0 Gypsum board 5-0.5 Concrete 1.5-0.1	Not measured	Not available	None	Lin and Corsi 2007
Household products and equipment	Air freshener (3 types), laundry supply (3 types)	To be added (paper under review)	To be added (paper under review)	Not measured	Identified as hazardous: Acetone, benzaldehyde, tert-butyl alcohol, 2-butanone, chloromethane, 1,4-dioxane, ethanol, ethyl acetate, isopropyl alcohol, alpha-pinene	Acetaldehyde	To be added (paper under review)	None	Steinemann 2010
	Pine oil-based cleaner, plug-in air freshener	2-4hrs	Active sampling, Tenax TA with Chrompack TCT 4020, DNPH, Particle sizer SMPS	Not reported	Yield (%): Acetic acid, formic acid, acetone	Yield (%): Acetaldehyde, formaldehyde	1, 3 hr^{-1}	ACH and ozone level affect SOA (OH)	Destaillats et al 2006
	Cleaning products (5 types), air freshener	0-60 mins and 1-24 hrs	50m^3 chamber, simulated –use, active sampling, Tenax TA only or Tenax TA and Carbosieve III	Not reported	Cleaning products: d-limonene, ethylene-based glycol ethers (direct dilution: terpene hydrocarbons and alcohols) Air freshener: d-limonene, dihydromyrcenol, linalool, linalyl acetate, citronellol, alpha-citral, 3,7-dimethyl-3-octanol, benzyl acetate, borryl acetate	Not measured	0.5 hr^{-1}	None	Singer et al 2006

7. VISION FOR A COMPREHENSIVE DATABASE

7.1. Attributes of material and product emissions databases

A regularly updated database that provides comprehensive information and key emission indicators for building materials and indoor products would be valuable. Although our review has found that no such database exists, several newly developed databases have the potential to be developed into such a comprehensive material and product database. Based on available information, a comprehensive emissions database could encompass the following five important elements:

1. General material and product information
    - Category (main category)
    - Sub-category (type of materials/ products)
    - Description (physical description and quantity)
    - MSDS (chemical contents, toxicity, health and safety data, compliance)
    - Manufacturer information (address, contacts, and specialization)
    - Related materials (similar items from other manufacturers)
    - Alternative contents (optional "green ingredients" in the formulation)

2. Emissions testing and results
    - Objective of testing (purpose of measurements)
    - Standard methods used for testing
    - Duration (materials age or duration of product application)
    - List of pollutants (targeted or detected compounds)
    - Emissions description (concentrations and emission factors)
    - Environmental or chamber test conditions (temperature, relative humidity, air exchange rate)
    - Test chamber or room description (size, materials)
    - Interaction effects (ozone, sorption, etc)
    - Identified pollutants of concern (according to health-based references)

3. Certification information
    - Certification or rating system (name, type, country, commercial or non-profit)
    - Laboratory (name of the certified laboratory or third-party verifier)
    - Sampling and test methods (standard methods)
    - Testing conditions (show compliance with standard)
    - Sensory evaluation (mostly conducted in Europe)
    - Reference standards (standards used for certification)
    - Period of validity
    - Record of periodic tests
    - Link to download certification

4. Material or product application (when applicable)
    - Use or application of material/ product (home, school, etc.)
    - Quantity used (volume/ area/ frequency/ amount of material)
    - Estimate of personal exposure (scenario-based exposure model)

5. Life-cycle assessment
    - Material contents degradation assessment
    - Long-term emissions data
    - End-of-life/ recyclable assessment

Elements 1-3 can be extracted from various sources whereas information concerning elements 4-5 is mostly unavailable. For example, the Pharos Project database compiles most points listed under element 1. Research publications and technical reports mostly contribute to element 2, and online databases from certification systems provide most of information under element 3 as well as some information for element 1.

Although many databases provide needed information, it is challenging to combine these data sets for several reasons: 1) different databases do not use the same data fields or categorizations, 2) the level of detail varies greatly among scientific reports, 3) emissions data from scientific publications could not be matched with product content descriptions or manufacturing data, 4) different testing standard methods are used[39], 5) for databases or emission tests results from other regions (such as BUMA, IA-QUEST, and the European certification system), the materials and products tested may not be the same as those distributed in the US, and 6) the numbers and types of items tested by research laboratories are not equal to those evaluated by the certification systems and their verifiers.

7.2. Developing a new emissions database and beyond

It is obvious that a concerted effort is needed to produce a comprehensive database. Through the review process, we have identified the key players that would contribute to the development of such a database. Figure 6 diagrams the flow of information for the database. Whereas all sectors will contribute to the database, testing laboratories appear to hold the key to most of the information concerning emissions behavior, test methods, and reference standards used. To extract information from these laboratories, consent needs to be obtained from the product manufacturers. Another method is to request the emissions data directly from the manufacturers.

A reporting process by stakeholders is therefore recommended with an organizing body – preferably led by a research institution – to specify and design the database architecture. Important information such as potentially hazardous pollutants or new compounds can provided to manufacturers as input for improving material or product formulations and to regulators for review and testing recommendations. The database would also provide timely updates to various organizations so that they can update their standards, and a list of target pollutants based on testing of new materials or products.

[39] Of note, California Specification 01350 presents a testing and benchmarking system that can be adopted as universal method for materials and products evaluation in the future.

Because of the level of cooperation needed between the different stakeholders, it is obvious that an enormous initial effort will be needed to establish a sustainable work flow and a reporting system. This effort will gradually decrease with proper coordination and the integration of automation in the data submission and retrieval process.

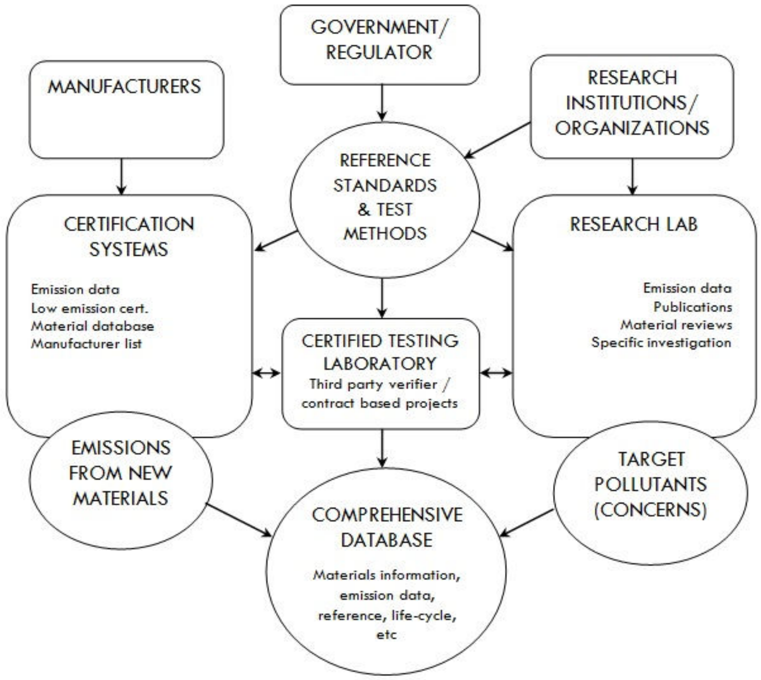


Figure 6. Schematic diagrams of material testing and database development flow

8. CONCLUDING REMARKS

This report provides a summary record of databases and recent publications, reviews, and technical reports related to the emissions behavior of residential building materials and products.

A notable number of databases for construction and indoor materials as well as household products are available from various certification systems. However, these databases collectively contain only a fraction of items available in the market today because of the focus of the database developers on low- emission materials or products. Because of increasing demand for green and healthy homes, low-emission materials and products will likely make up the majority of the new generation of materials and products. Therefore, the inclusion in these databases of emissions data for not only currently targeted compounds but also for the whole spectrum of detected compounds will be instrumental for identifying chemicals of concern in new or future homes.

In the U.S. there is currently no comprehensive, up-to-date database with complete chemical emissions data for residential materials that impact indoor air quality. There are, however, a number of databases that provide different parts of the picture. For example, VOC content data are provided by manufacturers in form of MSDSs and are commonly included in databases from certification organizations. By contrast, detailed VOC emissions data are only reported in peer-reviewed journals or technical reports from research institutions. The rather outdated information is incorporated in material and product libraries in indoor air quality emissions modeling software. There is currently no ongoing effort in the U.S. to develop a new or to update any existing emissions database. More recent databases that include emissions data are being developed in the EU.

Our review of recent publications confirms that various regulated pollutants of concern are still emitted from common materials and products currently used in residences. For example, formaldehyde and acetaldehyde are emitted by manufactured wood products, gypsum board, and photo catalytic paints and cleaners; naphthalene is emitted by additives; xylene is emitted by treated wood-based floor; and limonene is emitted from cleaning liquids. To be considered candidate chemicals with potential health hazards for addition to REL list are caprolactam (emitted by nylon-based carpets) and 2-butoxy ethanol (emitted by resilient flooring). Of note, OEHHA has recently issued a draft proposal for caprolactam REL value. No REL value has been proposed for 2-butoxy ethanol. Diisocyanate– HAP and toxic contaminant –is detected in carpet with polyurethane foam backing. EPA has recently cautioned against methylene diphenyl diisocyanate (MDI) exposure during application of spray polyurethane foam insulation. Toluene 2,4 diisocyanate (TDI), an asthma causative agent, is detected in carpet with polyurethane backing. OEHHA has also issued draft proposals for REL values for MDI and TDI. DEHP and DBP are two phthalates detected from flooring materials. EPA lists both as HAPs. 4-PCH emissions from carpet systems and Texanol from various building products are also possible causes for concern. Table 5 lists some compounds of potential concern identified from this review.

The number and variety of current databases can be confusing to the builders and consumers. We have presented a vision for a new comprehensive database containing key information from the various existing materials or products databases as well as other sources. We highlight the key role of research/ testing laboratories in the development of a comprehensive database, the much-needed support from other stakeholders such as manufacturers and regulators to provide access to information, and the need for an organizing body to design the architecture of the database.

Table 5. Some compounds of potential concern, their sources and reported health risks

Potential compounds of concern	Materials or products	Remarks
2-Butanonoxime	Paints	Allergic reaction and cancer risk
2-Butoxy ethanol	Resilient floor, cleaners	Potential carcinogen, irritant, blood pressure and metabolic effects
4-Nonylphenol and Nonylphenol ethoxylates	Disinfectant and cleaners	Potential hormonal disruptors
4-Phenylcyclohexene (4-PCH)	Carpets	Strong odorant, potential neurotoxic and reproductive effects
Bisphenol A (BPA)	Epoxy resins	Neurological development, cancer risk, heart disease, reproductive system, etc
Caprolactam	Nylon carpet	Irritant, toxicant
DEHP and DBP	Plasticizers in PVC flooring	DEHP: potential carcinogen; DBP: irritant, toxicant
Methylene diphenyl diisocyanate (MDI)	Spray polyurethane foam	Sensitization, asthma, dermatitis
Methanol	Solvents	Nervous system depressant, toxicant
Texanol (TMPD-MIB)	Resins and paints	Limited exposure study, concern due large production volume and wide applications
Toluene 2,4 diisocyanate (TDI)	Carpet polyurethane backing	Asthma causative agent
TXIB	PVC flooring	Strong odorant, irritant, potential reproductive toxicity

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