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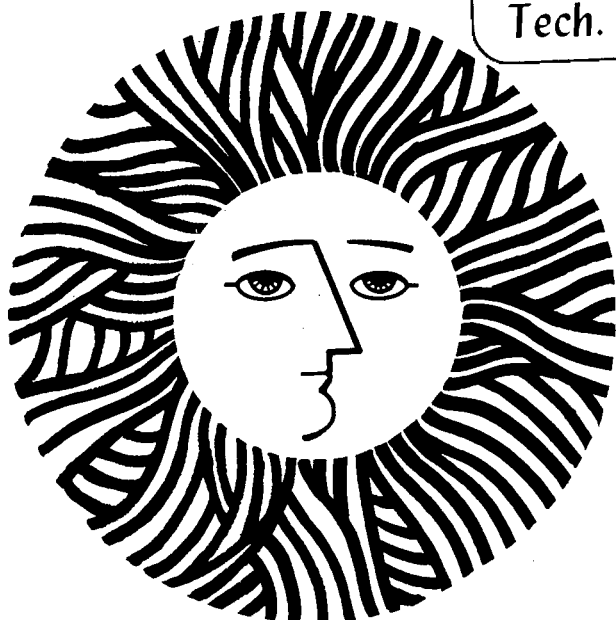
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ABSTRACT

Recent office construction practices have incorporated energy-conserving strategies to minimize the amount of air used for ventilation. Unfortunately, occupants of a number of such new office buildings have registered complaints of poor indoor air quality and non-specific health problems. The underlying etiological agent(s) remain unknown as determined by industrial occupational criteria; however, caution must be used when applying these criteria to organic contaminant exposures in closed office spaces. In this paper we present preliminary data suggesting that workers in offices are exposed to a broad spectrum of solvent related organic contaminants present in very low concentrations relative to permissible exposure levels, but in high concentrations relative to outdoor air. With the aid of simple modeling, conjectures about various pollutant sources--new and aged building materials, wet-process photocopiers, tobacco smoke, and building maintenance products--are made with respect to the composition, amounts and generation patterns of their organic contaminant emissions. The results show that effective control strategies can be implemented that do not compromise energy efficiency.

INTRODUCTION

Heating or cooling outdoor air as it enters an office building consumes a significant amount of energy, and recent office construction practices have incorporated energy-conserving strategies to minimize the amount of outdoor air used for ventilation. Unfortunately, occupants of a number of such new office buildings have registered complaints of poor indoor air quality (Sterling and Kobayashi, 1977; Rand, 1979; Turiel et al., 1981). As of July 1981 the National Institute of Occupational Safety and Health (NIOSH) had conducted more than eighty investigations of non-specific health complaints from workers in closed office spaces (Keenlyside, 1981).

Though it is recognized that indoor air quality can be poor in closed office spaces, the underlying etiological agent(s)--as determined by the criteria of current industrial hygiene tests coupled with established occupational health standards--remain unknown. However, these criteria are designed for use in industrial occupational environments where workers are commonly exposed to high concentrations of a small number of pre-identified compounds; it is possible, especially in the case of organic contaminants, that such criteria do not adequately address the non-industrial occupational environment of the closed office space. Existing occupational health standards, for example, rely on studies addressing one compound at a time--a practice that does not account for additive or synergistic effects of multiple exposures. Tests using sensitive analytical methodology suggest that workers in offices are exposed to a broad spectrum of organic contaminants present in very low concentrations relative to permissible exposure levels, but in high con-

centrations relative to outdoor air.

In this paper we present preliminary data on the identities and relative amounts of organic contaminants associated with closed office spaces. Conjectures about various pollutant sources--new and aged building materials, wet-process photocopiers, tobacco smoke and building maintenance products--are made with respect to the composition, amounts, and generation pattern of their organic contaminant emissions. The results show that, if organic contaminants are responsible for poor indoor air quality in closed office spaces, effective control strategies can be implemented that do not compromise energy efficiency.

EXPERIMENTAL

Air was sampled in four office sites at Lawrence Berkeley Laboratory (LBL) where occupants had complained of poor indoor air quality. Two sites were new office trailers and two were recently remodeled office spaces inside a large building. At each office site synthetic materials (including wall-to-wall carpeting, fabric-covered walls and office partitions) and furnishings were extensively used. There were few smokers and no photocopying machines at the sites where air samples were taken.

Samples were collected by drawing 60 L of air through a cartridge containing approximately 1.5 g of Tenax (a porous polymer sorbent) held in a 1.5 X 10 cm glass tube with glass-wool plugs. The cartridges were conditioned by passing clean nitrogen through them at 200 °C overnight. Stainless steel carrying tubes with Swagelock^R caps were used to transport cartridges to and from sampling sites.

At each site indoor and outdoor air were sampled simultaneously, and from three to six sets of parallel samples were taken. A blank cartridge was handled in a manner identical to the sample cartridges except that no air was drawn through it. The blank and one indoor sample from each site were analyzed using a Finnigan 4023 gas chromatograph-mass spectrometer (GC-MS). The remaining samples were analyzed using a Varian 3700 gas chromatograph equipped with a flame ionization detector (GC-FID). For both GC-MS and GC-FID analyses, organic contaminants retained in the Tenax sampling cartridges were introduced onto the chromatographic column via a thermal desorption device (Nutech Model 320 Thermal Desorption System) consisting of a heated desorption chamber, a six-port switching valve, and a capillary cryogenic trap for reconcentrating the sample prior to analysis (Pellizzari, 1977).

The composition of vapors emitted by representative building materials was determined by means of a simple glass and teflon headspace apparatus constructed at LBL. The apparatus consists of a small chamber and a cold-finger trap immersed in liquid nitrogen, which are connected via O-ring joints to a U-shaped manifold. One high-vacuum teflon stopcock attached to the manifold controls access to a vacuum, and a second stopcock allows the cold-finger trap to be isolated and removed from the system. In practice, a small (approximately 2" X 3") sample of building material was placed in the chamber, a vacuum was applied, and the system was sealed off with the manifold stopcock and allowed to stand overnight. Wet or pasty building materials were first applied to a 2 X 3" aluminum plate and allowed to dry out at room temperature and pressure for 24 h before being placed in the chamber. Condensed samples collected in the cold-finger trap were typically between 25 and 250 uL in

size, and were analyzed by injecting microliter quantities directly into the Finnigan 4023 GC-MS.

MODELING

The impact of organic contaminant sources in closed office spaces was estimated by considering a hypothetical office with dimensions of 100 X 100 X 10 ft³ containing 40 workers, and applying the simple well-mixed tank ventilation model of Turk (1963). In this model the mass balance equation describing a pollutant source inside a well-mixed tank with infiltrating and exfiltrating air streams is:

$$VdC = GdT - (C-C_1)Q_1dt \quad (1)$$

where V is the room (i.e., tank) volume, m³; C and C₁ are the pollutant concentrations in the room and infiltrating airstream respectively, mg/m³; G is the pollutant generation rate, mg/h; Q₁ is the volume rate of infiltrating (and exfiltrating) air, m³/h; and t is the time, h. By rearranging and integrating the mass balance equation an expression is derived relating the pollutant concentration, C, to the initial pollutant concentration, C₀, and the elapsed time:

$$C = C_0 e^{-Q_1 t/V} + \left[\frac{C_1 Q_1 + G}{Q_1} \right] \left[1 - e^{-Q_1 t/V} \right] \quad (2)$$

The term $-Q_1/V$ in the exponent has the dimensions of h⁻¹ and is commonly known as the ventilation rate expressed in air changes per hour (acph). In practice, the ventilation rate is best measured experimentally using

tracer gas techniques rather than calculated from mechanical air-system parameters. Provided that G remains constant, the equilibrium pollutant concentration, C_{∞} , is attained as t goes to infinity. Thus, equation (2) reduces to:

$$C_{\infty} = \frac{C_i Q_i + G}{Q_i} \quad (3)$$

This model, although oversimplified (particularly with respect to the assumption of perfect mixing) is useful for predicting the behavior of mean pollutant concentrations over time, especially if experimentally measured ventilation rates are used. It should be borne in mind, however, that point-specific measurements of pollutant concentrations within the office space will be distributed around the mean pollutant concentration in accordance with the variance introduced by imperfect mixing.

RESULTS AND DISCUSSION

Organic Contaminants Observed

Figure 1 compares gas chromatograms of equal size air samples taken simultaneously inside and outside a remodeled office at LBL. Qualitatively it is apparent that the numbers and concentrations of organic contaminants are greater indoors than outdoors. Comparison of peak areas with those of external standards prepared by injecting liquid stock solutions into clean sampling cartridges indicated that the largest peaks of the indoor chromatogram correspond to air concentrations of hydrocarbons of a few tenths of a milligram per cubic meter. This

method of calibration does not account for sample collection efficiency or stability and, hence, provides only a rough lower-boundary estimate of concentrations. These preliminary data are instructive in demonstrating two advantages of the solid sorbent/thermal desorption technique relative to traditional charcoal tube techniques. These are: (1) the elimination of a solvent peak in the chromatogram allowing improved resolution of low molecular weight compounds, and (2) the elimination of sample dilution by solvent desorption resulting in substantially improved sensitivity.

Figure 2 shows a reconstructed ion chromatogram, derived from GC-MS analysis, in which representative peaks are identified. Table 1 lists compounds identified at four LBL office sites for which the ratio of indoor to outdoor concentrations was five or greater. It can be seen that most organic contaminants identified indoors fell into one of three classes, the largest class being aliphatic hydrocarbons including straight-chain, branched-chain, and cyclohexane-derivative species. These hydrocarbons are constituents of petroleum distillate solvents. The second largest class was alkylated aromatic hydrocarbons, dominated by toluene but also including xylenes, trimethyl- and other higher-substituted benzenes, and even traces of methyl- and dimethylnaphthalenes. These compounds are either solvents themselves or constituents of tar naptha. type solvents. The third class observed was chlorinated hydrocarbons, including tetrachloroethylene, 1,1,1-trichloroethane and trichloroethylene. Miscellaneous other compounds observed were ketones, aldehydes, and benzene.

Source Characterization

By inspection, the major sources of organic contaminants in closed office spaces are: (1) new building materials; (2) aged building materials; (3) wet-process photocopiers; (4) tobacco smoke; and (5) building maintenance products. A summary of their characteristics is presented in Table 2.

The five organic contaminant sources listed above exhibit three characteristic generation patterns relative to an 8 h workday. Emissions from new and aged building materials change slowly and appear constant relative to a daily time frame. Emissions from wet-process photocopiers and tobacco smoke are generated at a constant rate during the workday, to a first approximation, but not at all during the non-workday period. Building maintenance products are usually applied over short time periods relative to the workday and their emission pattern is thus episodic.

In the hypothetical office space, where it is assumed that a mechanical air delivery system maintains a constant ventilation rate, the peak and cumulative pollutant exposures are dependent upon the generation pattern of the source. For new and aged building materials, equation (3) may be used, in which case exposures will be directly proportional to the ventilation rate. For the remaining sources, if the air exchange rate is low (in other words if the inverse of the air exchange rate is a substantial fraction of the workday), then equilibrium is not attained and equation (2) must be integrated over the workday to calculate exposures. Given effective ventilation rates of 0.2 and 1.0 acph in the office space, then the resultant ratios of the peak and cumulative exposures to

pollutants generated during the workday from wet-process photocopiers and tobacco smoke are 4.0 and 2.9 respectively. The respective ratios for the peak and cumulative exposures for a building maintenance product applied during the first hour of an 8 h workday are 1.4 and 3.9, respectively. Thus, for these cases, the exposure ratios are substantially less than the ventilation rate ratio of 5.0. Figure 3 shows the exposures arising from different pollutant generation patterns.

New building materials are a source of organic contaminants because they contain residual solvents and other compounds remaining after the manufacturing process. Table 3 summarizes the results of qualitative GC-MS analysis of the headspace vapors over seventeen representative new building materials. Compounds emitted in substantial quantities included aliphatic hydrocarbons, toluene, alkylated benzenes, ketonic solvents, and specialty compounds such as butylated hydroxytoluene (BHT). Though the number of materials examined was by no means exhaustive, it is interesting that no chlorinated hydrocarbons were detected.

Emissions of residual solvents from new building materials can be expected to diminish with time as the material "dries out." An instructive building material to consider is wall-to-wall carpeting because of its synthetic composition, large surface area, and effective mass (including pads and underlying adhesives). One can make some reasonable assumptions and attempt to scale the magnitude and duration of emissions in the hypothetical office space. The assumptions are: (1) the initial residual solvent load is 10 g/ft²; (2) the initial emission rate is 1 mg/ft²-h; and (3) the emission rate decays exponentially with time. The initial generation rate of organic pollutants in the office space is

thus 10 g/office-h ($1 \text{ mg/ft}^2\text{-h}$ times $10^4 \text{ ft}^2\text{-office}$) leading to nominal concentrations of 3.5 mg/m^3 for 1.0 acph and 18 mg/m^3 for 0.2 acph, with cumulative exposures over the 8 h workday of 28 and 144 mg-h/m^3 , respectively (see Figure 3). By setting the integral of the emission rate over all time equal to the initial solvent loading, the time required for the exposures to drop to half of their initial values can be determined to be 300 days.

Among aged building materials, wood and other urea-formaldehyde containing products are the only well-documented cases where a pollutant, in this case formaldehyde, is emitted over an extended period of time (Andersen et al., 1975; Berge et al., 1980). (With the exception of some furnishings, these products are usually not employed extensively in new office buildings where observed formaldehyde levels are low (Keenlyside, 1981; Turiel et al., 1981) and can be reasonably accounted for by tobacco smoke.) Nevertheless, aged building materials may still affect indoor air quality by adsorbing organic contaminants generated from other sources. When a step-change is made in a variable that affects pollutant levels in the office building (e.g., the ventilation rate is increased), the pollutants adsorbed by aged building materials might be re-emitted and thereby dampen or delay the expected corresponding step-change in pollutant levels.

Newer, inexpensive, wet-process photocopiers use toner and developer fluids that are nearly pure aliphatic hydrocarbon petroleum distillate solvents. Based on an informal survey of users, a conservative estimate is that one photocopier uses approximately one quart (1000 g) of combined fluids per week. On this basis, one photocopier operated during

the workday in the hypothetical office space would have a nominal emission rate of 25 g/office-h. As shown in the center of Figure 3, at 1.0 acph the pollutant concentration by the end of the day will nearly have equilibrated by the end of the day at 9 mg/m^3 , while at 0.2 acph the concentration rises continuously during the day and peaks at 35 mg/m^3 at the end of the day. Under the latter ventilation rate, there is barely enough time during the non-workday period to remove the accumulated pollutant. The cumulative exposures for 1.0 and 0.2 acph are 62 mg-h/m^3 and 177 mg-h/m^3 , respectively.

Tobacco smoke can be a major source of organic pollutants in office spaces, but quantification of its components is exceedingly difficult. Weber et al. (1976) determined the concentrations of formaldehyde and acrolein in a climatic chamber of 30 m^3 and 0.33 acph where sidestream smoke was produced by a smoking machine. Mainstream smoke (smoke drawn through the cigarette during inhalation) was diverted out of the chamber. During a 20 minute period when 29 cigarettes were smoked, formaldehyde and acrolein concentrations rose linearly, reaching 1.30 and 0.31 ppm (1.56 and 0.78 mg/m^3), respectively. By substituting known parameters into equation (2), the generation rate G can be determined which, in turn, can be divided by the cigarettes smoked to yield estimates of 5.2 mg of formaldehyde and 2.6 mg of acrolein generated in the sidestream smoke of each cigarette. If it is assumed that during the workday in the hypothetical office space one-third of the workers (13 out of 40) are habitual smokers who smoke two cigarettes per hour (in accordance with estimates reported by Repace and Lowrey, 1980) then, at 1.0 acph, formaldehyde and acrolein will reach steady-state concentrations of 48 and $24 \text{ } \mu\text{g/m}^3$ respectively. At 0.2 acph concentrations will

peak at the end of the workday at 191 and 95 $\mu\text{g}/\text{m}^3$. In the case of formaldehyde, these levels are similar to those observed by Keenlyside (1981) and Turiel et al. (1981).

Concern about exposure to components of sidestream tobacco smoke is not restricted to formaldehyde and acrolein, but includes carbon monoxide, oxides of nitrogen, hydrogen cyanide, and nicotine as well as a host of miscellaneous organic compounds present at levels an order of magnitude or more less than formaldehyde (U.S. Department of Health, Education and Welfare, 1979). A great many organic compounds, including carcinogenic polycyclic aromatic compounds, are present in the respirable particulates generated by combustion of cigarettes. Exposures to such particulates can easily exceed limits promulgated by National Ambient Air Quality Standards (Repace and Lowrey, 1980).

Building maintenance products comprise a very broad category and the organic contaminants they emit include a large variety of solvents and many specialty compounds. To characterize the airborne contaminants in any given office space, one must know the exact products used, how and how often they are applied, and other relevant information. On the other hand, their generation pattern is primarily episodic and, of the five pollutant sources considered in this paper, these products are the most amenable to manipulation. The bottom third of Figure 3 shows the effects of a one-hour application of 100 ml of dust remover containing hydrocarbon solvent at the beginning of the workday in the hypothetical office space. At ventilation rates of 0.2 and 1.0 acph, respectively, the peak exposures are 32 mg/m^3 and 22 mg/m^3 , respectively, and the cumulative exposures are 137 and 35 $\text{mg}\text{-h}/\text{m}^3$, respectively. If the pro-

duct were applied during the last hour of the day instead of the first the respective cumulative exposures would be only 16.5 and 13.0 mg-h/m³. Furthermore, the exposures could be reduced to zero by conducting maintenance activity immediately after the workday period.

CONCLUSIONS

Application of sensitive analytical methodology in closed office spaces shows that, relative to outdoor air, the levels of a variety of organic solvent vapors generated within and contained by the built environment are high. When compared with exposure levels recommended for healthy workers in industrial environments, the concentrations of individual organic contaminants are lower by two to four orders of magnitude. The additive exposure, expressed as the sum of the percentage ratios of individual organic contaminants to their recommended exposure levels, does not exceed more than a few percent.

To answer the fundamental question, "Do these organic contaminants contribute substantially to poor indoor air quality?", a number of factors must be considered. From a toxicological point of view existing industrial hygiene criteria may not be sufficient to evaluate the toxic effects of exposure to organic contaminants in closed office spaces. First, the number of compounds is far greater and the levels far lower than in the industrial workplace. Second, additive or synergistic effects are not well understood. Third, the office population is more diverse than that typical of industry; it includes greater numbers of older, sedentary, child-bearing and atopic individuals, all of whom may be more susceptible to adverse health effects from organic contaminants.

From a psychological point of view organic contaminants may act by annoyance (through their odor characteristics) or may exacerbate comfort problems occurring when temperature, relative humidity or carbon dioxide values fall outside of accepted limits. This latter point of view is largely subjective and difficult to quantify.

Conclusions regarding the ranking and control of sources of organic contaminants in office spaces can be made even though this basic question remains unanswered. As is evident from Table 2, the highest exposures are associated with wet-process photocopiers; however, the petroleum distillate solvent emitted by these devices is the least toxic of the organic contaminants identified. The source emitting the most toxic organic contaminants is tobacco smoke, the effects of which become even more pronounced when carbon monoxide, oxides of nitrogen, and odor emissions are considered. The impacts of new building materials and building maintenance products are only rough estimates, and more research is needed to characterize the magnitude, composition, and dependence on environmental variables of emissions from these sources.

In choosing control strategies, the generation pattern of organic contaminant sources is clearly an important factor. In the case of new building materials emitting over extended periods, further research may allow us to define an acceptable "drying out" period prior to occupancy, or may allow the judicious selection of a low-emitting material among several candidates. For organic contaminants generated during the work-day direct source elimination is a more efficient remedy than increasing the ventilation rate. (Care must be exercised, however, since replacement of wet-process photocopiers with dry-process photocopiers, for

example, may introduce a new pollutant--ozone, as reported by Allen et al., 1978; Selway et al., 1980.) As episodic sources, building maintenance products can be efficiently handled by appropriate scheduling rather than by increasing the ventilation rate.

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Table 1

SPECIFIC ORGANIC CONTAMINANTS DETECTED IN FOUR OFFICE
SITES AT LAWRENCE BERKELEY LABORATORY (LBL)

	LBL 67C ^a	LBL 90H ^a	LBL 90-3143 ^b	LBL 90-3145 ^c
HYDROCARBONS				
n-hexane	x	x	x	
n-heptane			x	
n-octane			x	x
n-nonane			x	x
n-undecane			x	x
2-methylpentane	x	x		
3-methylpentane		x		
2,5-dimethylheptane			x	
methylcyclopentane	x	x	x	
ethylcyclohexane			x	x
methylcyclohexane			x	
pentamethylheptane			x	x
AROMATICS				
benzene		x	x	
xylene	x			
toluene		x	x	x
HALOGENATED HYDROCARBONS				
trichloroethane	x	x	x	x
trichloroethylene	x		x	x
tetrachloroethylene			x	x
MISCELLANEOUS				
hexanal		x		
methyl ethyl ketone	x			

^aOffice trailer

^bRemodelled office inside a large building

^cExisting office inside a large building

Table 2

CHARACTERISTICS OF SOURCES OF ORGANIC
CONTAMINANTS IN A HYPOTHETICAL OFFICE SPACE^a

Source	Nominal Emission Rate (g/h)	Generation Pattern	Nominal 8 hr TWA Exposure at 1.0 acph (mg-h/m ³)	Major Known Types of Organic Contaminants Emitted
new building materials	10 ^b	continuous	29	aliphatic hydrocarbons aromatic hydrocarbons ketones esters formaldehyde miscellaneous organics
aged building materials	low	continuous	low	formaldehyde
wet-process photocopiers	25 ^c	workday	62	aliphatic hydrocarbons
smokers	0.135 ^d 0.068 ^d 0.033 ^d (4)	workday	0.33 0.17 0.08 9.9	formaldehyde acrolein nicotine total particulates miscellaneous organics
building maintenance	100	episodic	33 ^e	aliphatic hydrocarbons aromatic hydrocarbons formaldehyde amines chlorinated hydrocarbons miscellaneous organics

^aThe hypothetical office being considered has dimensions of 100 x 100 x 10 ft³ with an occupancy of 40 workers.

^bFigures given are for wall-to-wall carpeting with an assumed emission rate of 1.0 mg-h/ft².

^cAssumes one wet-process photocopier using 1000 g of fluid per week.

^dCalculated from data in Weber et al. (1977) assuming 13 smokers each of whom smoke 16 cigarettes during the workday (in accordance with estimates made by Repace and Lowrey, 1980).

^eFigures given are for 100 g of dust-remover fluid assumed to be applied during the first hour of an 8 hr workday

Table 3

ORGANIC CONTAMINANTS IDENTIFIED IN HEADSPACE VAPOR OVER
SELECTED BUILDING MATERIALS

Building Material ^a	Description	Major Organic Contaminants ^b	Organic Contaminants of Interest ^c	Remarks
carpet #1	nylon (?) fiber, jute backing	3-phenylcyclohexene, aliphatic hydrocarbons	3-phenylcyclohexene	3-phenylcyclohexene derived from alcohol?
carpet #2	polypropylene fiber, foam backing, self-stick	trimethylcyclohexane, aliphatic hydrocarbons	traces of alkylbenzene	
carpet #3	synthetic fiber, thin composition backing	n-octane, n-nonane aliphatic hydrocarbons	none	
carpet #4	nylon fiber, jute backing	3-phenylcyclohexene, decane, dichlorobenzene, styrene, aliphatic hydrocarbons	3-phenylcyclohexene, dichlorobenzene, styrene small amounts of alkylbenzenes, traces of naphthalene, 1- and 2-methylnaphthalene, nonanal, analog of butylated hydroxytoluene (BHT)	3-phenylcyclohexene derived from alcohol? dichlorobenzene from air deodorizer
carpet #5	acrylic fiber, foam backing	heavy oxygenated compound, aliphatic hydrocarbons	heavy oxygenated compound, small amounts of phenol, biphenyl, naphthalene, 1- and 2-methylnaphthalene	heavy oxygenated compound clearly largest component emitted, unknown
linoleum #1	vinyl, self-stick	dimethylcyclohexane, n-octane, aliphatic hydrocarbons	none	
linoleum #2	vinyl asbestos, self-stick	octane isomers, nonane	small amounts of toluene, xylene, propylbenzene, trace of trichloroethylene	
linoleum #3	vinyl	acetone, methyl ethyl ketone (MEK), toluene, butyl acetate, aliphatic hydrocarbon background	acetone, MEK, toluene, butylacetate, small amounts of dimethyldioxane, trichloroethylene, benzaldehyde, 2-(2-ethoxyethoxy) ethanol (carbitol)	

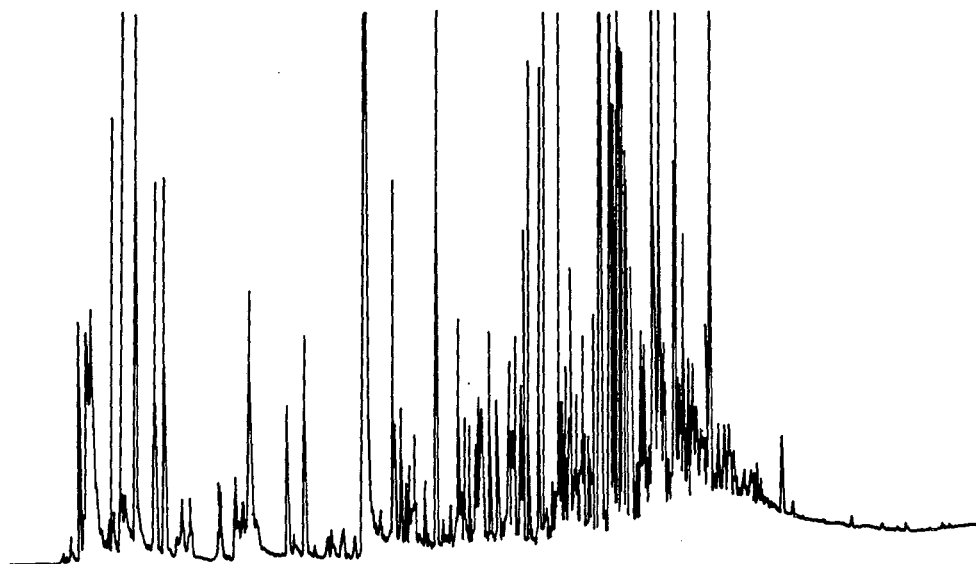
Building Material ^a	Description	Major Organic Contaminants ^b	Organic Contaminants of Interest ^c	Remarks
Linoleum #4	vinyl asbestos	toluene	toluene, small amounts of benzaldehyde, acetophenone, benzylalcohol, butyl benzyl ether, alkylbenzenes	
acoustic ceiling tile	pulp faced by vinyl acrylic latex coating	butyl acetate, aliphatic hydrocarbon background	butyl acetate	water was major emission
acoustical tile/ tileboard cement	mastic	aliphatic hydrocarbons	xylene, ethylbenzene toluene, traces of benzene, naphthalene, alkylbenzenes, butylated hydroxytoluene (BHT)	allowed to dry 24 hrs before vapor collected
contact cement	liquid	trimethylcyclohexane, methyl ethyl ketone (MEK), aliphatic hydrocarbons	none	allowed to dry 24 hrs before vapor collected
linoleum cement	mastic	denatured alcohol (ethanol, methanol)	methyl isobutyl ketone (MIBK)	allowed to dry 24 hrs before vapor collected
ceramic tile cement	mastic	hexane, aliphatic hydrocarbons	small amounts of alkylbenzenes, trace of trichloroethane	allowed to dry 24 hrs before vapor collected
caulk #1	"Phenoseal"	butylacetate, 2-(2 ethoxy-ethoxy) ethanol (carbitol)	butylacetate, carbitol small amount of butyl propyl ether	water was major emission, allowed to dry 24 hrs before vapor collected
caulk #2	vinyl acrylic latex caulk	ethylene glycol	ethylene glycol	allowed to dry 24 hrs before vapor collected
caulk #3	butyl caulk	octane, octene, nonane, aliphatic hydrocarbons	octene, small amounts of alkylbenzenes	allowed to dry 24 hrs before vapor collected

^aSamples were purchased in local hardware stores, obtained from local building sites, or supplied by interested consumers.

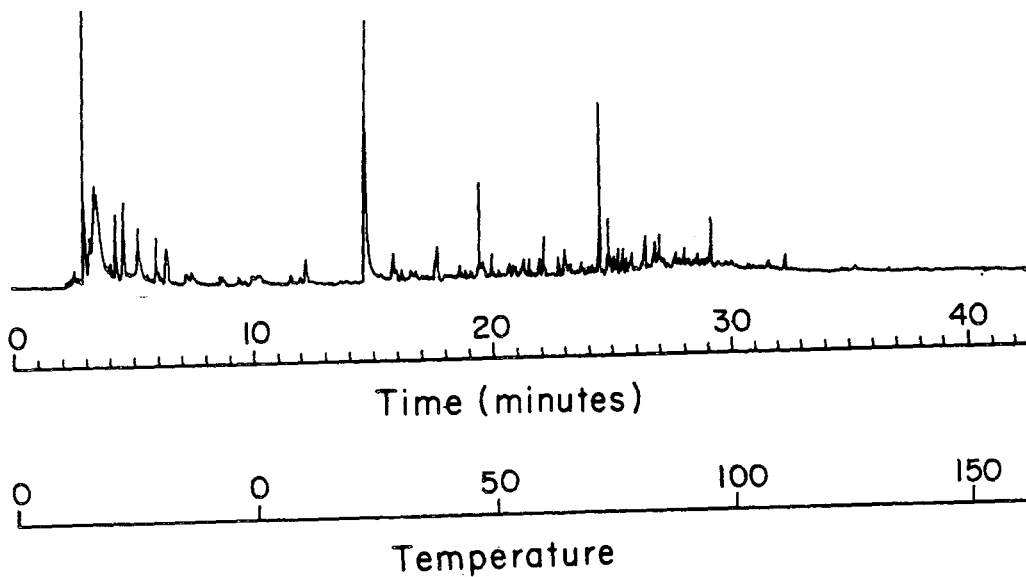
^b"Major" is defined as one of the five largest peaks. Aliphatic hydrocarbons is used in place of a detailed description of the components of petroleum-derived solvent constituents.

^c"Organic contaminants of interest" are defined as those compounds which possess functional groups that enhance chemical reactivity. "Trace amounts" applies to compounds that were approaching the limit of detection, while "small amounts" refers to compounds that were clearly present yet which did not form one of the five largest peaks (see previous footnote).

Indoor

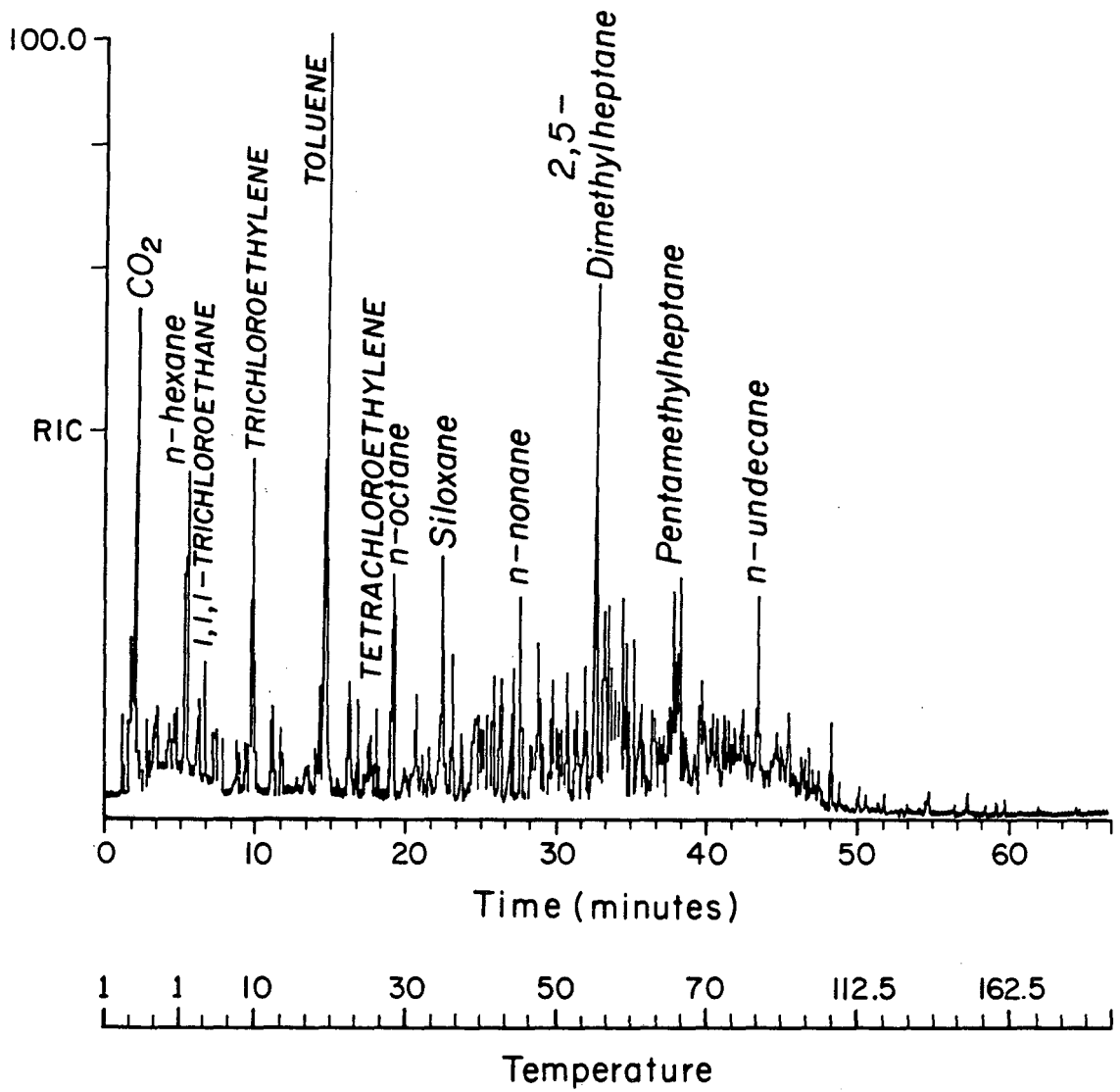


Outdoor



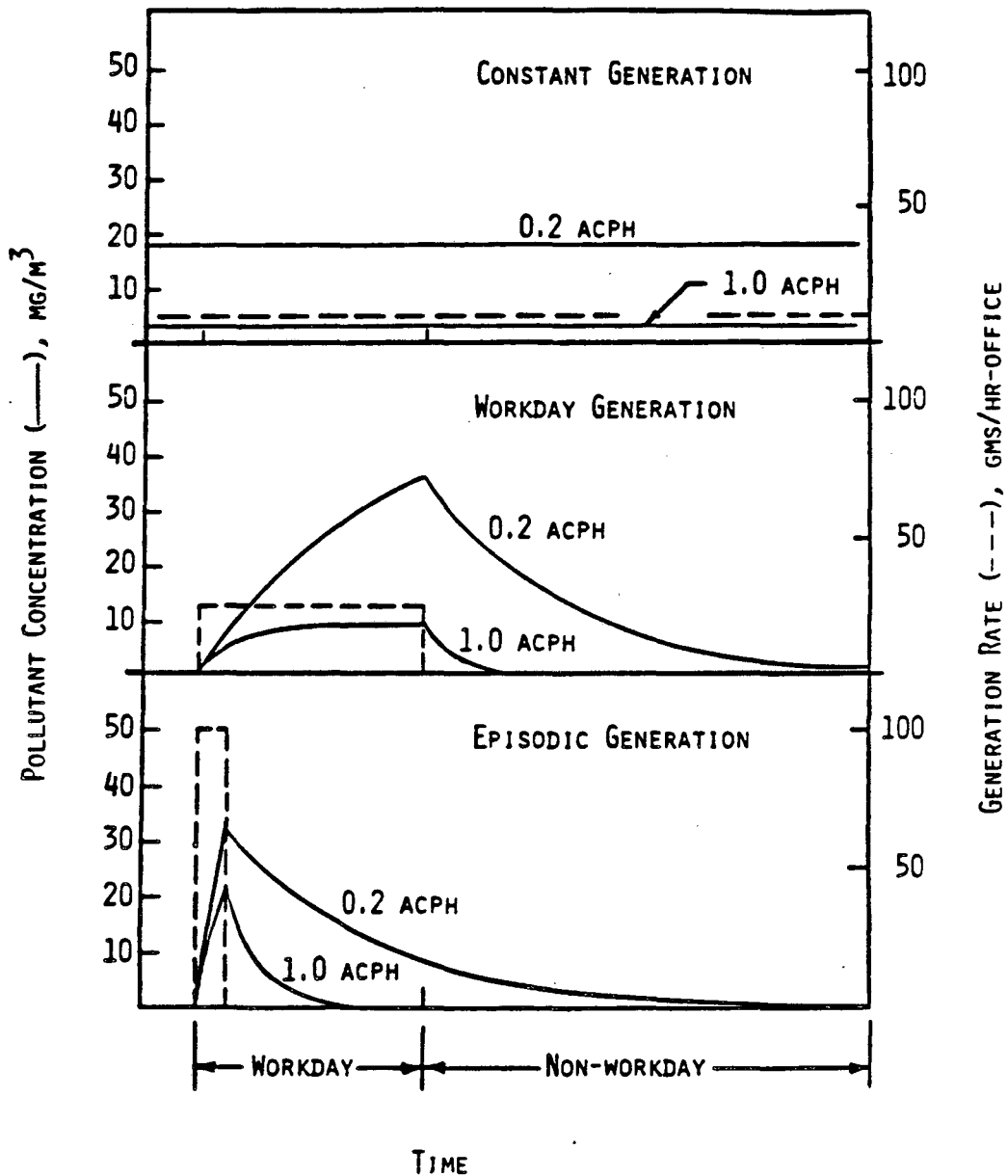
XBL808-1727

Fig. 1. Comparison of gas chromatograms for equal size air volumes sampled with the porous polymer Tenax-GC inside and outside an office where indoor air quality complaints were registered.



XBL 808-1726

Fig. 2. Reconstructed ion chromatogram from an analysis of a sample of office air by GC-MS with representative compounds identified. (Siloxane is an experimental artifact arising from the use of silanated glass wool in the sample cartridges.)



XBL 818-11301

Fig. 3. Behavior of mean pollutant exposure levels for different generation patterns, as predicted by the ventilation model of Turk (1963). Upper: constant generation of 10 g/office-hr by wall-to-wall carpeting emitting 1 mg/ft². Center: workday generation of 25 g/office-hr by one wet-process photocopier. Bottom: episodic application of 100 g of dust remover during the first hour of the workday.

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