CALIFORNIA INDOOR AIR QUALITY SPECIFICATIONS FOR OPEN OFFICE SYSTEMS FURNITURE AND BUILDING MATERIALS

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ABSTRACT

California has a long history of contributing to increased understanding of indoor air quality issues and the means to enhance the quality of air in buildings. This paper describes the evolution of selected IAQ activities in California. It focuses on the indoor air quality aspects of the open office systems furniture specification, volatile organic compounds (VOCs) emissions testing protocol for building material selection including summary results from the first completed building, and a recently-completed study of emissions of building materials by the Department of Health Services (DHS). The reader is referred elsewhere for more details on California's other sustainable building efforts, including issues related to indoor air quality other than those discussed herein.[1, 2, 3, 4]

The emissions testing protocols developed in California during the past two decades have resulted in a practical and effective tool to improve indoor air quality while minimizing the individual manufacturers' financial burden to obtain acceptable emissions test results to meet individual project requirements. These protocols are designed to improve the public health aspects of IAQ and to improve on the results from emissions testing.

INTRODUCTION

Californians have been leaders in addressing indoor air quality issues since the late 1970s. As a result of IAQ problems in some innovative, energy-conserving office buildings, the California State government began including consideration of IAQ in its building projects in 1981.[5] Throughout the early 1980s, the State began addressing IAQ as an explicit part of its facilities programs.[6,7] A multi-disciplinary IAQ program was established by the California Legislature at the State Department of Health Services (DHS) in the mid-1980s; it was the first such program in the U.S. and remains one of the leading programs of its kind in the nation.[8]

A number of landmark projects completed by DHS include a major study of formaldehyde in mobile homes.[9, 10] That study formed the basis for the California Air Resources Board (ARB) guideline target concentration of 50 ppb for formaldehyde in indoor air.[11] In the early 1990s, in response to a mandate from the California Legislature, the DHS IAQ program developed guidance on controlling VOCs in buildings.[12] The recently-released study (described later in this paper) of emissions from conventional and alternative building materials conducted by DHS and supported by the California Integrated Waste Management Board compared

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emissions from "standard" and alternative products including those with high recycled content.[13]

The California Air Resources Board has also played a role in leading California's efforts to improve indoor air quality and reduce human exposure to indoor air pollutants. It established an IAQ program in the mid-1980's to develop indoor air guidelines and a research program using the total exposure assessment approach to identifying and listing toxic air pollutants on the ARB Toxic Air Contaminant (TAC) List. [14] [15] Three important emissions test studies have been supported by ARB (Hodgson and Wooley,[16] Kelly,[17] and Hodgson[18]). These surveys have provided valuable information on the emissions of chemicals of concern from major indoor sources.

In the late 1990s, the Office of Environmental Health Hazard Assessment (OEHHA) began publishing Reference Exposure Levels (RELs) for acute and chronic non-cancer health effects.[19] These are based on consistent risk assessment methods and reflect the latest and most relevant literature. There are now 78 Chronic RELs (CRELs) intended to establish "safe" exposure levels for general population exposures that have been the basis for the most recent IAQ control efforts related to the new State office building complex and the materials emissions test study. OEHHA adds new substances to the list as assessments are completed. The CREL values have been important in the attempt to incorporate potential public health impacts into the criteria and procedures for evaluation of emissions test results. OEHHA also promulgates Proposition 65 "safe harbor" values for cancer risks.[20] Some of the OEHHA values are cited by the U.S. EPA in its updates of reference concentrations in the IRIS database.[21] The CRELs form the basis for the California specification (described later in this paper).

Prior non-State Governmental and Other Developments Leading to the Emissions Testing Protocol

Pacific Bell Administrative Center, San Ramon, CA

Private sector and other non-state government buildings were affected by the attention paid to indoor air quality by the news media. In the mid-1980s, the first reported private sector emissions testing was conducted on carpet tiles, open office work station components, and ceiling panels for the new Pacific Bell Administration Center in San Ramon, California, designed to house 7,500 employees. Those products were selected for testing on the basis of their relative surface areas in the absence of any relevant literature on emissions from specific products For example, exposed workstation panel surface areas were estimated to be 3.5 times the floor area where they were to be located.

As a result of that testing, recommendations were made on the selection of carpets, the aging of ceiling panels, and on modifications to the office furniture systems. In the case of the latter, recommendations were made to reduce formaldehyde emissions from the work surfaces[22, 23, 24]. The emissions testing conducted at that time was simple and crude compared to current, more robust emissions testing protocols. The chamber used was a 1.3 m^3 galvanized steel box with primitive control of temperature and airflow compared to the typically sophisticated, temperature and humidity-controlled environments in the stainless steel emissions test chambers used today. VOC samples were collected on charcoal adsorbents and solvent-desorbed using carbon disulfide resulting in far less sensitivity than today's Tenax™ sorbents and thermal desorption.

U.S. EPA Headquarters, Washington, DC

In 1988, following installation of new carpeting at the U.S. EPA's Headquarters building at Waterside Mall in Washington, DC, many employees reported irritation and health symptoms. At that time, U.S. EPA's Division of Administration was planning a new headquarters building to be built in the District of Columbia. A draft Solicitation for Offers (SFO) had been prepared, but it lacked provisions for assurance of good IAQ. One of the present authors (Levin) was retained to write an IAQ section for the SFO. Material surface area or mass to space volume ratios were used to select target products for emissions testing. In addition, products suspected or known to emit toxics were also identified for testing. Meanwhile, Congressional hearings on proposed IAQ legislation focused attention on the problems at the U.S. EPA Headquarters building at Waterside Mall. Language inserted into the Bill considered by the House of Representatives required that the U.S. EPA's new headquarters be a model of good indoor air quality. The Bill was not adopted and the SFO for a new headquarters building was never issued. However, many of its provisions were used or adapted for use in the development of new facilities for the U.S. EPA in Washington and later in Research Triangle Park, NC.

ASTM Standards

In 1985, Subcommittee D22.05 on Indoor Air was formed in the American Society for Testing and Materials (ASTM). Since that time, one of the central themes of the work has been development of standardized methods for sampling and analysis of indoor air. Among these standards is the widely-used standard guide for emissions testing, ASTM D5116-97, first adopted in 1990 and revised in 1997.[25] This standard was based on development of procedures for emissions testing by U.S. EPA's Office of Research and Development and has been the basis for small chamber emissions testing in Europe and North America. More than 30 additional standards have been developed for measurement of organic compounds and many other substances in indoor air as well as for procedures for using sampling and analytical equipment and for interpretation of results of measurements.[26] ASTM Subcommittee D22.05 on Indoor Air has also sponsored six symposia resulting in peer-reviewed "Special Technical Publications." Among these is arguably the most comprehensive and important single publication on emissions testing, STP 1287, *Characterizing Sources of Indoor Air Pollution and Related Sink Effects*, edited by Bruce Tichenor, formerly of U.S. EPA's Office of Research and Development.[27]

San Francisco Main Library

In the early 1990s, a new building was designed to serve as the Main Library for the City and County of San Francisco. Concerns about IAQ led to the inclusion of materials testing requirements in the bid documents for the project.[28] Materials were classified as shown in Table 1.

Table 1. Classification of materials and products according to review of product data

Class	Description
1	Acceptable as is
2	Acceptable with specific installation procedures (e.g., temporary ventilation)
3	Acceptable in small quantities or at specific locations
4	Acceptable with preconditioning
5	Acceptable with modification (e.g., encapsulation)
6	Unacceptable. Manufacturer was requested to reformulate and re-test product

Many precursors of the requirements in the emissions testing specifications for State of California projects discussed below were developed for the SF Public Main Library building project.[29, 30, 31] Products were selected for testing on the basis of an analysis of the mass or area of the material in comparison to the volume of the space in which the material was to be installed or on the basis of other identified potential to affect indoor air quality adversely.[32 33]

In general, this was seen as a "screening" procedure to identify products emitting chemicals likely to result in concentrations of concern using available relevant guidelines and Threshold Limit Values[34] adopted by public health and governmental bodies. Where such values were not available, a limited review of available literature was conducted. Specific criteria for pass-fail were not established for most individual chemicals. Instead, individual chemical compound emissions were reported and the project IAQ consultant [first present author] reviewed the emissions to determine the acceptability of the product for inclusion in the project. Exceptions included the State's guideline target concentration of 50 ppb formaldehyde adopted as a specific criterion and a few others including, styrene, formaldehyde, and a few others. Additionally, to avoid the potential presence of the odorous compound characteristic of new carpets, SBR latex rubber backed carpets were excluded from the project.

It was assumed by the design team that the major sources of formaldehyde would be the office workstations, library furnishings, and ceiling tiles. Therefore, each of these sources was limited to half the total emission limit of 50 ppb formaldehyde based on a calculated concentration. In the end, the ceiling tiles, made from fiberglass with a formaldehyde-based binder, were encapsulated with a polyester (top) and Mylar™ - polyvinylflouride film - (bottom), less than 1 mil (1/1000 of an inch) thick to suppress formaldehyde emissions from them and protect them from contamination by pollutants in the return air plenum.

Various other building projects in California and elsewhere have been constructed using requirements similar to those used for the San Francisco Public Library. The experience gained in these projects was applied in developing the requirements for the State of California projects described below.

California State Governmental Developments Leading To The Emissions Testing Protocol

The development of California's first building-related environmental specification started in early 2000, when DGS's Procurement Division was in the process of issuing a request for bids for a three-year, $60 million open office systems furniture contract. The Green Team, a group of state agencies advising DGS on sustainability issues for this project, and the CAEEC Management Team realized that about 6,000 workstations would need to be purchased for this project. The enormous amount of effort that had been put into enhancing the indoor air quality of the CAEEC project, made the sustainability aspect of this purchase a high priority. To address this issue, the Green Team (led by this paper's second author) worked with DGS, other state agencies, the systems furniture industry, and a private consultant (first present author) to issue a benchmark environmental specification for procuring modular office systems.

The specification was issued in December 2000, and included testing and selection criteria for indoor air quality as well as requirements for recycled content and energy-efficient lighting.[35] In early 2001, the State selected the successful bidder who met the environmental

specifications at a price 38% lower than the State was paying under the previous contract.[36] In addition, the California Prison Industry Authority, which has first right of refusal for state furniture purchases agreed to abide by this specification. Therefore this specification is now used for all state-funded projects and by some local government authorities.

The specification developed for modular office systems was considered in the development of the environmental specification for screening building materials by one of the two CAEEC design-build teams. This specification, *Special Environmental Requirements, Specifications Section 01350,*[3] (described later in this paper), includes emissions-testing procedures, maximum allowable concentrations for selected VOCs, minimum recycled content requirements, and certification of recycled materials. Section 01350 has now been rewritten for use on other projects such as the Collaborative for High Performance Schools initiative and is available on the Internet.[7, 8] It is incorporated in DGS's Standard Agreement as a resource document for all professional architectural and engineering services.[9]

The State of California is working to widen the application and impact of environmentally improved building approaches. One of the goals of the State is to increase markets for products with recycled-content, thus diverting materials from landfill disposal. Because little was known about the emissions of building materials with recycled-content, the CIWMB funded the Public Health Institute (PHI) with DHS as Principal Investigator to conduct a laboratory-based research study. The main objective was to compare the emissions of building materials commonly used in classroom and state office building construction to alternative products containing lower-emitting, rapidly renewable, and higher recycled-content materials.

The modular office furniture specification, the emissions testing protocol for building material selection, and the study of emissions of building materials are discussed below.

Modular Office Systems Furniture Indoor Air Quality (IAQ) Specification

The specification[37 38] drew from ASTM Standard D5116-97 and the U.S. EPA-Research Triangle Institute's Environmental Testing Verification (ETV) testing protocol. The primary requirements of this specification are listed in Appendix A. Based on published data on the decay rates of various building materials, it was the judgment of the consultants with the concurrence of the State officials that a 10-day conditioning period followed by 4 days of testing was sufficiently long for the initial evaporation-driven emissions to dissipate. Thus, it was concluded that the test results from the revised protocol would yield reliable and useful results without the high cost of the 14-day testing used previously for the State of Washington and the proposed Environmental Testing Verification program/Business and Institutional Furniture Manufacturers Association (ETV/BIFMA) testing protocol. This saves considerable expense to the manufacturers and allows more systems to be tested in the severely limited available large test chambers. The details were commented upon by several industry representatives as well as by staff of the primary private testing laboratory. The details are listed in Appendix A of this paper.

The criteria used were those of the European VOC guideline document[39] The successful bidder for this state contract reported detectable levels of alpha-pinene, beta-pinene, limonene, pentanal, and hexanal. At 0.5 air changes per hour (ach), the adjusted chamber concentrations for the seven chemical classes and the SumVOCs were well below the guideline values. However, in the case of formaldehyde, the adjusted chamber concentration

of 38 ppb above background at 0.5 ach, exceeded the recommended 20 ppb concentration limit.

When the tested workstation components were tested separately in the same chamber, it was found that adjusted chamber concentrations of: (a) the work surfaces; and (b) the panels systems' acoustical boards were 6.5 ppb and 22 ppb respectively at 0.5 ach. Over the next year, the furniture manufacturer worked with the fiberglass manufacturer to reduce the formaldehyde levels from the acoustical boards. The fiberglass manufacturer was unable to produce a low formaldehyde-emitting acoustical board consistently due to slight variations in the curing process of this product. The furniture manufacturer was able to meet the 20 ppb requirement before the 12-month contractual "grace" period expired by airing the acoustical boards for a period of 37 days prior to assembly, at which point the adjusted chamber formaldehyde levels from this component were reduced to less than 10 ppb at 0.5 ach. The furniture manufacturer and the fiberglass manufacturer agreed to air out the acoustical boards at a dry, well-ventilated, independent processing facility.

As a result of the California specification, the fiberglass manufacturer recently announced that they eliminated formaldehyde emissions from all their products, including acoustical boards. The furniture manufacturer is looking into other types of acoustical boards with non-formaldehyde resin-based binders such as soy-based foam and a material with similar composition to ceiling tiles. The same manufacturer also is investigating the soy-based foam as a formaldehyde-free replacement of the particleboard surfaces. When the current State contract expires and a new specification is issued for bids, the State's formaldehyde requirement is likely to be reduced even further from the present value. It is clear that California's stringent requirements have stimulated systems furniture manufacturers to address some of the strongest sources of formaldehyde emissions in their products.

This specification is now more widely used throughout the United States. As a result, future office building occupants, not only in California but elsewhere, can benefit from reduced emissions of formaldehyde and other VOCs from new workstations. The manufacturer has indicated an interest in developing an ASTM standard for the protocol used in testing the office furniture systems.

Capitol Area East End Complex (CAEEC)

Under the administration of Governor Gray Davis, in 1999 the California State's Legislature directed the Department of General Services (DGS), the agency responsible for the construction of most state government buildings, to incorporate "sustainable" building measures into the design and construction of a new $392 million state office building complex in Sacramento. Known as the Capitol Area East End Complex (CAEEC), this five-building, 140,000 m^2 (1.5 million ft^2) complex is the largest state government office construction project in California's history and was completed in early 2003.

A multi-agency "Green Team" was formed to work with DGS to integrate "sustainable" building measures into this project. The Green Team was composed of representatives from the Department of Health Services (DHS), California Integrated Waste Management Board (CIWMB), California Energy Commission (CEC), and Air Resources Board (ARB). The measures included general requirements for enhanced indoor air quality, benchmark protocols for testing and selecting open office systems furniture and building materials based on their emissions of volatile organic compounds (VOCs), minimum requirements for

recycled content of numerous building materials, and other energy and water efficiency requirements.

The new office building complex contracts were awarded to design-build teams based on criteria that included 20% of the scoring for each team's experience in sustainable construction as well as environmental enhancements offered to the State. The first building in the complex, known as Block 225 and now occupied by the State's Department of Education, was developed by a diverse team of consultants with extensive experience in environmentally-responsive building including indoor air quality and ventilation system design. That team included this paper's first author who brought much of the experience described above to the task of developing the specification for materials selection. Working together with other members of the team, the consultant developed detailed requirements for materials emissions testing. Those requirements were embedded in the construction documents as Section 01350 of the Specifications. That specification section was later applied to the remainder of the four buildings now occupied by the Department of Health Services.

Special Environmental Requirements Specifications for Building Materials (Section 01350)
In its present version, the indoor air quality portion of Section 01350 requires:

- Test results supplied by manufacturers of products considered for inclusion in the project specifications
- Specific procedures for test specimen preparation
- Conditioning of test specimens for 10 days at 23±2°C and 50±10% Relative Humidity, followed by a 96-hr test.
- After completion of conditioning, sample collection at 24, 48 and 96 hr based on small chamber tests as per ASTM Standard D5116-97. Samples are collected at each time point for TVOCs and formaldehyde and at 96-hours for individual VOCs. The 24 and 48 hour test results are used for quality control purposes only and are not used to determine pass-fail against the criteria.
- Identification of the following chemicals of concern as listed by Cal-EPA:
  - Chemicals listed as: (a) probable or known carcinogens, or (b) reproductive toxins.[40] The responsibility for addressing the presence of known carcinogens or reproductive toxins is that of the manufacturer of the products and may result in preparation of a risk assessment or labeling the product as required by Proposition 65.
  - Chemicals with established Chronic Reference Exposure Levels (CRELs). A CREL is an airborne concentration level that would pose no significant health risk to individuals exposed to that level over long periods. CRELs are based solely on health considerations and are developed from the best available data in the scientific literature.[41]

The conditioning and testing sequence is deemed useful in providing values that are a reasonable compromise between the "worst case" values given by a 24-hour time point test and a long term test. The 14-day test point is in contrast to the 24 hour and 96 hour test points commonly used in other certification and labeling test protocols. The 14-day test point also reduces the need to conduct tests at loading ratios specific to different buildings and the need for multiple tests. This is because at the 14 day test point VOC emissions from most materials are diffusion-limited. Thus, the loading ratio is not a significant determinant of emission rates.

The emissions factors calculated from the small chamber tests for each of the identified chemicals of concern are then used to estimate the "modeled" indoor air concentrations for the specific intended building application using the building's ventilation rate, the quantity (surface area, length, or units) of the material to be installed, and the ventilated volume of the space (assumed to be 90% of the volume calculated from the plans) where it is to be installed. Section 01350 requires that modeled indoor air concentration of any chemical at 96-hr not exceed half of the CREL. Formaldehyde is an exception. For formaldehyde, no single product's modeled concentration can contribute more than half (13.5 ppb) of the total maximum 27 ppb concentration limit for this chemical. The 27 ppb guideline is based on Cal-EPA's current acute 1-hour Reference Exposure Level (REL) of 76 ppb (94 $\mu g/m^3$), extrapolated to an 8-hour exposure period.[42]

This specification also has special requirements for adhesives and cleaning/maintenance products. It requires that no carcinogen or reproductive toxicant be present at more than 1% of the total mass of the product. This compliments DGS's specifications for cleaning/maintenance products and their published list of such products[43, 44] as well as their current efforts to improve these specifications.

At the CAEEC, most manufacturers whose products were used in large quantities provided the required information. However, some manufacturers whose products were used in small quantities were not willing to provide the required information due to the additional cost involved. As more projects require that such specifications be met, an increased number of manufacturers will undoubtedly provide such information. At this point, numerous materials have been tested according to this specification, and most manufacturers are willing to provide this information to clients and their architects.

Indoor Air Testing at CAEEC Block 225

As part of the IAQ Commissioning, air sampling was conducted at Block 225 on 6 different occasions starting when the building was enclosed before furniture, after furniture, twice more before occupancy, and twice after full occupancy. Different ventilation protocols were used during various test days, and ventilation rates were measured using tracer gases in order to be able to calculate emission rates based on concentrations and volumes. The results demonstrated that the individual materials emissions testing data predicted the building concentrations with reasonable accuracy.

The air sampling results also showed that expected decay in emission rates occurred as materials aged. For example, the calculated emissions factors for one chemical (caprolactam) emitted only from a single source (carpet fibers) decreased steadily over the period of our testing. Note that even the highest concentrations of this chemical (measured on the first test day) were less than 1/10 the OEHHA interim concentration limit. Table 2 shows the emission factors in micrograms per square meter of floor area per hour over the test periods.

Table 2. Calculated Caprolactam emission factors on the 6th floor, southwest perimeter location (source data from Berkeley Analytical Associates and Indoor Environmental Engineering)

Date:	**2/28/2002**	**4/2/2002**	**6/28/2002**	**10/29/02**	**6/5/2003**
ach:	3.1	3	1.3	0.9	0.8
$\mu g/m^2$-h:	96.7	86.4	79.0	13.3	11.5

Finally, the results showed that new VOC sources were introduced during the final touch-up and clean-up procedures prior to occupancy and again after occupancy by the building occupants and their equipment, supplies, and other articles.

Building Material Emissions Study (BMES)

Objectives

In order to determine the effect of materials with recycled content in relation to indoor air quality, it became clear that emissions data were required for alternative "sustainable" materials and their standard building materials counterparts. This need prompted the CIWMB to fund a laboratory-based, three-phase study by the Public Health Institute (PHI), with the Department of Health Services (DHS) being the Principal Investigator.[45] The study focused entirely on those building materials with indoor air quality implications and consisted of three phases:

(a) Phase I focused on building materials used for permanent and portable classroom construction in California;
(b) Phase II focused on materials specific to state construction; and
(c) Phase III focused on tire-derived resilient flooring products.

The study had the following four main objectives:

1. To measure emissions from alternative sustainable materials and compare them to those emitted from standard material counterparts.
2. To measure chemical emissions from tire-derived resilient flooring and compare them to those emitted from their non-tire-derived counterparts.
3. To investigate the applicability of *Section 01350* as a screening tool for alternative and standard building materials.
4. To identify additional chemicals of concern to the State using the test methods and reporting procedures described in *Section 01350*.

Alternative materials, as defined for the study, do not only include recycled-content products, but also take into consideration the State's definition of an *Environmentally Preferable Product* as "a product that promotes healthy indoor environments…." (Public Resources Code Section 42635) Such materials utilize increased amounts of recycled content and other environmental features with the goal of reducing impacts to the environment during their production and disposal. While a complete Life Cycle Assessment would have been the most desirable approach for this study, the main emphasis focused on materials' efficiency, including recycled-content products and their impact on IAQ. It is also important to note that some standard materials include various amounts of recycled content while some alternative materials include low or no-recycled content, but have enhanced IAQ features.

Test Protocols

The study utilized the Section 01350 emissions testing requirements and protocols. Standard building scenarios were created for portable classrooms, offices, and auditoria for estimating concentrations resulting from use of each material tested. The study also targeted odorous compounds and the most abundant compounds, and it identified possible additional chemicals of concern to the State. In all, 121 target compounds were identified for testing.

An effort was made to obtain materials directly from manufacturers immediately after material production. However, not all manufacturers provided material samples, so some were obtained from retail outlets. Since products were obtained from both sources, results

should be interpreted cautiously. The emissions from samples obtained from manufacturers directly after production and products obtained from commercial sources may differ significantly. While all study samples were conditioned for ten days before commencing the 96-hour test period, some significant differences in environmental history may exist between and among samples obtained from diverse sources. The emissions in a short-term test may be affected by product age, packaging, storage, transport, environmental conditions, exposure to emissions from similar or dissimilar products, and other factors. Longer-term tests may be less affected by such differences. The ten-day conditioning period specified in Section 01350 decreases the potential differences, but it cannot completely eliminate them.

Summary of Key Findings

- Both standard and alternative materials exceeded Section 01350 concentration limits more or less equally. One possible reason for this similarity is that several of the standard products have characteristics (e.g., the amount and type of recycled content) similar to the alternative products,.
- Alternative materials performed similarly in both classroom and state office calculations.
- Twice as many standard products exceeded Section 01350 concentration limits for the state office calculations than they did for the classroom application. This results from the impact of two factors on the estimated concentrations:
  1) Approximately three times the dilution of emissions is provided by ventilation in classrooms than in offices, and
  2) the ratio of the area of the material used to the ventilation rate changes with the different scenarios configurations and amounts of each material used. This is especially true of materials used on walls since the office scenario was based on a small private office.
- The majority of the products that exceeded Section 01350 concentration limits did so by exceeding the limits for only one chemical.
- Section 01350 concentration limits most frequently exceeded were naphthalene, formaldehyde, and acetaldehyde, compounds with low CRELs.
- An interim concentration limit for caprolactam and the odor thresholds for octanal and nonanal were exceeded by several carpet samples,
- Although only 4 of the 11 tested tire-derived products exceeded Section 01350 for one chemical for the classroom and state office calculations, all 11 products emitted a large number of compounds, in some cases more than a hundred, that were not reported because the individually constituted less than 1% of the total ion current area of the chromatogram. However, the aggregate sums of their areas was significant. The emission of these compounds warrants further investigation.

Discussion of the Building Materials Emissions Study

Low-emitting building materials are available within each of the major categories studied. Many products tested emitted chemicals at rates that result in calculated concentrations that exceed the concentration limits used in the study. Limits were exceeded by more or less equal proportions of both standard and alternative products.

Some of the results reported in this study are inconsistent with those reported by industry-supported product certification programs such as CRI Green Label for carpets or 'low-' or 'no-VOC' labels for paints. These inconsistencies can be attributed to: (a) the differences in the sampling and analytical techniques employed by these programs and those used in the study; or (b) to the definitions upon which these labels are based. Other researchers have

reported similar discrepancies between their findings and those of industry-supported programs. (See, for example, the study of carpets by Hodgson et al, for the Consumer Products Safety Commission.[46]) Based on the results of the study, manufacturers should conduct product testing according to Section 01350 through independent laboratories.

DISCUSSION

Overall Summary

The California program of emissions testing results from the combined efforts of both the public and private sectors. It moves emissions testing from the realm of inter-product comparisons toward that of public health protections. This is accomplished by comparing results from emissions testing to health-based criteria to determine the acceptability of a material's estimated concentrations based on emission factors, amount of material used, and ventilation for a particular application.

Specific Issues Addressed

Cost of "Green" Building Products

The office furniture contract demonstrates that "green" does not necessarily cost more. In fact, resource conservation may, in some cases, offset the additional costs involved in the procurement of environmentally preferable products.

Use of Existing and Future Emissions Data

Depending on the methodology used, it may be possible to apply existing emissions test results to any similar new application without re-testing. This provides manufacturers with the ability to inform potential building designers, specification writers, and other purchasers of the likelihood that a product will be acceptable in a given application without delays for further testing. As more and more products are tested, (approximately 70 were tested for CAEEC and another 70 for the Building Material Emissions Study) it will be routine for designers to rely on these test data to determine whether a product can meet the criteria for their intended application.

Unresolved Issues

Specimen Acquisition

There are still issues to be resolved. One is the process for collection or acquisition of samples for testing. If products are purchased on the open market, it is not easy to determine their age and environmental exposure history. While the specified 10-day conditioning may reduce the uncertainty associated with purchasing products for testing on the open market, it is not able to guarantee that the purchased product accurately reflects the product that will be delivered to the building project. On the other hand, relying solely on manufacturers to supply products to test laboratories potentially creates other uncertainties. One way to ensure representative test specimens is to include in construction documents a requirement that the products supplied to the project must perform within a certain percentage (*e.g.*, ±25% or ±35%) of those submitted for testing. The modular office systems contract discussed above required that this percentage be no greater than 50%. As manufacturers are able to test their products more frequently and resolve manufacturing variations quickly, the requirement for this percentage may be reduced.

Frequency of Testing
Another issue that needs to be addressed is the frequency of product testing. Since manufacturers obtain raw materials and other components for their products from diverse sources, the chemical content of the products may change. Furthermore, small changes in the manufacturing process or conditions under which it occurs can result in significant changes in the resultant products. Therefore, frequent testing is required. Industry-specific studies might be necessary to determine the appropriate frequency of such tests to ensure that testing program objectives are met.

Health-Based Concentration Limits
There is a need to develop health-based concentration levels for additional chemicals that are of concern. However, many identified chemicals do not have Section 01350 concentration limits or other guidelines, so further research is needed. The study report encourages manufacturers to reduce emissions of naphthalene, formaldehyde, and acetaldehyde from their products.

Total VOC Concentrations
High Total VOC concentrations were reported for most of the rubber-based resilient flooring products tested. However, most of these products did not fail against the Section 01350 criteria for individual VOCs. Total VOC concentrations are dependent on the method used for their determination.[47] That is, the sample collection, analyte preparation, and analytical method can yield significantly different results. Furthermore, different chemists may interpret the results differently. It is widely accepted that Total VOC concentrations cannot be used to indicate the potential for health effects.[48, 49]

Generalization of Results
Variations within and between product categories suggest that individual products must be tested to determine compliance with the criteria used. Based on the results of the BMES, manufacturers are encouraged to conduct product testing according to Section 01350 through independent laboratories.

Rubber-Based Resilient Flooring
Further refinement and testing of rubber-based resilient products is suggested before these products are promoted for wide-use in most indoor environments. The potential health effects associated with the numerous (in some cases hundreds of) compounds detected at low concentrations in these products needs to be examined. These products may be acceptable for use in larger spaces such as gymnasiums and multi-purpose rooms provided that: (a) the proper design ventilation rates are supplied to these spaces; and (b) design ventilation rates are maintained continuously during part and full occupancy loads. Further research on the differences between new and aged building products is also necessary.

Sustainability Criteria
The BMES report does not address sustainability criteria other than recycled content and emissions of VOCs of finished building products. For example, the report does not address emissions generated during the manufacturing of each product, disposal of these products at the end of their useful life, environmental effects of product transportation between manufacturing plants and job sites, packaging, etc. Furthermore, the report does not address other components for maintaining healthy indoor environments such as ventilation, microbial contamination, cleaning and maintenance practices, and building operations and use.

Manufacturer Product Improvement Initiatives
Manufacturers of products that emit chemicals at concentrations that are of concern to the State can consider improving or reformulating their products. For example: (a) the systems furniture manufacturers have responded with lower-emitting workstations and are pursuing alternative components that would reduce even further the workstation emissions; (b) a major ceiling tile manufacturer has drastically reduced formaldehyde emissions from their previously high-emitting tiles; and (c) a major fiberglass manufacturer has eliminated formaldehyde emissions from all their building insulation products and recently announced that it has eliminated formaldehyde emissions from their acoustical board products.

Future Steps

ASTM Standard for Section 01350 Requirements
Section 01350 emissions test requirements are now being incorporated into a draft standard that will be balloted through the ASTM open consensus process for standard adoption. Interested parties will comment on the draft, and eventually the standard may be referenced in design specifications and product literature.

Additional RELs
OEHHA will continue to add chemicals to its list of RELs as future assessments are completed. Currently, an interim guideline for caprolactam has been established, and formal adoption of a regular REL should emerge soon.

Cleaning and Maintenance Products
Further work is required on building cleaning and maintenance products since these products may easily result in occupant exposure to chemicals of concern than the building materials to which they are applied. The State is taking the first of a series of steps to address this very important issue.

Laboratory Quality Assurance and Certification
Emissions testing laboratories should be certified and periodically audited by independent agencies. Procedures for certification of emissions test laboratories and on-going audits should be developed and overseen by an independent body. Standards for such procedures should be developed in an open, publicly accessible standards-writing body such as ASTM or ANSI. DHS is planning to address this issue based on a recently signed bill.

Certification of Materials
Certification of materials based on emissions testing should be done by independent organizations that are not affiliated with organizations that develop the standards nor with laboratories that perform the testing required for certification. This is the only means to ensure unbiased data and to provide the public with confidence in the certification process.

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APPENDIX A

Summary of California's indoor air quality requirements for the open office systems furniture (Levin et al., 2000):

- A 10-day conditioning at 3.0 air changes per hour (ach) (20-27 °C at 50% RH +/- 15%) prior to testing, followed by a 96-hr test. Data collection for TVOCs and formaldehyde: at 6, 24, and 96 hr and for individual VOCs at 96 hr as per ASTM Standard D5116-97
- Testing at 1.0 ach with results calculated at 0.5 ach, a weekly average ventilation rate for California state office buildings
- Calibration and quality assurance requirements
- Less stringent background requirements than the USEPA protocol for TVOCs (25 $\mu g/m^3$ instead of 10 $\mu g/m^3$) and for individual VOCs (5 $\mu g/m^3$ instead of 2 $\mu g/m^3$)
- Criteria for acceptability based on the 96-hr test results
- Size and components of a "standard" workstation to be tested based on a six-pack configuration, the most common configuration for state office buildings
- Specific maximum allowable concentrations for formaldehyde, SumVOCs, and seven classes of VOCs [alkanes, aromatic hydrocarbons, terpenes, halocarbons, esters, aldehydes and ketones (excluding formaldehyde) and others] as listed by the European Commission (1992). Identification of 65 compounds within these seven classes (European Commission, 1997)
- The maximum acceptable formaldehyde concentration established as 20 ppb above background [based on California Office of Environmental Health Hazard Assessment's (OEHHA acute 1-hr Reference Exposure Level and a calculated maximum 8-hr concentration from all sources at 27 ppb]
- If maximum adjusted formaldehyde chamber concentrations were between 20 ppb and 50 ppb above background at the time that the manufacturer was awarded the contract, then the manufacturer had 12 months to produce and test new workstation emitting less than 20 ppb. A formaldehyde-reduction plan was required with the bid documents if formaldehyde concentrations exceeded 20 ppb. Formaldehyde concentrations exceeding 50 ppb would disqualify a manufacturer
- Fabrics chemically different from the one tested with the full workstation to be tested in a mini-chamber at 0.5 ach. Pre-conditioning was required at 1.0 ach for ten days. The maximum concentration allowed for the fabric tests for each class were 1/3 of those allowed for the full workstation
- The manufacturer to submit maintenance, cleaning, refinishing, and disposal procedures with their bid documents
- The manufacturer to agree in writing that their products would comply with the maximum emissions within ±50% for the duration of the contract.

KEY WORDS
Emissions testing
Section 01350
Volatile organic compounds
Green building
Office furniture
Concentration limits