THE EVALUATION OF BUILDING MATERIALS AND FURNISHINGS FOR A NEW OFFICE BUILDING

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ABSTRACT

Building products and materials were evaluated during the design of a large California office building. The work was part of a program to control indoor pollutant levels. Materials were evaluated using data available from manufacturers and suppliers and information in the published literature. Tests were conducted using an environmental chamber, bulk testing, and headspace sampling.

Results from the different test types were comparable to results from tests conducted elsewhere for certain products and were useful for predicting air levels found in the completed building. The age of test materials appears significantly to affect test results. Noteworthy is the rapid decline in formaldehyde content and emissions for recently manufactured carpet specimens.

As a result of the tests, modifications to the products or their handling were recommended. Ventilation protocols during product installation, building start up, and initial occupancy periods were also recommended.

The work demonstrates the value of material testing for building design and construction, material selection, procedures for moving in, and operation of mechanical ventilation systems. Further work is needed to reduce the cost of testing and analysis and to understand the interactions of multiple materials in test chambers and buildings.

INTRODUCTION

New building materials, products and furnishings are known to emit a large number of chemicals into indoor air (Berglund et al. 1984; Levin 1985; Molhave 1984; NRC 1981; Stolwijk 1983; Tucker 1986; Wallace 1984). Building occupants' sickness, irritation and discomfort are often blamed on the presence of such chemicals in indoor air (Finnegan 1984; Meyer 1983; Stolwijk 1984; Turiel 1985). The health effects of these chemical emissions are not well understood, but substantial numbers of known or suspected human irritants and carcinogens are among the chemicals emitted by building products, materials and furnishings into indoor air (Ammann et al. 1986; Molhave, 1984).

Building designers, owners, operators and occupants are increasingly concerned about problems related to indoor air pollution (Levin 1986). The results of emissions testing of building products and materials are beginning to be used in the design process as well as in the establishment of operational protocols for ventilation system to maintain acceptable indoor air quality. Special procedures are utilized to prevent or remedy problems of indoor air quality that result from material emissions. Many office buildings are now operated under special ventilation protocols prior to or shortly after initial occupancy to "bake off" chemicals from materials, products, and furnishing (Levin 1984, 1985). Product manufacturers and building designers (architects, engineers, interior designers) are increasingly concerned about the products specified for use in buildings.

As part of a program of activities to improve indoor environmental quality, evaluation and emissions testing program for building products and materials was conducted during the design of a large office building in California. The entire program included identification of potential sources of indoor air contamination and environmental problems outside the scope of the present paper. Among the other elements of the program were reviews of environmental lighting, sun control, ventilation system operational protocols, and interior acoustics. This paper describes the utilization of building materials evaluation and emissions testing for building design, construction planning, and building operation. Only the materials evaluation portion of the indoor environmental quality control program is considered here. Other elements of a comprehensive program are described in a companion paper (see "Protocols to improve indoor environmental quality in new construction").

This paper discusses the process used as a basis for a general procedure to be applied by others. It also recommends further research to improve the recommended procedure's usefulness. The results of the emissions testing and other materials evaluation procedures are presented in order to illustrate the process and to describe some noteworthy findings. Some of the references cited in the paper were not used during the reported work but are presented to assist in future efforts to conduct similar work.

The testing reported here was limited by budget and other constraints, so that the number of tests for each product or substance was too small for statistical analysis. While the results were considered adequate for the purposes of the project, more extensive testing should be done to validate the findings before they are applied elsewhere.

MATERIALS EVALUATION PROCESS

Background: Building Description

Open space office planning was utilized in the building for the majority of the several thousand workers, with private, enclosed offices for only a small fraction of the executives. The 1.75 x 10^6 ft^2 (1.6 x 10^5 m^2) building has eight zoned, centralized air handlers with supply air difusers and return air slots located in the suspended ceiling. The concealed space above the suspended ceiling is used for return air. Illumination is by daylighting through the extensive glazing on major facades, supplemented by switchable dual-tube ceiling-mounted, recessed fluorescent light fixtures.

Elements of the Materials Evaluation Process.

The materials evaluation process had four major phases as follows:

1. Review of products and materials and identification of those considered likely to emit toxic or irritating chemicals in the completed building.
2. Screening of target products and materials based on printed information from manufacturers and information in the open literature.
3. Testing of selected materials to determine chemical content, emissions rate, or change in composition due to environmental exposure.
4. Make recommendations to the building owner and architect for materials selections, modifications or handling to control indoor air contamination.

Phase 1. Identifying Target Products

The first step was becoming familiar with the overall project, design, and space planning program (owner's requirements and directions to the designers), building design, and construction schedule. This understanding was essential for other tasks as well as for the building materials evaluation work. The timing of construction tasks in relation to installation of major interior furnishings and work station components increases the potential for retention of airborne contaminants from construction processes on large surface area materials such as carpets and textiles until long after initial occupancy.

This was followed by a review of the designer's intended use of major interior materials including floor coverings, wall coverings, ceiling system, HVAC duct materials, and furnishings. Discussions included the criteria for selection of certain products (for example, maintenance, cost, acoustics, aesthetics, and functional performance) as well as the quantities and applications contemplated. This review phase concluded with identification of products and materials that might emit toxic or irritating chemicals in the completed building. At this point, all questionable products and materials were considered for further screening.

Phase 2. Screening Target Products

Screening of major components of the building fabric and furnishings was done by (1) determining their quantity and distribution in the building, (2) their chemical composition, (3) the stability of chemical substances of concern, and (4) the toxic or irritation potential of their major chemical constituents (National Academy of Sciences 1975). The result of this screening process was the selection of products and materials for further investigation.

Quantitative Assessment. Quantitative use and distribution assessment involved identifying the major classes of materials, furnishings, and finishes to be used and determining the extent of use and use per unit floor area. On this basis, materials such as floor coverings and ceiling tiles were considered significant due to the large extent of their use -- each had virtually 100% coverage (100 square feet or meters of material per 100 square feet or meters of floor area) in occupied open office areas of the building. In fact, since both the upper and the lower surfaces of the ceiling tiles were exposed to the circulating indoor air, the ceiling tiles had virtually 200% (of floor area) coverage.

[INSERT FIGURE 1]

Office work station "work surfaces" (desktops) were determined to have 32% coverage. This material was also used for shelving in the work station closets which added an additional 15% to the coverage ratio. This material was also exposed on both upper and lower sides and was considered especially significant due to the normally large amount of contact or close proximity between the office workers and the product.

The coverage of work station interior partitions (half-height on three and one-half sides of each work station) varied somewhat with occupant density but approached 100% of the floor area in open office areas where the work stations were used. Again, two sides of the product were exposed to the indoor air, and the product was also in close proximity to the office workers. The open office areas were occupied by more than 90% of the building's office workers.

Chemical Content. At this phase, chemical content was assessed from published general information on building products and materials, information obtained from the building's interior designers, or from manufacturers' and suppliers' product literature and data sheets (Kent 1983; Olin 1980; Progrssive Architecture 1980; Watson 1978). These were obtained by requiring all potential vendors to provide Manufacturer's Safety Data Sheets (MSDSs) for all products assembled by them and the names of suppliers of each product not assembled by them (Miller 1986). Additionally, they were required to provide contact information for each of their suppliers and to request the contact individual to cooperate with us. These secondary suppliers and manufacturers were contacted and additional MSDSs and other information was obtained.

MSDSs are United States Occupational Safety and Health Administration (OSHA) mandated documents listing all hazardous substances contained in the product they cover; they are generally available for most products of interest. OSHA requires that MSDSs be available to workers for all hazardous substances to which the worker will be exposed. Thus, whether in a factory or at the construction site, each substance used in building materials, products, and furnishings is theoretically covered by an MSDS.

As an illustration of the large number of chemicals involved in furnishings, approximately 30 chemicals used in the production of the fabric covering the interior partitions were identified by the fabric supplier. The name of the chemical and its function in the manufacturing process or the finished product were listed by the manufacturer to provide a more complete understanding of the finished product. This fabric was attached to a tempered hardboard frame by a vinyl acetate adhesive. The panel was insulated with fibrous glass batting, which was adhered to a hardboard sheet. There were also metallic components used for the exposed frame of the panel and for the adjustable legs that supported the panel above the floor.

In general, the vendors were very cooperative in providing the required information. It should be pointed out that the scale of the project made it an important one for potential vendors (the largest known single office furniture contract was awarded for the project). It is also interesting to note that the furniture manufacturer's principal representative to the project was a trained chemist who was able to be of considerable assistance.

Chemical Stability. Stability (chemical emissions) assessments were done by reviewing the vapor pressure and molecular weight data for chemicals of concern as identified on the MSDSs. Many sources were used to obtain the data (ACGIH 1982: NIOSH 1982, 1984, 1985; Sax 1979; Verschueren 1983). A particularly useful source is the Table of Solvent Drying Time in Industrial Ventilation (ACGIH 1982).

Additional information on potential emissions into building air was obtained by reviewing emissions test reports and articles in the published literature (Griffis and Pickrell 1983; Pickrell et al. 1984; Matthews and Westley 1983; Matthews et al. 1984a,b,c).

Toxicity Evaluation. Toxicity or irritation potential was evaluated using standard reference sources (ACGIH 1980; Clayton 1981; Gosselin 1984; National Academy of Sciences 1981; NIOSH 1983, 1985; Olishifski 1979; Sax 1979; Sittig 1985).

For example, Sax (1979) lists a "summary of tox[icity] statement" or rating (THR) for each substance covered. Ratings of "none," "low," "moderate," "high", or "unknown" are given. Routes of entry are given for specified toxic effects. LD_{50} (lethal dose for 50% of experimental animals) are given for various exposure routes and experimental species. Human irritation potential and target organs or sites are also listed and carcinogenic and mutagenic assessment is reported.

NIOSH's Registry of Toxic Effects of Chemical Substances, 1981-1982, Volumes 1-3 (RTECS) plus the RTECS 1983-4 Supplement (2 volumes) provide an annotated listing of toxicity and irritation research for tens of thousands of chemical susbstances. RTECS also provides a comprehensive list of alternative trade and generic names by which products may be known or marketed, chemical formulas, and cross references to the Chemical Abstracts Service (CAS) number for each chemical.

From this review, determinations were made regarding materials which would require laboratory testing according to the outcome of the combination of reviewed factors. A combination of high volatility and moderate toxicity would result in further consideration of the substance and the product. A very low volatility and moderate toxicity would be examined in terms of the quantity of the product and the quantity of the substance present in that product. No algorithm was established for this evaluation; a qualitative assessment was done.

Results. The results of this screening process led to the determination that the products most likely to emit significant quantities of irritating or toxic substances were the carpet, the work station (office furnishings) work surfaces and interior partitions, and the fibrous glass ceiling tiles. These materials were evaluated during the emissions testing phase reported below.

It may be of interest to point out that the carpeting was 45 cm x 45 cm tiles with integral rubber backing which were installed using a single glue-line at 9 m on center in both directions. Due to the very limited use of carpet adhesive, that material was not considered significant as a potential source of emissions. Were a typical uniform application of adhesive used, it would be considered significant on the basis of the extent of its use. Due to the open office plan, there was extremely limited use of wallboard, paint, and fabric wall coverings. Wall coverings in executive (enclosed) offices were mounted without adhesive.

Built-in cabinetry in conferences rooms was constructed of particle board that was determined to be adequately sealed to control emissions. Sealing was by complete enclosure with plastic laminate.

Phase 3. Emissions testing

Test Methods. Test methods included bulk testing and environmental chamber and headspace air sampling. Air sampling was also done in the first completed portion of the building.

The effect of temperature variations on emissions was investigated in some of the chamber and headspace tests, although the number of temperature tests and the use of their results were limited. Temperatures of approximately 23 C and 37 C were used in both devices to compare airborne levels of target substances or classes of substances. The 23 C temperature was chosen as being typical of office environments. The higher, 37 C temperature is double the increment dictated by California state-mandated office minimum and maximum temperature requirements, 18.3 C to 25.6 C.

Chamber tests were conducted in a 1.7 m^3) sheet metal box with controlled airflow rate and temperature and with good air mixing within the chamber. Air movement in the chamber was by recirculated flow at approximately 12 air changes per hour. Humidity was not controlled during the chamber tests, but it was measured and reported. Relative humidity was generally in the 50% to 55% range in most chamber tests. Airflow was controlled by introducing and removing air from the chamber through perforated headers placed diagonally from each other at the bottom and top of opposite chamber side walls.

Material samples were generally conditioned by placing them in the chamber at ambient (indoor) temperature and pressure and forced air circulation for $\geq$16 h prior to testing. In order to best meet the purpose of the testing, handling of the material was intended to resemble that employed in actual installations of the materials in buildings. Products were stored in factory containers until testing. Once opened, they were kept in a normally ventilated room containing typical, new office furnishings until additional testing was conducted.

The use of an environmental chamber large enough to accommodate full-size test specimens reduces potential distortions associated with the edges of cut specimens. It also allows for extrapolation of results from the chamber to actual buildings with cautious interpretation of surface conditions and material surface-area-to-chamber-volume ratios. Smaller chambers might be useful in evaluating more precisely the factors affecting emission rates or the interactions between specimen materials.

Sample Collection and Analysis. For bulk samples, collection was through extraction by solvents as dictated by the standard test method employed. Where deemed appropriate, samples were crushed or ground before extraction.

Air samples for chamber and headspace tests were collected using personal monitoring pumps following standard NIOSH, EPA, or ASTM methods for the substances of interest. The exceptions were in the sample collection in the completed building. The carbon dioxide sampling in the completed building was done using a hand-operated bellows pump to collect samples in detection tubes for colorimetric (length-of-stain) quantification. The 90-hour formaldehyde samples were collected on passive sampling tubes.

Air samples for the chamber tests were collected by pulling the air through tubing with the inlet in the chamber's external air duct system containing the equipment (fan and heater) used for circulating air and controlling its temperature. This procedure allowed placement of the sampling pumps, impingers, and collection tubes externally to the closed sampling system, where equipment could be assembled, calibrated, and observed without disturbing the air within the chamber. Early testing with sampling equipment within the chamber was found to give unacceptable results. Air samples were collected within the room but several yards distant from the chamber to determine background levels.

Air samples for the headspace tests were collected from stainless steel laboratory canisters containing a 5 cm x 5 cm specimen. The cannister and air sample collection tubing were placed in a water bath to control temperature for tests where elevated temperature protocols were indicated. Air supplied to headspace canisters was filtered through the same media as was used for collection at rates determined by the sample collection rate.

Analysis of the air and bulk samples was performed by a AIHA-certified laboratory using standard ASTM, EPA, and NIOSH methods for the substances of interest.

Results. Test results for materials are given in Tables 1 and 2. Table 1 contains the results of tests for formaldehyde (HCHO) and Table 2 contains results for total hydrocarbons (THC). Results for the sample collection in the completed building are given in Table 3.

Discussion of Results. Results from various test methods were generally consistent (see Tables 1, 2, and 3) and comparable to results of tests conducted elsewhere for similar products (Matthews et al. 1984; Matthews and Westley 1984; Meyer 1983; Pickrell et al. 1983, 1984; Sheldon et al. 1986). The age of materials being tested was generally known, although not precisely in each instance.

Testing results show a relation between the age of some materials and their chemical content, suggesting an effect of material age on emission rates as indicated by measured air levels. Both chamber and headspace test results support this hypothesis. For example, carpet samples tested at three weeks, six weeks, and nine weeks resulted in bulk formaldehyde concentrations of 17.99, 1.95, and 0.71 ppm, respectively (Table 1). Bulk samples of ceiling boards tested at 1.5 months, 3 months, and approximately 17 months of age had formaldehyde concentrations of 48.23, 8.04, and 5.7 ppm, respectively (Table 1). Headspace sampling of carpets for THCs showed decreasing concentrations with increasing age, but the relative differences were not as large as for the two previously cited instances (Table 2).

Formaldehyde in Carpet and Ceiling Tiles. There was an approximately tenfold decrease in carpet formaldehyde content during the first three to six weeks of exposure to room air. Fibrous glass ceiling tile showed a measurable decline in formaldehyde content through the 20th month after manufacture (Table 1). It is apparent from the results of bulk testing that both the carpet and ceiling tile samples tested released substantial portions of their initial formaldehyde content during aging through normal exposure to room air.

Some investigators have reported carpet to be a weak emitter of formaldehyde (Matthews et al. 1984). This may be a result of the age of the products tested or a difference between the carpets tested in this project and in others. Investigations of complaints of building sickness are typically done several weeks (or more) after carpet installation. Thus, carpet samples collected in these instances may also have contained significant quantities of formaldehyde, which may be dispersed and some of which may still be in the building fabric or air.

Ceiling Tiles. Relatively new samples (less than four months since manufacture, wrapped in brown paper, or unwrapped and exposed to mock-up room air) of ceiling tiles resulted in significant air levels of volatile organic compounds (VOCs) measured as total hydrocarbons (THC) in headspace and chamber studies. Bulk concentrations were reported at approximately 0.1 mg/m^3. The bottom surface (exposed to the occupied space) of the ceiling tile was coated with a plastic acoustic material, which appeared to be the THC source. The results of these tests were somewhat ambiguous, probably due to incomplete separation of the fibrous glass, the adhesive, and the bottom surface coating (acoustic) material. Further work should be done to obtain more reliable data.

The architects had expressed concern about the possible release of fibers from the upper surface of the ceiling tiles. This surface formed the bottom of the concealed space above the ceiling and below the structural floor. This concealed space was used as a return air plenum and a chase for supply air ductwork and utility lines. In the tests, the ceiling tiles were exposed to air velocities several times higher than would be expected during their use in the building to determine the effect of higher velocity airflow on particle release. Elevated temperatures were also employed during some of the particle-release tests to determine if heating the material would break down the formaldehyde-based resin used as a binder and produce fiber release. No significant elevation of fiber air levels (measured as dust) were detected on filter collection media by gravimetric analysis.

Work surfaces. The measured reduction in the chamber test formaldehyde air levels from work surface components (plastic-laminated, medium-density particle board) was significant when the 1 cm pre-drilled holes in the bottom surface were plugged. These holes (between 6 and 12 per component) were present to allow assembly of the components into various work station configurations. In two pairs of tests, the reduction in formaldehyde air levels was large. In one test, the levels went from 80 to 30 ppb, and in the second test, the levels went from 37 to 7 ppb.

Vertical Panels. The freshly unwrapped work station vertical panel (fabric covered, free-standing, half-height partition) produced a total hydrocarbon (THC) air level of 45.4 ppm during one test in the chamber. The THC found consisted primarily of an unidentified, low molecular weight compound. After discussions with the chemical analyst and with the product manufacturer's technical representatives, this was assumed to be a cleaning solvent that may have been used to remove soiling at the factory.

Phase 4: Recommend Mitigations

Carpets. Because of the rapid decay of formaldehdye content in carpet sample tests, it was recommended that the carpeting be conditioned prior to shipping from the factory or installation in the building. Treatment by heating or steam or other formaldehyde extraction processes was suggested. Furthermore, a building bake-off with elevated humidity was considered. The use of maximum outside air and no recirculation during and after installation of the carpets were recommended. Finally, the longest possible lead time between carpet installation and initial occupancy was recommended.

Work Surfaces. As a result of the findings, it was recommended that these components be shipped to the building with the pre-drilled holes plugged and that plugs be left in unused holes after assembly of the work stations. It was also recommended that the concealed but unsealed ends of the shelving units be fully laminated to reduce formaldehyde emissions.

Ceiling Panels. Further investigation of the ceiling tiles is required to determine the identity of the organic material in the acoustic facing.

Vertical Panels. Since the substance detected in the chamber test was a "low boiler" (had a low molecular weight), there was concern that it might be emitted during a episodic warm period after initial building occupancy. The freshly cut samples of vertical panels emitted strong, unpleasant odors upon being cut for use in bulk and head space tests. The combination of the subjectively observed odor and the high THC levels in the chamber test resulted in a notification to the manufacturer that the volatile substance had been detected. We recommended that the manufacture avoid shipping panels to the building containing the substance. Furthermore, the owner was advised to test randomly panels arriving at the building for installation to determine if the "low boiler" or strong odor was present.

Additional comments. The purpose of the materials evaluation project was to assist the building owner and architect in achieving improved indoor air quality in the completed building. It was important to the owner to be assured that actions had been taken to minimize the possibility of a building sickness incident in the completed structure. The screening, evaluation, and testing were done in pursuit of these objectives and with typical building budget constraints.

No work of this type was reported in the literature or known to the investigators. Thus, many of the procedures were developed based on the knowledge and judgments of the individuals involved, the investigators and the client's and architect's representatives. Replicate testing was not conducted where results were consistent with reports in the literature, calculated values, and other test results from the project. The test results are insufficient for statistical analyses and none were performed. The results are deemed acceptable for the purposes of the project.

SUMMARY OF APPLICATIONS

Product Modifications. An important outcome of the work was discussions with product manufacturers and suppliers that resulted in several product modifications to reduce unstable chemical content or emissions.

The rapid decline of formaldehdye bulk content of the carpet samples tested during the first six weeks of exposure to the environment warranted special consideration. Factory processing (steam, heat, or both) was considered, as well as treatment at the warehouse or other pre-installation staging areas. No recommendations were made, but this is an area that should be explored in future projects where aging (environmental exposure) can significantly affect bulk content or the emissions rates of significant chemicals.

Shipping and Handling. There was concern that panels brought wrapped into the building might release a VOC into the air during a period of elevated temperatures. This was believed to be a potential situation of brief, episodic exposure, but if it resulted in occupant discomfort, irritation, or other ill health, an investigation later would be unlikely to detect the very volatile compound. Therefore, the manufacturer was notified that panels should not be shipped with the solvent present. Furthermore, it was recommended that packaging and shipping procedures be modified to allow air movement across all surfaces of the panels, air exchange between the shipping container and the environment, and, if possible, warehouse conditions with definite building ventilation.

Product Quality Control. For products meriting considerable concern and requiring special attention by manufacturers or suppliers, random samples of products shipped could be tested using environmental chambers, headspace sampling, or bulk analysis for quality control. Levels could be tied to contract specifications for emissions rates, chamber air levels, or bulk content. This was considered but not implemented.

Forecasting Indoor Air Concentrations. Test results were helpful in forecasting indoor pollutant concentrations in the completed building. For example, the formaldehyde levels in chamber tests of slightly aged (6 to 12 weeks) samples of all four major materials tested were within the range of levels measured in the completed building. Results of measurements in the newly completed and occupied building were compared with chamber and headspace levels and projected levels and found to be within reasonable limits of what was expected.

Interim Ventilation Protocols. Ventilation protocols were recommended to control certain air pollutants during construction and initial occupancy. The recommendations included operating the building at minimum acceptable temperatures and maximum acceptable ventilation rates during the initial occupancy period. During construction, 100% outside air with no return air fans operating was recommended. Sealing all ventilation system return air openings and protecting the ductwork from intrusion of construction fumes and dusts was recommended. If necessary, temporary exhaust could be installed using stair towers or exterior openings.

Subjective Evaluation by Occupants. It was also suggested that panels of occupants subjectively evaluate indoor air quality to assist building engineers determine acceptable rate of phased transitions to normal HVAC operations involving the hours of operation, the amount of outside air to be introduced, and the acceptable operating temperature range. The composition of the occupant panels was suggested as including a mix of job classification, age, sex, and location in the building. Standardized reporting formats were developed to be filled in upon entering and leaving the building. Odor, temperature, air movement, comfort, and overall air quality were to be rated. Responses would be scaled to normalize them, and trends would be plotted and monitored to indicate unacceptable air quality, temperature, or air movement.

RESEARCH NEEDS

It is important that future research and applied work involving building material chemical content and emission testing carefully consider product aging and conditioning. Additionally, an effort should be made to relate test conditions to conditions expected to be found in the field.

The effects of different chamber surface materials on concentrations of diverse compounds (especially those of low volatility) need to be determined. For purposes of economy, our chamber consisted of a galvanized sheet metal box, and surfaces were periodically wiped with acetone. However, other economically suitable chamber materials and cleaning procedures might be more practical or might increase the reliability and usefulness of the testing.

Further research is needed to determine the usefulness of testing at elevated temperatures. The tests reported here used a doubling of the normal range of indoor air temperature to test the effect of elevated temperature on emissions rates. Insufficient data were obtained to provide confidence in the results of this test protocol and the technology employed to achieve it. More systematic testing of this type can assist in determining the usefulness of building bake-off procedures, which are being used to mitigate indoor air quality problems. There is currently insufficient information to model the performance of bake-off procedures in order to improve their effectiveness.

Tests using several building products and furnishings containing compounds known or expected to interact with each other or to affect air concentrations need to be conducted to improve current understanding of source-sink dynamics.

Further work is needed to develop economically acceptable, reliable methods to identify organic compounds. The current conmmercial laboratory costs of GC/MS analysis make extensive use prohibitively expensive.

Inclusion of consumer and office products and appliances should be considered in future testing projects. The results from such testing will broaden the contributions that emissions testing can make in the prediction or modeling of indoor air quality during building design.

CONCLUSIONS

Screening building materials based on manufacturers' information on content reduces the number of materials that require actual emissions testing. Using existing data on chemical and toxicological properties of materials further assists in screening materials for testing as well as in interpretating results.

Results from tests using an environmental chamber and from bulk testing and headspace sampling are consistent and comparable to tests conducted elsewhere for formaldehyde and total hydrocarbons. Extrapolations to the actual building environment are demonstrated to be practical, within limits.

The age of test materials appears significantly to affect emission rates and chemical content of materials. There is a rapid decline in formaldehyde content and emission rates for certain carpet specimens.

The work illustrates the contribution that material testing can make to building design and construction, material selection, moving-in procedures, and mechanical ventilation system operations. Improvements can be made and additional approaches can be developed. Particularly useful to researchers and professionals would be a coordinated data base, standardized test protocols and standardized reporting formats.

Further work is needed to reduce costs of testing and analysis and to improve understanding of the interactions among multiple materials in test chambers and buildings.

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TABLE 1. Formaldehyde Test Results

Test Method	# of Samples	Description of Material(s)	Sample Age mo.	Results (ppm) Range	Ave.
		----- Carpet -----			
Bulk	15	5 mfrs.	1.3-4.5	<0.4-2.3	0.83
	1	Mfr A	0.7		17.99
	1	"	1.5		1.95
	1	"	2.3		0.71
HdSp	1	"	2.0		<0.003
Chbr	3	"	1.3		>0.067
		------ Fibrous glass ceiling board ------			
Bulk	1		16-18 ?		5.7
	1		1.5 ?		48.23
	1		3.0 ?		8.04
HdSp	1	Composite bd	3.0 ?		<0.003
		Fiber glass only			0.10
		Acoust mtl only			0.11
Chbr	1		2.0 ?		0.03
	1		2.0 ?		>0.03
		------ Vertical Panel ------			
Bulk	1	Cut sample	Unknown		2.1
Chbr	1	3 full panels	2.0 ?	0.03-0.06	0.043
		----- Work Surface -----			
Bulk	1	Cut sample	?		346.7
Chbr	1	Full sample	?		0.030 (1)
	1	Full sample	2.0		>0.034
	1	Full sample	3.0		
		w/ screws			0.030
		w/o screws			0.080
		Full sample	3.3		
		w/ screws			0.007
		w/o screws			0.037
		Full sample	3.4		0.075

TABLE 2. Hydrocarbon Test Results

Test Method	# of Samples	Description of Material(s)	Sample Age mo.	Results (ppm) Range	Ave.
		----- Carpet -----			
Bulk	3	3 mfrs.	2.3-5.5	19.5-23.6%	22.15%
	1	Mfr. A	2.0		9.93
HdSp GC/MS	3	3 mfrs.	2.3-5.5	0.45-0.73 (1)	0.58
GC/MS	1	Mfr. A	0.8	0.68-0.90 (2)	0.80
	1	"	2.1		0.62
Chbr	3	"	1.3		>0.03
		-----Fibrous Glass Ceiling Board-----			
Bulk	1	Composite bd	3.0 ?		<18.77
		Fibrous glass only			<9.73
		Acoust mtl only			<16.42
HdSp	2	@ T = 24.5 C.	21-23		<0.03
	2	@ T = 38 C	21-23		0.06
	1	Composite	3.0 ?		0.75
		Fiber glass only			0.07
		Acoust mtl only			0.60
Chbr	1		2.0 ?		0.7
		----- Vertical Panel -----			
HdSp	1	Cut sample	Unknown		0.41
	2	" "	"	0.25-0.82	0.43 (1)
Chbr GC/MS	1	3 full panels	2.0 ?		45.4 (2)
		----- Work Surface -----			
Chbr	1	Full sample	3.3		-----
		Full sample	3.4		1.048

Notes:
(1) GC/MS analysis identified the content as >95% Dioctyl Phthalate, a plasticizer.
(2) C_8-C_{10} Aliphatics.

TABLE 3. Summary of Monitoring Results from First Day of Occupancy of the Completed Building

Location	Temp (F)	RH (%)	Sample Time	Substance CO_2[a] (ppm)	VOC[b] (mg/m^3)	HCHO[c] (mg/m^3)
Rooftop	44	91	Inst[d]	200		
			4 hr[e]		1.2[f]	0.004
Room 358	66	58	Inst	1000		
Sup. Air			4 hr		1.2[f]	0.038
			90 hr			0.092
Ret. Air	66	58	Inst	600		
			4 hr		3.7	0.052
			90 hr			0.092
Basement	57	66	Inst	500		
Open Area:						
So. Cent	68	55	Inst	800		
			90 hr			0.109
No.Cent	69	46	Inst	1000		
			90 hr			0.107
So.West	66	49	Inst	600		
			90 hr			0.095
No.West	69	40	Inst	1100		
			90 hour			0.112
So. East			90 hour			0.081
No. East			90 hour			0.096

NOTES:
(a) Carbon Dioxide
(b) Volatile Organic Compounds
(c) Formaldehyde (1.0 ppm = 1.248 mg/cu m)
(d) Instantaneous reading taken on first day of test week.
(e) 90 hour readings using passive samples continuously from 3 PM on Day 1 to 9 AM on Day 5.
(f) Sampled volume too small for accurate quantification.

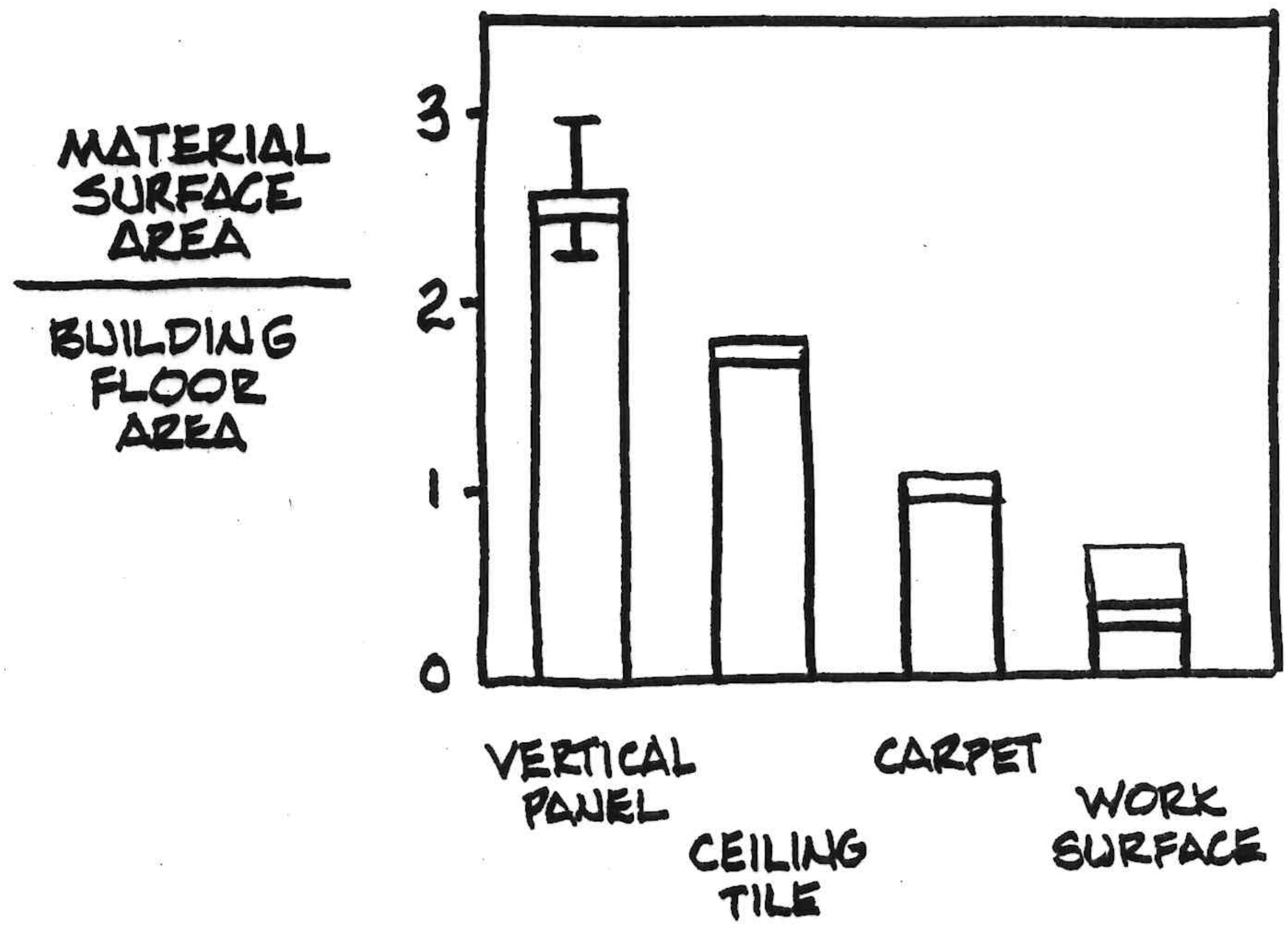

FIGURE 1. RATIOS OF MATERIAL SURFACE AREA (EXPOSED TO INDOOR AIR) AND FLOOR AREA IN A NEW OFFICE BUILDING.

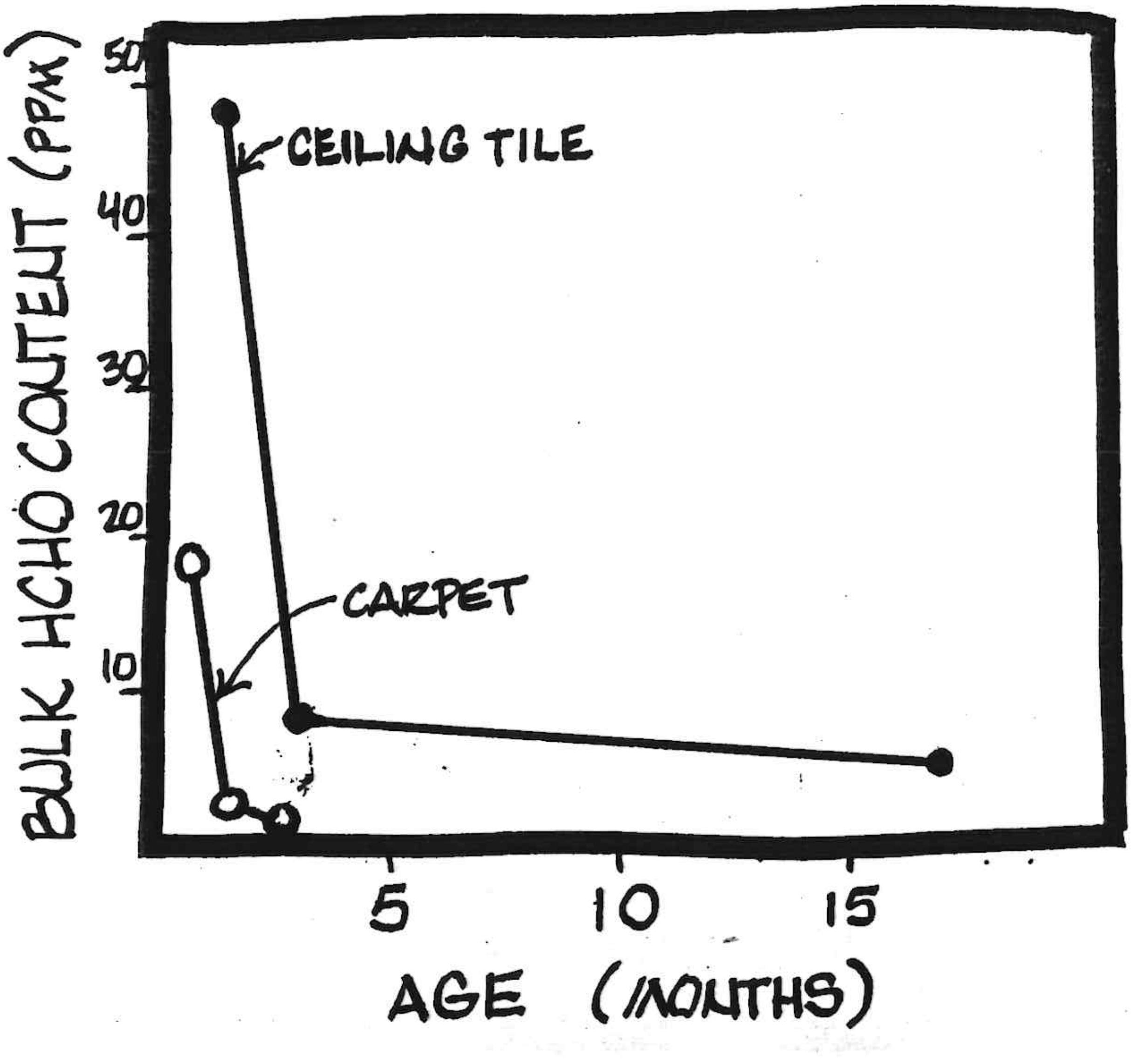
BULK HCHO CONTENT (PPM)
50
40
30
20
10
CEILING TILE
CARPET
5
10
15
AGE (MONTHS)

FIGURE 2.

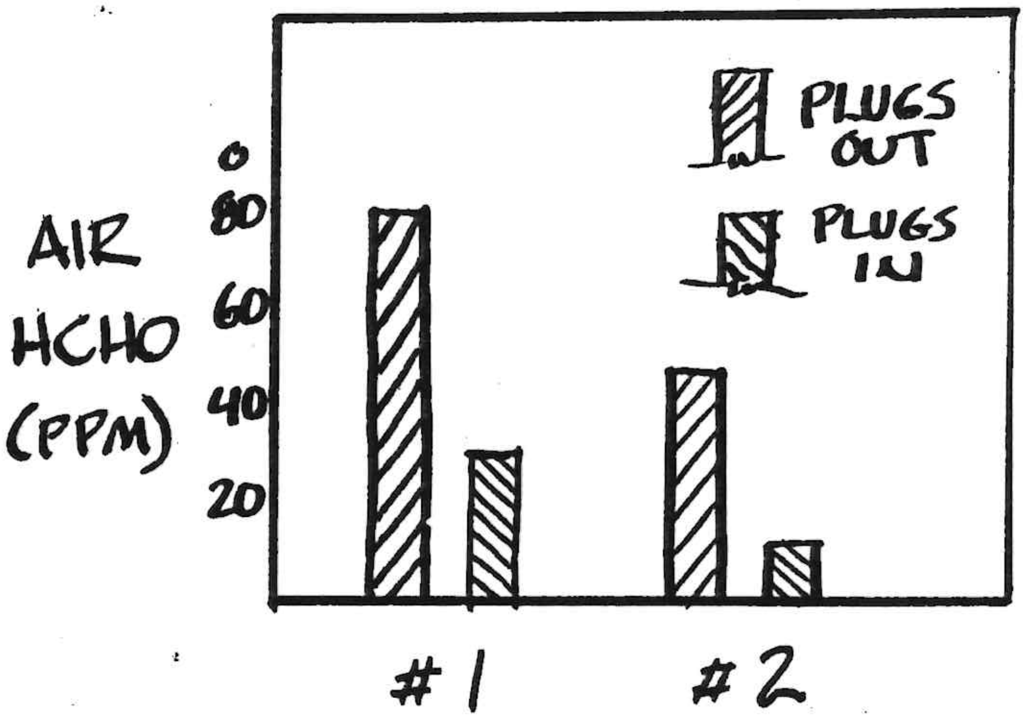

FIGURE 3.