☙ EPA *Inside IAQ*

EPA's Indoor Air Quality Research Update

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PLEASE NOTE: We regret that the Fall/Winter 1997 issue was not published due to unanticipated delays

A COMPARISON OF INDOOR AND OUTDOOR CONCENTRATIONS OF HAZARDOUS AIR POLLUTANTS

Many researchers who study IAQ believe that overall exposure to air pollutants is greater indoors than outdoors. We note that most air pollutants have many potential sources inside buildings, and therefore indoor concentrations are likely higher, on average, than outdoor concentrations. We then infer that indoor exposures (concentrations breathed multiplied by duration of time breathed) must be higher–perhaps much higher, given the high percentage of time most people spend indoors. (In general, we have thought of "indoor" time as time spent in buildings, in spaces that do not contain industrial, manufacturing, or commercial processing operations. Time spent in vehicles is counted by some authors as "indoors," and not counted by others.)

The expectation that indoor concentrations of pollutants generally equal or exceed outdoor concentrations (and that indoor exposures exceed outdoor exposures) is based on three principal considerations.

! *Concentrations of air pollutants are not reduced greatly when outdoor air enters a building.* Air that is brought into a building by a mechanical ventilation system rarely has air cleaning devices for pollutants other than particles, and these devices have very low removal efficiencies for fine particles (with aerodynamic diameters less than 10 µm, and especially less than 2.5 µm). Air that enters a building through infiltration is, in general, cleaned very little as it penetrates openings in the building envelope. Literature on outdoor-to-indoor reductions implies 0 to 50% reduction for most substances. For reactive species like SO_x, NO_x, and ozone, the reported reductions range from only 20% to a maximum of 80% (Weschler et al., *ES&T*, **26**: 179-184, 1980; Brauer et al., *JAPCA*, **4**:171-181, 1991; Hoek et al., *JAPCA* **39**:1348-1349, 1989; Liu et al., *Proc. Indoor Air; 93*, **2**:305-310, 1993; Andersen, *Atm. Environ., 6:275-278, 1972).*

- *People spend approximately 90% of their time indoors* (Analysis of the National Human Activity Pattern Survey [NHAPS] Respondents from a Standpoint of Exposure Assessment, EPA/600/R-96/074). The order-of-magnitude greater time spent indoors than outdoors more than offsets reductions in pollution concentrations that may occur when air enters a building. Therefore, even if there were no indoor sources, indoor exposures would be greater than outdoor exposures.

- *There are sources in buildings for most air pollutants.* The growing literature on measured emissions of gaseous and particulate pollutants, supplemented by compositional data on thousands of products used in buildings, confirms that indoor sources can be significant contributors to indoor concentrations and exposures.

Several field studies have shown higher indoor than outdoor concentrations for many types of pollutants, especially for volatile organic compounds (VOCs). A study of that literature is underway in IEMB to determine the indoor/outdoor (I/O) concentration and exposure ratios for hazardous air pollutants (HAPs). This article summarizes the status of that study.

The starting point for the analysis was the list of 188 HAPs, on the presumption that these substances are generally considered health-hazardous by EPA and by U.S. society in general. (Clean Air Act Amendments of 1990, Public Law 101-549, 104 Stat 2532-2534, November 15, 1990.)

In reviewing the literature on measured indoor and outdoor concentrations, the list was narrowed to the 29 HAPs for which two or more original references were available. The three xylene isomers were grouped which resulted in a list of 27 substances. Eight of these substances are on the Agency's list of HAPs "that present the greatest threat to public health in the largest number of urban areas" and are being addressed under the Urban Air Toxics Program in the Office of Air Quality Planning and Standards (OAQPS) (See sections 112(c)(3) and 112(k) of Clean Air Act Amendments of 1990) .Those eight substances are indicated by an asterisk in Tables 1-4.

The I/O concentration and exposure ratios determined in this study are presented in Table 4. Tables 1-3 and the discussion below provide the background information and the rationale for the values presented in Table 4.

Using the eight references listed in the box below, reported I/O concentrations and concentration ratios were compiled, and typical concentrations and concentration ratios were selected. Simple estimates of typical daily exposures (i.e., the product of concentration and hours/day a person is exposed) were then made for each of the 27 substances. Exposure estimates are particularly important when comparing I/O situations because of the order-of-magnitude difference in the amount of time the typical person spends indoors versus outdoors.

Sources of data for indoor and outdoor concentrations and concentration ratios (see Table 4 for citations).

Shah and Singh 1988	Literature survey Outdoor concentrations	U.S. ambient air data through 1986
Samfield, 1992	Literature survey Indoor concentrations	U.S. and foreign data through late 1980's data on residences, office buildings, schools, other commercial buildings
Brown et al., 1994	Literature survey, Indoor concentrations I/O ratios	Comprehensive compilation and analysis of U.S. & European literature, data on residences, office buildings, schools, and other buildings
Kelly et al., 1994	Literature survey Outdoor concentrations	Comprehensive update of Shah and Singh, 1988
EPA Nonoccupational Pesticide Exposure Study (NOPES) 1990	Field study of pesticides Indoor concentrations, Outdoor concentrations, I/O ratios	Approximately 350 samples from homes in Jacksonville, FL and Chicopee-Springfield, MA
Sheldon et al., 1992	Field study, Indoor concentrations, Outdoor concentrations, I/O ratios	128 homes in Woodland, CA
Daisey et al., 1994	Field study, Indoor concentrations, Outdoor concentrations, I/O ratios	12 office buildings in northern CA with 3 different types of ventilation systems
Shields et al., 1996	Field study, Indoor concentrations, Outdoor concentrations, I/O ratios	70 telephone company buildings in 25 states and Washington, D.C., 50 telecommunications centers, 11 office buildings, 9 data centers

Concentration values from the literature that were extreme, or from studies of locations or buildings with known high concentrations, were avoided. A statistical meta-analysis was not attempted, given the limited amount of data for most substances. Median or geometric mean values were used when possible, with the thought that arithmetic means tend to be too biased by large values to represent typical conditions. Ultimately, selection of the "typical" indoor or outdoor concentration was subjective, based on the spread of the summary data from the various references, the age of the data in the references (more recent data were generally favored), and the number of measurements represented by the references (large data sets from a large number of sites or studies were generally given more weight). Data from buildings in the U.S. were given the greatest weight to reduce possible confounding with data from countries where the materials used in buildings and ventilation practices might be different. However, a brief review of a Canadian study (Olson et al., *Atm. Environ.*, **28**(22): 3563-3569, 1994) of 757 homes in which 12 of the 27 HAPs were measured showed that only two of the substances had means that were a factor of more than 5 different from the typical indoor concentrations shown in Table 4 (trichloroethylene was lower, paradichlorobenzene was higher).

The concentration and exposure ratios in Table 4 are, where possible, from studies where both indoor and outdoor measurements were made: those values are shown in italics and brackets in Table 4. For 15 of the 27 substances, such data were not available, so straight arithmetic ratios of typical indoor over typical outdoor were used. It is important to understand that this compilation and analysis amounts to a screening, or order-of-magnitude, assessment. Since most studies in the literature have experimental design limitations (e.g., in most studies the buildings were not statistically selected), accurate estimates of exposures experienced by the U.S. population cannot really be determined.

The analysis of data supports the hypothesis that indoor exposures to most of these chemicals significantly exceed outdoor exposures. The indoor concentrations of these 27 organic vapor HAPs are generally 1 to 5 times outdoor concentrations, and indoor exposures are 10 to 50 times outdoor exposures. Ratios for the pesticides in this group, although less certain because of very limited data, appear to be somewhat higher. This is an inevitable consequence of the fact that the ratio of time spent indoors versus outdoors (about 10) greatly offsets the fraction (generally 10 to 50%) that outdoor pollutant concentrations are reduced when outdoor air enters a typical building. In addition, there are indoor sources for most of these substances, and these indoor sources can be the major contributors to exposures.

Note that this analysis does not address health risk. Whether any of the tabulated concentrations or exposures–indoor or outdoor–pose health risks could only be estimated through risk assessment.

This analysis is continuing and will consider new data as they become available. An analysis of trends of some of these substances, as reported over the past 15 years, is planned. Relating them to sources is another challenging possibility. (EPA Contact: W. Gene Tucker, 919-541-2746, e-mail, tucker.gene@epamail.epa.gov)

TABLE 1. Summary of Reported Indoor Concentrations of Selected HAPs ($\mu g/m^3$)

HAP	Survey Articles or Reports					Individual Studies					"Typical" Value
	Shah and Singh (1988)		Samfield (1992)		Brown et al. (1994)	NOPES (1990) Average of Wghtd Arith Means		Sheldon et al. (1992)	Daisey et al. (1994)	Shields et al. (1996)	
	Mean	Median	Avg of Medians	Avg of Means	WA, GM[a]	J'ville[b]	Spr/Chic[c]	Median	GM	Avg of GMs	
Acetaldehyde*				9.6							<10
Benzene*	17	10	8	8.2	8			2.2	3.2		5
Captan				0.00185		0.001	0.0001				<0.001
Carbon Tetrachloride*	25	0	<4	12				0.5			<5
Chlordane			3.3	2.8		0.26	0.12				0.2
Chloroform*	2.9	0.5	>8	8	10			<1.2			1
Cumene				5.1							1
2,4-D (salts, esters)				0.0018		0.001	0.001				0.001
DDE						0.0003	0.0008				0.0005
Dichlorvos				0.07		0.082	0.003				0.05
Ethylbenzene	13	4.9	2.8	13.8	5				2.2	2	5
Formaldehyde*	62	52		92							50
Heptachlor			1.2	0.7		0.13	0.017				0.1
Hexachlorobenzene				0.000126		0.0007	0.0001	<<0.8			0.0005
Hexane			5	33	12, 5				2		5
Methoxychlor						0.0002	0				0.0001
Methyl Ethyl Ketone	28	21	5.3	7	4, 21						10
Methylene Chloride				342	17			15	1.4		10
Naphthalene			<0.4	11							1
Paradichlorobenzene	24	1.7	<2	31	8			1		~0.1	1
Propoxur			0.093	0.34		0.3	0.022				0.1
Radionuclides/Rn**											2
Styrene*			1.2	1.8				1	1.7	~2	2
Tetrachloroethylene*	21	5.1	<4	9.5	7			0.3		2	5
Toluene	28	6.3	42	56	37				10	7	20
Trichloroethylene*	7.4	0.7	<1.4	5.9	47***			<0.3	9.8		5
Xylenes (o+m+p)			~12	~25	24			6	12	~7	15

* Urban Air Toxics substance
**Radionuclides/Rn in pCi/L
*** Measurements from buildings with IAQ complaints
[a] WA = Weighted Average   GM = Geometric Mean
[b] Jacksonville, FL
[c] Springfield/Chicopee, MA

Notes for Table 1

o   Values from Brown et al. (1994) were given the most weight, since they represent the most comprehensive, albeit international, data set (Extracting U.S. data has not been attempted at this point.)

o   Data on acetaldehyde are limited, and some investigators report measurement problems, hence the "less than" value.

o   Chloroform data in the Brown survey are from only one office building, so greater weight was given to the more recent studies.

o   Cumene and naphthalene data are very limited. Rather than deleting them, they were given a substantially lower value than the reported means, which are relatively old data.

o   The paradichlorobenzene value in Brown seemed high relative to other references, so more weight was given to more recent data from Sheldon et al. (1992) and Shields et al. (1996).

TABLE 2. Summary of Reported Outdoor Concentrations of Selected HAPs (µg/m^3)

	Survey Articles		Individual Studies				
	Shah and Singh (1988) Median	Kelly et al. (1994) Median or Range	NOPES (1990) Average of Weighted Arith Means J'ville [a]	Spr/Chic [b]	Sheldon et al. (1992) Median	Shields et al. (1996) GeoMean	"Typical" Value
HAP							
Acetaldehyde*	2.4	2.7					<3
Benzene*	5.4	5.1			1.1		5
Captan		ND	ND	ND			<0.0001
Carbon Tetrachloride*	0.77	0.8			0.5		1
Chlordane		ND-0.63	0.025	0.0025			0.01
Chloroform*	0.29	0.2					0.2
Cumene		0.2					0.2
2,4-D (salts, esters)		ND-0.004	0.00003	ND			0.00003
DDE		ND-0.13	ND	ND			<0.002
Dichlorvos		ND-0.15	0.001	ND			0.001
Ethylbenzene		1.1				1	1
Formaldehyde*	5.1	3.3					4
Heptachlor		ND-0.63	0.015	0.0002			0.002
Hexachlorobenzene		ND-0.013	0.00007	ND	<<0.8		0.0001
Hexane		3.8					4
Methoxychlor		ND-0.007	0.00003	ND			0.00003
Methyl Ethyl Ketone		ND					<1
Methylene Chloride	2.7	0.5			<2.8		1
Naphthalene	1.2	1.2					1
Paradichlorobenzene	0.26	ND			<0.3	<0.05	<0.05
Propoxur		0.001-0.2	0.045	0.0004			0.01
Radionuclides/Rn**		(0.07-0.2)					0.1
Styrene*		0.6			<0.2		0.6
Tetrachloroethylene*	2.4	1.7			<0.3	0.5	2
Toluene	7.2	8.6				2.6	5
Trichloroethylene*	0.86	0.4			<0.3		0.5
Xylenes (o+m+p)		10.7			2.3	~3.4	10

* Urban Air Toxics substance
**Radionuclides/Rn in pCi/L
ND = Not Detected
[a] Jacksonville, FL
[b] Springfield/Chicopee, MA

Notes for Table 2

o   Kelly et al. (1994) is the primary reference for selection of typical values.
o   Captan and DDE values based on detection limits reported in NOPES (1990).
o   Hexachlorobenzene value arbitrarily selected from wide range of values reported.
o   Methyl Ethyl Ketone detection limit not reported. Typical value of <1 is arbitrary, but I/O ratio in Table 3 is basis for exposure ratio.

TABLE 3. Summary of Reported Indoor/Outdoor Concentration Ratios of Selected HAPs ($\mu g/m^3$)

HAP	Sheldon et al. (1992) GeoMean	Brown et al. (1994) GeoMean	Daisey et al. (1994) Range	Shields et al. (1996) Avg. of Geo. Means	"Typical" Ratio
Acetaldehyde*		5			5
Benzene*	2.1	3	0.25-4.2		2
Captan					
Carbon Tetrachloride*	1	2			2
Chlordane					
Chloroform*		5			5
Cumene					
2,4-D (salts, esters)					
DDE					
Dichlorvos					
Ethylbenzene		6	0.48-2.5	2.1	3
Formaldehyde*					
Heptachlor					
Hexachlorobenzene					
Hexane		9	0.26-18		10
Methoxychlor					
Methyl Ethyl Ketone		4			4
Methylene Chloride		6	1.0-45		10
Naphthalene		4			4
Paradichlorobenzene	6.9	5			5
Propoxur					
Radionuclides/Rn**					
Styrene*	4.1	10	0.69-13		5
Tetrachloroethylene*	1.8	5		2.8	3
Toluene		6	0.63-5.2	3	5
Trichloroethylene*		6	1.7-84		5
Xylenes (o+m+p)	2.4	6	0.5-3.5	~2	2

* Urban Air Toxics substance
** Radionuclides in pCi/L

Note for Table 3

o   All four references weighted about equally in selecting typical ratio.

TABLE 4. Summary of Indoor and Outdoor Air Concentrations and Exposures for Selected HAPs
All ratios based on typical values from Tables 1-3; rounded to one significant figure.

HAP	References	Typical Concentration***			Typical Daily Exposure[#]		
		Indoor ($\mu g/m^3$)	Outdoor ($\mu g/m^3$)	I/O Ratio	Indoor ($\mu g/m^3 \cdot h$)	Outdoor ($\mu g/m^3 \cdot h$)	I/O Ratio
Acetaldehyde*	a,b,g	<10	<3	[5]	<216	<7.2	[50]
Benzene*	a,b,g,ef,h	5	5	[2]	108	12	[20]
Captan	c,a,b	<0.001	ND[@]	10	<0.02	<0.0002	~100
Carbon Tetrachloride*	a,b,g,h	<5	1	[2]	<108	2.4	[20]
Chlordane	c	0.2	0.01	20	4.32	0.024	200
Chloroform*	a,b,e,g,h	1	0.2	[5]	21.6	0.48	[50]
Cumene	a,b	1	0.2	5	21.6	0.48	50
2,4-D (salts, esters)	a,c,b	0.001	0.00003	30	0.0216	0.000072	300
DDE	c	0.0005	<0.002	>0.2	0.0108	<0.005	>2
Dichlorvos	c,b	0.05	0.001	50	1.08	0.0024	400
Ethylbenzene	a,d,b,g,e,f	5	1	[3]	108	2.4	[30]
Formaldehyde	a,b,g	50	4	10	1080	9.6	100
Heptachlor	c	0.1	0.002	50	2.16	0.0048	400
Hexachlorobenzene	c,b	0.0005	0.0001	5	0.0108	0.00024	50
Hexane	a,b,e,f	5	4	[10]	108	9.6	[90]
Methoxychlor	c	0.0001	0.00003	3	0.00216	0.000072	30
Methyl Ethyl Ketone	a,b,e,g	10	<1	[4]	216	<2.4	[40]
Methylene Chloride	a,g,e,f,h	10	1	[10]	216	2.4	[90]
Naphthalene	a,b	1	1	[4]	21	2.4	[40]
Paradichlorobenzene	a,d,b,e,h	1	<0.05	[5]	21.6	<0.12	[50]
Propoxur	c,a,b	0.1	0.01	10	2.16	0.024	90
Radionuclides/Rn **	a	2	0.1	20	43.2	0.24	200
Styrene*	a,b,d,f,h	2	0.6	[5]	43.2	1.44	[50]
Tetrachloroethylene*	a,d,b,e,e,g	5	2	[3]	108	4.8	[30]
Toluene	a,c,b,d,e,f,	20	5	[5]	432	12	[50]
Trichloroethylene*	a,b,g,f,h	5	0.5	[5]	108	1.2	[50]
Xylenes (o+m+p)	a,d,b,e,f	15	10	[2]	324	24	[20]

* Urban Air Toxics substance

**Radionuclides/Rn in pCi/L

*** Typical values from the literature for U.S. locations. I/O ratios based on typical concentrations *[or reported ratios as indicated by values in italics and brackets].*

[#] Based on assumption that the typical person spends about 90% of the typical day indoors (in residential, non-industrial workplace, educational, transportation, and commercial spaces such as retail) and 10% outdoors or industrial workplace [ref. i]. "Typical Daily Exposure" is the product of typical concentration ($\mu g/m^3$) times 21.6 hours for indoors, or times 2.4 for outdoors. *[Ratios in italics and brackets based on typical reported concentration ratios.]*

[@] Substance undetected in hundreds of ambient air samples (ref. a); typical ambient value arbitrarily assumed to be 10% of indoor concentration.

References
a Kelly et al., *ES&T*, **28**(8): 378A - 387A, 1994.
b Samfield, EPA-600-R-92-025 (NTIS PB92-158468),1992.
c NOPES Final Report, EPA/600/3-90/003 (NTIS PB90-152224), January 1990.
d Shields, Fleischer, and Weschler, *Indoor Air*, **6**:2-17, 1996.
e Brown et al., *Indoor Air*, **4**:123-134, 1994.
f Daisey et al., *Atm. Environ.* **28**(22):3557-3562, 1994.
g Shah and Singh, *ES&T*, **22**(12): 1381-1388, 1988.
h Sheldon et al., "Indoor Pollutant Concentrations and Exposures", California Air Resources Board, contract A833-156, final report, January 1992.
i Klepeis, N. et al., Analysis of the National Human Activity Pattern Survey (NHAPS) Respondents from a Standpoint of Exposure Assessment, EPA/600/R-96/074, 1996.

REDUCING EMISSIONS FROM ENGINEERED WOOD PRODUCTS

Engineered wood products include computer stations, desks, entertainment units, book cases, kitchen and bathroom cabinets, and counter tops. Particleboard (PB) and medium density fiberboard (MDF) are the most common types of engineered wood for constructing interior products. Hardboard (HB) is also used. PB is made from finely ground wood particles of various sizes, whereas MDF and HB are made from wood fibers. In the U.S., most interior-grade PB and MDF are bonded with urea-formaldehyde (UF) resins; hardboard is bonded with phenol-formaldehyde (PF) resins.

Engineered wood is typically finished prior to being assembled into a product. Boards are printed or overlaid with materials to give them a solid color, a wood grain pattern, or other decorative look. Common types of overlays include vinyl, wood veneer, and paper. A protective coating may also be applied to the paper after it is overlaid to the board. Wood veneered boards are usually coated with sealers and topcoats.

IEMB and Research Triangle Institute (RTI) recently completed cooperative research to identify and evaluate pollution prevention (P2) techniques to reduce indoor emissions from engineered wood products. The research included three phases:
1) conducting emission tests on several types of finished engineered wood;
2) identifying the highest emitting components of the samples in phase 1; and
3) identifying and evaluating potential low-emitting substitutes for the higher-emitting raw materials identified in phase 2.

The results from the phase 1 and 2 research were highlighted in the Spring/Summer 1996 issue of Inside IAQ (EPA/600/N-96-002). In summary, emissions were screened from four types of finished engineered wood: oak-veneered particleboard coated and cured with a heat-curable acid-catalyzed alkyd-urea sealer and topcoat (PBVST); oak-veneered hardboard coated and cured with a stain, and a heat-curable acid-catalyzed alkyd-urea sealer and topcoat (HBVSST); PB overlaid with vinyl; and PB overlaid with melamine. The PBVST and HBVSST had substantially higher initial emission factors of summed VOCs relative to the other two. The PBVST and HBVSST also had higher long-term emission factors of formaldehyde. In the phase 2 component testing, the acid-catalyzed alkyd-urea coating and the PB were identified as primary sources of VOCs and formaldehyde emissions from the PBVST and HBVSST.

The remainder of this article covers the phase 3 research which identified and evaluated potential low-emitting engineered substrates and coatings.

Methods

Phase 3 consisted of two separate sets of emissions tests designed to evaluate potential P2 options to reduce emissions from finished engineered wood. One set of tests focused on alternative engineered fiber panels, while the second focused on alternative coatings.

Six types of engineered fiber panels were identified as potentially low-emitting substitutes for constructing engineered wood products (Table 5). Screening tests were conducted on the six types of panels (samples A,B,C,D,E,N) and on PB manufactured with wood fibers and UF resins (sample F). For the fiber panel evaluation, three panels of each material were collected from the last step in the manufacturing process, when the panels were "ready for shipment." Several 0.006 m^2 coupons were cut from the center of each panel. All coupons cut from the same panel were placed in an airtight steel container and transported to RTI. At RTI, the edges of the coupons were sealed with sodium silicate, and the coupons were placed in conditioning chambers, i.e., 3.8L steel cans operated at 50 % RH, 23 ± 2 °C, and 1 air exchange per hour (ACH). After 26-30 days of conditioning (representative of time elapsed before installation), the coupons were placed in individual test chambers and air samples collected.

Five alternative coatings systems were also identified and evaluated as potentially low-emitting substitutes for heat-curable acid-catalyzed alkyd-urea coatings (Table 6). Performance and quantitative emissions tests were conducted on the five coatings (coatings 2-6) and on the heat-curable acid-catalyzed alkyd-urea coating (coating 1). The Electrotechnology Application Center in Bethlehem, Pennsylvania, coated and cured the unfinished PBV and conducted the performance testing of the coatings. Performance tests included: hardness; adhesion; fingernail mar resistance; and chemical resistance to methyl ethyl ketone (MEK), mustard, and 10 types of stains. Coatings were applied to coupons using a drawdown bar which is a standard laboratory technique for applying a uniform thickness of coating to small substrates.

For the emissions testing of the coatings, each cured coupon was placed in an airtight steel can and shipped to RTI. After 1 week, the coupons were removed from their containers and placed in individual conditioning chambers (i.e., 3.8L steel cans operated at 50 % RH, 23 ± 2 °C, and 1 ACH). The coupons were conditioned for 27 days, at which time they were removed from the conditioning chambers and placed in individual test chambers. Chamber air samples were collected 1 day after each coupon was placed in the test chamber.

TABLE 5. Selected Engineered Panels

Panel Identification	Fiber Source	Resin Source	Interior Applications
A	Recycled newspaper	None	floors, walls , subfloors, roof decking, filler board for furniture
B	Wheat straw	MDI[a]	PB applications such as furniture, cabinetry, shelving
C	Recycled corrugated cardboard	None	furniture, store displays, countertops, shelving, etc.
D	Lumber and plywood residuals	MDI	MDF applications such as furniture, cabinetry, shelves
E	Lumber and plywood residuals	UF	MDF applications such as furniture, cabinetry, shelves
F	Lumber and plywood residuals	UF	PB applications such as furniture, cabinetry, shelves, floor underlayment, stair treads
N	Lumber and plywood residuals	PF	PB applications such as furniture, cabinetry, shelves, floor underlayment, stair treads

[a] MDI = Methylene diisocyanate

TABLE 6. Selected Coatings Systems

	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
Chemistry	Acid-catalyzed alkyd-urea	Two-component polyurethane	Non-air-inhibited unsaturated polyester	Acrylate	Multi-functional acrylate-free emulsion	Polyurethane dispersion
Carrier	organic solvents	water	water	none	water	water
Cure method	heat	heat	UV light	UV light	heat + UV light	heat

Dynamic environmental test chambers, constructed of glass, Teflon, and stainless steel, were used to measure emissions of the engineered panels and the coated panels at RTI. The 0.012 m^3 chambers were operated at 50% RH, 23 ± 2 °C, 1 ACH, and a loading ratio of 1.0 m^2/m^3 [total surface area of the tested material (0.012 m^2) divided by the volume of the test chamber]. Target aldehydes and ketones were collected on dinitrophenyl-hydrazine (DNPH)-coated silica gel cartridges and analyzed by high pressure liquid chromatography with ultraviolet (UV) detection. Other VOCs were collected on multisorbent cartridges and analyzed by gas chromatography/mass spectrometry (GC/MS). Emission factors for total VOCs (TVOC) were estimated from the analysis of the multisorbent cartridges, and did not include aldehydes and ketones collected on the DNPH cartridges. Emission factors for "Summed VOCs" were calculated by summing the individual emission factors of aldehydes and ketones collected on the DNPH cartridges, and of other VOCs collected on the multisorbent cartridges.

Results

Figure 1 presents emission factors of TVOCs and formaldehyde for coupons of unfinished fiber panels. The TVOC and formaldehyde data were statistically analyzed using a 95% confidence interval to ascertain which samples differed with respect to their emissions of TVOCs and formaldehyde. The mean emission factors of TVOCs for test squares A, F, and N were significantly higher than the mean emission factors of TVOCs for test squares B through E. The mean emission factors of formaldehyde for test squares E and F (the UF bonded panels) were significantly higher than the mean emission factors of formaldehyde for test squares A through D, and N.

For the coatings, the results of the performance tests are discussed first followed by results of the emission testing. Coating 1, the heat-curable acid-catalyzed alkyd-urea coatings system, is the coating system that is currently used. Alternative coatings systems 3, 4, and 5 outperformed coating 1 in the MEK test. Coatings 4 and 5 outperformed coating 1 in the mustard test. For the stain tests, coatings 2, 4, 5, and 6 performed the same as coating 1; coating 3 performed fairly well in the stain tests except for its performance with grape juice and coffee. All coatings performed equally well in the adhesion and fingernail mar resistance tests.

Mean emission factors for the samples of veneered particleboard (PBV) coated and cured with each of the six coatings systems and for samples of uncoated PBV are presented in Table 7. The data were statistically analyzed using a 95% confidence interval to ascertain if emission factors of summed VOCs for test squares of coated and cured PBV were significantly different than those for test squares of uncoated PBV. The mean emission factors of summed VOCs for test squares coated and cured with coatings 1, 3, and 6 were statistically higher than the mean emission factor of summed VOCs for test squares of uncoated PBV, indicating that these coatings systems are a significant source of emissions from finished PBV. The mean emission factors of summed VOCs for test squares coated and cured with coatings 2, 4, and 5 were statistically lower than the mean emission factor of summed VOCs for test squares of uncoated PBV, indicating that these coatings systems are not a significant source of emissions from finished PBV.

The emission data were also statistically analyzed using a 95% confidence interval to ascertain if emission factors of individual and summed VOCs for test squares of PBV coated and cured with coatings system 1 (i.e., the existing coatings system for finishing PBVST in phases 1 and 2) were statistically different than those for test squares of PBV coated and cured with the five alternative coatings systems. The mean emission factor of summed VOCs for test squares of PBV coated and cured with coating 1 was significantly higher than the mean emission factors of summed VOCs for test squares of PBV coated and cured with coatings 2 through 6. The mean emission factors of most organic solvents [such as butanol, C_4- benzenes, 2-(2-butoxyethoxy)ethanol] were significantly higher for test squares of PBV coated and cured with coating 1 compared to test squares with coatings 2 through 6.

A few caveats exist regarding the emissions tests. Certain nonvolatile compounds that were listed in the material safety data sheet (MSDS) for some of the coatings systems were not analyzed in the emission tests; these included nitrocellulose, p-toluene sulfonic acid, hexamethylene diisocyanate, polyisocyanates, acrylate oligomers, and acrylic polymers. These compounds were not analyzed because: 1) they were not expected to be emitted into the air during testing (because of their low volatility); 2) they were not expected to recover efficiently from the emission test chambers, and 3) they were not expected to be amenable to the analytical methods used for this study. Certain volatile compounds that were listed in the (MSDS) for some of the coatings systems were also not analyzed in the emission tests; these included acrylate monomers, N,N-dimethylethanolamine, and ammonia. Acrylate monomers and N,N-dimethylethanolamine were not analyzed in the emission tests because they were not amenable to the analytical methods in the study and because they were not expected to recover efficiently during the

chamber tests (due to their polar nature). Ammonia was not tested for in the emission tests because it was not amenable to the analytical methods in the study.

Summary

A variety of commercially available engineered fiber panels (i.e., those made with wheatstraw and MDI; wood and MDI; and recycled corrugated cardboard) were found to have very low emission factors of TVOC and formaldehyde (relative to UF-bonded PB and MDF). These low-emitting engineered fiber panels can be finished with veneer, vinyl, melamine, etc., and are currently used to construct a wide variety of products for interior applications. In future research, a broader study of the low-emitting engineered fiber panels could be conducted to assess manufacturing issues (e.g., cost) and performance.

A coatings study was conducted to evaluate performance and emissions of potentially low-emitting substitutes for the acid-catalyzed alkyd-urea coating. Within the scope of the tests conducted, the heat-curable two-component polyurethane, the UV-curable acrylate, and the UV-curable multifunctional acrylate-free emulsion appear to be viable alternatives for the heat-curable acid-catalyzed alkyd urea coating. In future research, a broader study of the recommended coatings systems could be conducted to determine how they perform in the manufacturing environment, in terms of their ease of use, worker safety, cleanup, manufacturing emissions, etc. The cost of the coatings could be assessed in terms of equipment needs; e.g., stainless steel or plastic pipes for waterborne coatings, and UV lights for UV coatings. Standard air sampling methods and recovery techniques could also be developed for compounds that could not be analyzed during the coatings evaluation. (EPA Contact: Kelly Leovicc, 919-541-7717, E-mail: kleovic@engineer.aeerl.epa.gov)

FIGURE 1 - Mean estimated emission factors of TVOC and formaldehyde
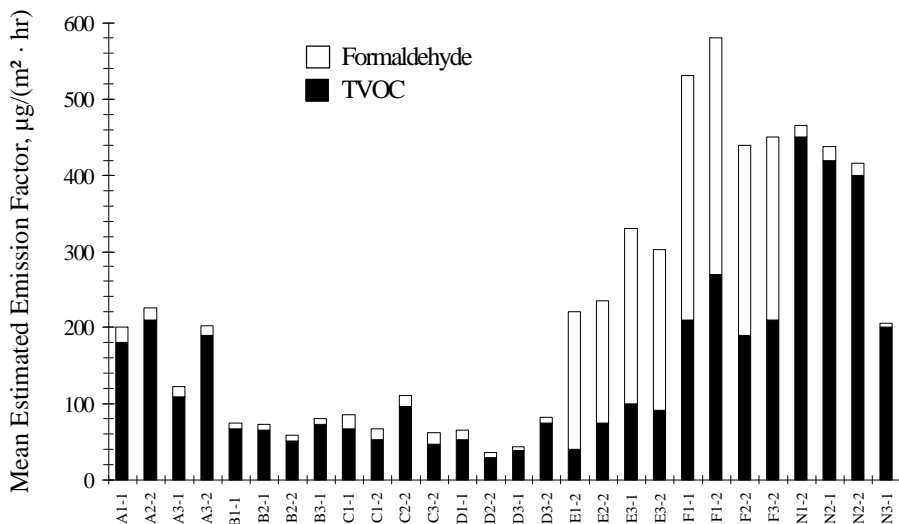
Test squares are labeled by material letter (A,B,C,D,E,F, or N) followed by panel number and test square number.

A = panel made from recycled newspaper

B = panel made from wheatstraw and MDI resin

C = panel made from recycled corrugated cardboard

D = MDF MDI resin

E = MDF UF resin

F = particleboard with UF resin

N = particleboard with PF resin

TABLE 7. Mean Emission Factors for Uncoated and Coated Test Squares

	Mean Emission Factors, $\mu g/(m^2 \cdot hr)$						
	Uncoated test squares of PBV	Test Squares Coated and Cured with					
Compounds		Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
Formaldehyde	140	400	20	70	18	19	33
Acetaldehyde	61	53	41	65	68	41	68
Acetone	420	520	490	380	390	430	510
Propionaldehyde	21	16	15	16	16	12	17
2-Butanone	-[a]	-	-	-	-	-	-
Butyraldehyde	15	-	-	18	-	-	12
Benzaldehyde	23	-	-	30	14	18	23
Valeraldehyde	65	37	26	54	28	19	57
m-Tolualdehyde	-	-	-	-	-	-	-
n-Hexanal	410	150	120	280	79	93	350
1-Pentanol	62	150	16	38	13	14	49
Limonene	79	68	54	74	38	37	83
Junipene	89	61	24	54	16	13	67
Terpenes	170	320	220	170	110	100	120
1-Butanol	6	800	-	5	-	8	7
Toluene	-	16	-	5	22	-	6
2-Methyl-1-butanol	-	55	-	-	-	-	-
Butyl acetate	-	38	-	-	-	-	-
1,2-Propanediol	-	15	-	33	-	-	-
Ethylbenzene	-	270	-	-	33	-	-
m,p-Xylene	-	660	-	-	110	-	-
2-Heptanone	15	550	8	13	9	7	22
o-Xylene	-	210	-	-	32	-	-
Propylbenzene	-	91	-	-	-	-	-
Ethyl 3-ethoxypropionate	-	111	-	-	-	-	-
1-Methyl-2-pyrrolidone	-	11	-	20	-	5	2400
2-(2-Butoxyethoxy)ethanol	8	1700	43	610	18	6	7
Naphthalene	-	24	-	-	-	-	-
Hexyl acetate	-	400	-	-	-	-	-
Indan	-	13	-	-	-	-	-
C3-Benzenes	-	1100	-	-	-	-	-
C4-Benzenes	34	190	25	33	17	16	33
Dipropylene glycol, methyl ether	-	-	-	-	-	24	240
Unknown 1	-	-	-	180	-	-	-
Unknown 2	-	-	-	260	-	-	-
TVOC[b]	1000	5200	610	1700	810	540	2800
Summed VOCs[c]	1600	7800	1100	2300	1000	900	4100

Coating 1 = heat-curable acid-catalyzed alkyd-urea
Coating 2 = heat-curable two-component polyurethane
Coating 3 = UV-curable non-air-inhibited unsaturated polyester
Coating 4 = UV-curable acrylate
Coating 5 = UV- and heat-curable multifunctional acrylate-free emulsion
Coating 6 = heat-curable polyurethane dispersion
[a] < 5 $\mu g/(m^2 \cdot hr)$
[b] TVOC = total volatile organic compounds from TVOC analysis of multisorbent cartridges
[c] Summed VOCs are the sum of emission factors > 5 $\mu g/(m^2 \cdot hr)$, rounded to two significant figures

ENERGY COSTS OF IAQ CONTROL THROUGH INCREASED VENTILATION IN A WARM, HUMID CLIMATE

Increasing the outdoor air (OA) ventilation rate is perhaps the most common approach from improving IAQ. However, the conditioning of this increased OA will increase energy consumption and cost. The energy penalty associated with increased OA will be greatest in hot, humid climates.

To assess the costs of increased ventilation in a hot, humid climate, a series of computer runs has been completed using the DOE-2.1E building energy model, simulating a small office in Miami, FL. These simulations assessed the energy penalty, and the impact on indoor RH, when the OA ventilation rate of the office is increased from 5 to 20 cfm/person.

One objective of this analysis was to systematically assess how each parameter associated with the building and with the mechanical system impacts the energy penalty resulting from increased OA. Another objective was to assess the cost and effectiveness of off-hour thermostat set-up (vs. system shut-down), and of humidity control (using overcooling with reheat), as means for reducing the number of hours that the office space is at an RH above 60% at the 20 cfm/person ventilation rate.

The small office modeled in this analysis was a 372 m^2 (4,000 ft^2) office in a single-story strip mall. Typical of such space, this office is cooled by two packaged single-zone heating, ventilating, and air-conditioning (HVAC) units.

With the baseline set of variables selected for this analysis, an OA increase from 5 to 20 cfm/person is predicted to increase the annual cost of energy consumed by the HVAC system by 12.9%. The analysis showed that the parameters offering the greatest practical potential for energy savings are conversion to very efficient lighting and equipment (1.5 W/ft^2) and conversion to very efficient cooling coils (electric input ratio = 0.284). If the increase to 20 cfm/person were accompanied by either of these conversions, the 12.9% HVAC energy penalty for the increased OA rate would be eliminated; the modified system at 20 cfm/person would have a 2 to 5% *lower* annual HVAC energy cost than the baseline system at 5 cfm/person.

Other parameters offering significant practical potential for energy savings are: conversion from packaged single-zone units to a variable air volume system; conversion to cold-air distribution (minimum supply air temperature = 42 °F); or improvements in the glazing or in the roof resistance to heat transfer. If the OA increase were accompanied by any one of these modifications, the 12.9% penalty would be reduced to between 2 and 7% (the modified system at 20 cfm/person compared against the baseline at 5 cfm/person).

According to the DOE-2.1E model, the increase in ventilation rate could be achieved with an 85% reduction in the number of occupied hours above 60% RH, compared to the baseline system at 5 cfm/person -- with only a $19/year increase in energy cost -- if the economizer were eliminated. That is, most of the elevated-RH hours in the baseline case were predicted to be the result of economizer operation. If the control system were modified so that it controlled the humidity as well as the temperature in the office space, *all* of the elevated-RH occupied hours would be eliminated, at an energy cost of $90/year.

Neither economizer elimination nor humidity control would address *un*occupied periods, when most of the elevated-RH hours occur. Building operators concerned about biological growth at elevated RH should consider operation of the cooling system during unoccupied hours, perhaps with the thermostat set up, rather than system shut-down off-hours. Off-hour set-up from 75 to 81 °F would add only $10/year to energy costs, and would provide some modest reduction in unoccupied elevated-RH hours. Set-up to 79 °F would provide a greater reduction, at an energy cost of $38/year.

DOE-2.1E underestimates the number of elevated-RH hours because it does not address the moisture capacitance of building materials and furnishings, or re-evaporation off the cooling coils when they cycle off with the air handler operating. As a result, the performance of the RH reduction steps above may be over-estimated, or the costs of the steps underestimated. (EPA Contact: Bruce Henschel, 919-541-4112, bhenschel@engineer.aeerl. epa.gov)

COST ANALYSIS OF INDOOR AIR CLEANERS FOR ORGANIC COMPOUNDS: ACTIVATED CARBON VS. PHOTOCATALYTIC OXIDATION

In the Fall/Winter 1996 edition of *Inside IAQ* (EPA-600/N-97-001), an initial cost analysis was presented comparing granular activated carbon (GAC) versus photocatalytic oxidation (PCO) as means for removing VOCs from indoor air. Since the time of that earlier analysis, a more rigorous cost comparison has been completed.

For this new analysis, it was assumed that an office having a steady-state VOC concentration of 2 mg/m^3 and an air recirculation rate of 7 air changes per hour, is to be reduced to a steady-state concentration of 0.3 mg/m^3 (about 0.1 ppmv). Mass balance indicates that the air cleaner would require a per-pass removal efficiency of 82%.

Design of the GAC Air Cleaner

At the steady-state inlet concentration of 0.1 ppmv and 50% RH, the GAC was assumed to have the capacity to adsorb 2.0 g VOC per 100 g carbon before breakthrough becomes unacceptable. This is the measured capacity of GAC for hexane at those conditions. Carbon's capacity for hexane is at about the median for organic compounds having four or more atoms (exclusive of hydrogen). Lighter organics could have capacities that are one or more orders of magnitude poorer.

The GAC unit costed here is illustrated in Figure 2. This configuration–involving a series of 2.5-cm-thick GAC panels in a V-bank arrangement–is representative of many units offered commercially for IAQ applications. With the assumed sorption capacity, the carbon would have to be replaced every 3.7 months.

Design of the PCO Reactor

The PCO reactor was assumed to have a differential oxidation rate of 0.11 μmol/hr per cm^2 of illuminated TiO$_2$ at an inlet concentration of 1 ppmv and an UV illumination intensity of 1 mW/cm^2. This rate is based on limited literature data available at such low concentrations. The rate is assumed to decrease with concentration below 1 ppmv according to first-order kinetics, consistent with theory and data. To achieve this rate, the required UV intensity incident on the catalyst is assumed to be 1 mW/cm^2, consistent with published data.

Since design information for PCO reactors on the market is highly proprietary, a model PCO reactor was designed for the purposes of this analysis. Since this model reactor contains a significant catalyst surface area per unit reactor volume, it should illustrate the major cost centers associated with PCO reactors, even though it undoubtedly differs from the proprietary commercial units.

The model PCO reactor is shown in Figure 3. It assumes the same V-bank panel bed configuration as for the GAC unit, but with the carbon panels replaced by panels of ceramic foam substrate coated with catalyst. For the oxidation rate and illumination assumptions cited above, there would need to be six banks of panels to achieve the desired 82% per-pass efficiency, and the total input power would be 9,000W to the UV bulbs plus an additional 900W to the ballasts.

The installed costs of these reactors (expressed as cost per m^3/s reactor capacity) and the operating costs (in cost per year per m^3/s) are presented in Table 8. These costs are based largely on vendor quotes and on Means Mechanical Cost Data (e.g., for labor rates). The DOE-2 building energy model was used to compute the increases in energy consumption and cooling capacity requirements.

Conclusions

Analysis of these results leads to the following conclusions.

1. With the assumptions used in this analysis, the PCO reactor has an installed cost over 10 times greater, and an annual cost almost 7 times greater, than those of the GAC adsorber.

2. Changes in the assumptions for the GAC unit, to include VOCs not effectively sorbed on carbon, can increase GAC installed and annual costs to levels comparable to (or higher than) the PCO unit.

3. However, even with the most optimistic adjustments to the assumptions for the PCO unit, it does not appear possible to reduce the PCO installed and annual costs by a factor greater than 2 to 4. Even with reductions by a factor of 2 to 4, PCO would still be sufficiently expensive such that it would not likely be widely accepted for general indoor air applications.

4. The high PCO costs result from the large amounts of catalyst surface area and of UV power that are required for the photocatalysts reported in the literature. The high surface area and power requirements are dictated by the literature data, and cannot be reduced by innovations in reactor or lighting configurations.

5. Only a significantly improved catalyst having a greater quantum efficiency – capable of providing faster oxidation rates with less catalyst area and less illumination -- can reduce PCO costs by a factor greater than 2 to 4.

(EPA Contact: Bruce Henschel, 919-541-4112, bhenschel@ engineer.aeerl.epa.gov)
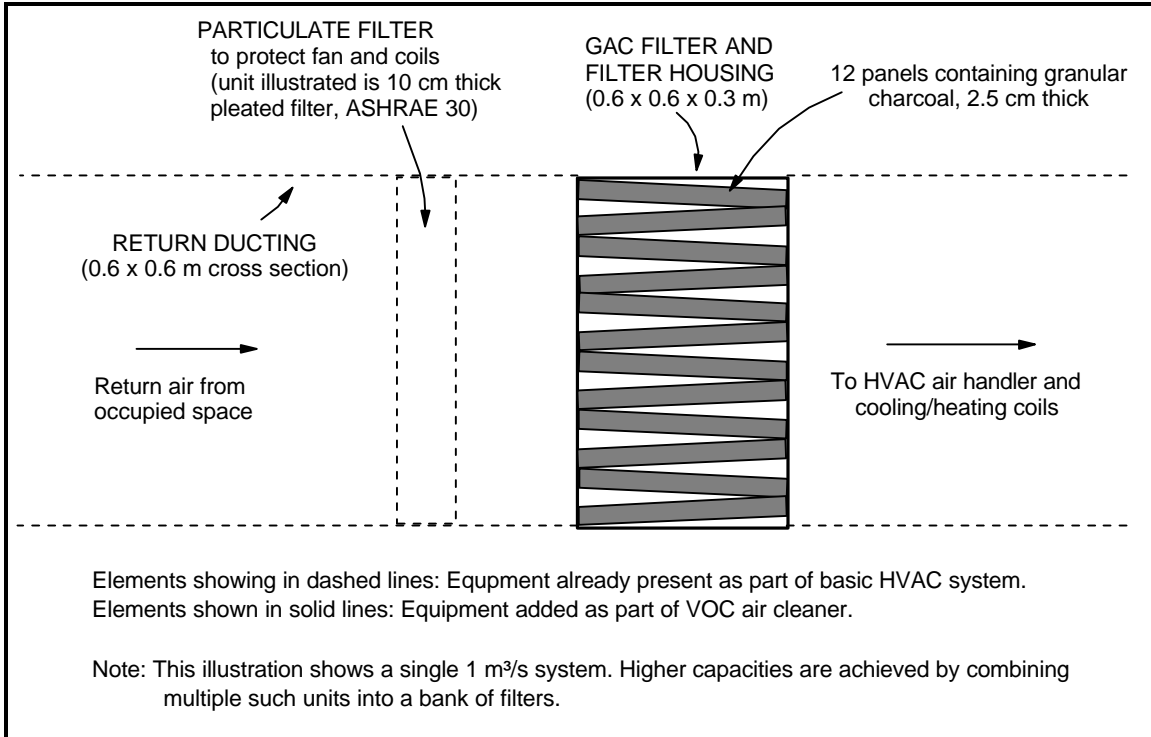
FIGURE 2. GAC VOC air cleaner (side view).

PARTICULATE FILTER
to protect fan and coils
(unit illustrated is 10 cm thick
pleated filter, ASHRAE 30)

GAC FILTER AND
FILTER HOUSING
(0.6 x 0.6 x 0.3 m)

12 panels containing granular
charcoal, 2.5 cm thick

RETURN DUCTING
(0.6 x 0.6 m cross section)

Return air from
occupied space

To HVAC air handler and
cooling/heating coils

Elements showing in dashed lines: Equpment already present as part of basic HVAC system.
Elements shown in solid lines: Equipment added as part of VOC air cleaner.

Note: This illustration shows a single 1 m³/s system. Higher capacities are achieved by combining
multiple such units into a bank of filters.

FIGURE 3. Model PCO VOC air cleaner (side view).

One medium-pressure mercury bulb operated at:
750 W   1,500 W

PARTICULATE FILTER
to remove TiO$_2$ particles
(illustrated is a pleated
filter, ASHRAE 30)

PARTICULATE
FILTER
to protect fan

PCO REACTION UNIT
AND HOUSING (1 of 6)
(0.6 x 0.6 x 0.3 m)

12 panels of substrate (each 0.6 x 0.3 m)
coated with TiO$_2$ photocatalyst:
Ceramic foam (4 pores/cm), 2 cm thick

Return
air
25 °C

To fan
and coils
33 °C

Unit #1   Unit #2   Unit #6

Housing for ballast
and wiring

Total reactor length = 3.4 m
Total input power to UV bulbs = 9,000 W

Elements shown in solid lines: Equipment added as part of the VOC air cleaner.

Note: This illustration shows a single 1 m³/s system.
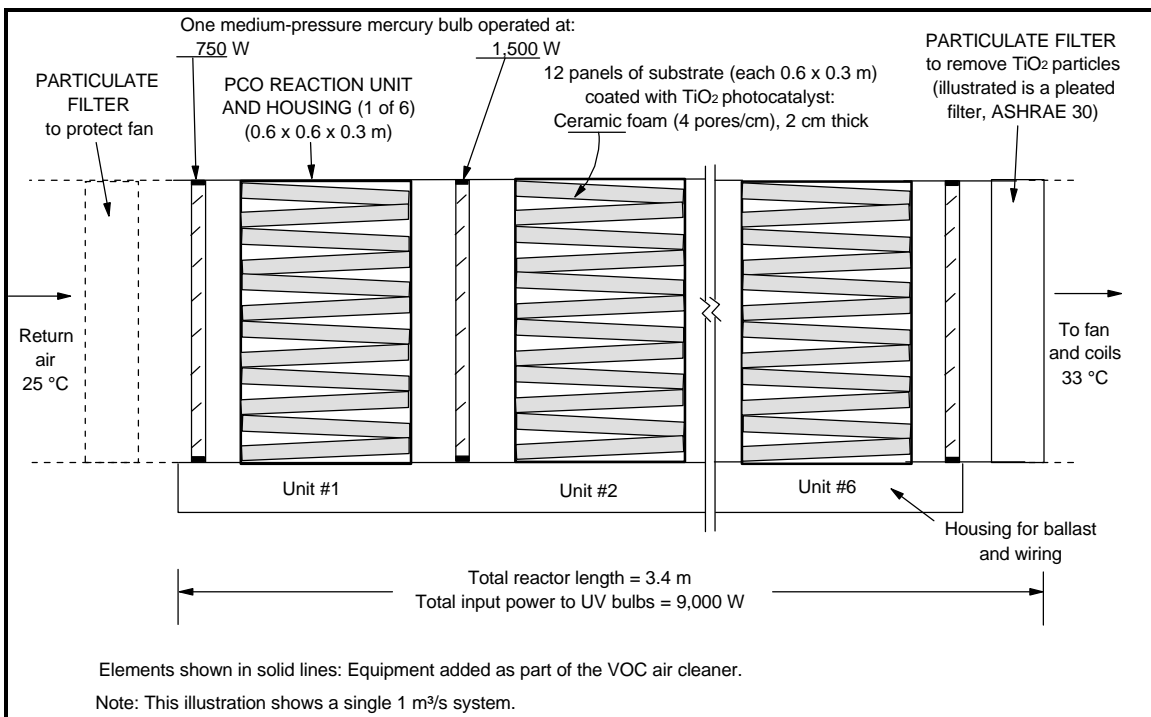
TABLE 8 -Summary Cost Comparison of GAC vs. PCO for VOC Control in Indoor Air

COST ITEM	COST ($ per m^3 / s or $ /yr per m^3 /s)	
	ACTIVATED CARBON	PHOTOCATALYTIC
Equipment and Installation Costs ($ per m^3 / s)		
Reactor (excluding carbon/catalyst)	850	8,090
Initial carbon/catalyst charge	470	6,480
Enlarged central air handler (to provide increased static pressure)	60	20
Increased cooling coil capacity (to remove air handler, bulb heat)	150	1,720
TOTAL INCREMENTAL INSTALLED COSTS	1,530	16,310
Total Annual Costs ($ per yr / m^3 / s)		
Operating		
Electricity cost (for increased HVAC cooling load, fan static pressure, power for UV bulbs)	100	4,440
Maintenance		
Replacement of carbon	1,360	—
Regeneration of catalyst	—	1,510
Disposal of spent carbon/catalyst	20	~ 0
Replacement of UV bulbs	—	2,370
Replacement of final filter	—	20
Capital Charges		
Equipment depreciation (10 year straight)	150	980
Catalyst depreciation (5 year straight)	—	1,500
Insurance and real estate taxes	30	330
Interest on capital (installed cost)	60	650
TOTAL INCREMENTAL ANNUAL COST	1,720	11,800

SUMMARIES OF RECENT PUBLICATIONS

This section provides summaries of recent publications on EPA's indoor air research. The source of the publication is listed after each summary. Publications with NTIS numbers are available (prepaid) from the National Technical Information Service (NTIS) at 5285 Port Royal Road, Springfield, VA 22161, 703-487-4650, or 800-553-6847.

Development of an Innovative Spray Dispenser to Reduce Indoor Air Emissions from Aerosol Consumer Products - The operating principles and performance of a new type of spray nozzle are presented in this report. This nozzle, termed a "ligament-controlled effervescent atomizer," was developed to allow consumer product manufacturers to replace VOC solvents with water and hydrocarbon propellants with air, while meeting the following restrictions: that the spray mean drop size (reported here as Sauter mean diameter, or SMD) remain below 70 μm, that the atomizing air consumption be less than 0.009, and that atomizer performance be uncompromised by the increase in surface tension or by changes in viscosity. The current atomizer differs from previous effervescent designs through inclusion of a porous disc located immediately upstream of the nozzle exit orifice. The disc controls the diameter of ligaments formed at the injector exit plane. Source: EPA Report (EPA Contact: Kelly W. Leovic, 919-541-7717, kleovic@ engineer.aeerl. epa.gov)

Energy Costs of IAQ Control Through Increased Ventilation in a Small Office in a Warm, Humid Climate - A series of computer runs were done using the DOE-2.1E building energy model, simulating a small (4,000 ft^2) strip mall office cooled by two packaged single-zone systems, in a hot, humid climate (Miami, FL). These simulations assessed the energy penalty, and the impact on indoor RH, when the OA ventilation rate of the office is increased from 5 to 20 cfm/person. With the baseline set of variables selected for this analysis, an OA increase from 5 to 20 cfm/person is predicted to increase the annual cost of energy consumed by the HVAC system by 12.9%. The analysis showed that the parameters offering the greatest practical potential for energy savings are conversion to very efficient lighting and equipment (1.5 W/ft^2) and conversion to very efficient cooling coils (electric input ratio = 0.284). If the increase to 20 cfm/person were accompanied by either of these conversions, the 12.9% HVAC energy penalty for the increased OA rate would be eliminated; the modified system at 20 cfm/person would have a *lower* annual HVAC energy cost than the baseline system at 5 cfm/person. Other parameters offering significant practical potential for energy savings are: conversion to cold-air distribution (minimum supply air temperature = 42 °F); or improvements in the glazing or in the roof resistance to heat transfer. According to the DOE-2 model, the increase in ventilation rate could be achieved with an 85% reduction in the number of occupied hours above 60% RH, compared to the baseline system at 5 cfm/person – with only a $19/year increase in energy cost – if the economizer were eliminated. Source: EPA Report, EPA 600/R-97-131, November, 1997 EPA Contact: D. Bruce Henschel, (919-541-4112, bhenschel@engineer.aeerl .epa.gov)

Field Methods to Measure Contaminant Removal Effectiveness of Gas-Phase Air Filtration Equipment; Phase 1 : Search of Literature and Prior Art - Gas-phase air filtration equipment (GPAFE) has been used in HVAC systems for many years. Traditionally it has been used primarily for controlling odors contained in outdoor air used for building ventilation. Today, because of the emphasis on good IAQ, GPAFE is being used more and more for the control of indoor gaseous and vaporous contaminants that are known or suspected to affect human health and comfort. One of the problems facing HVAC design engineers is how to choose a test method to determine the effectiveness of a gas-phase air filtration device. Many different filter systems and test methods are available with differing test protocols, instrumentation types and sensitivities, and costs. This report, which is the first phase of a two-phase research project, presents the results of a literature search into existing in-field GPAFE effectiveness test methods including required instrumentation and costs. Source: EPA Report, EPA 600/R-97-092 (NTIS PB98-111677), September 1997 (EPA Contact: Russell N. Kulp, 919-541-7980, rkulp@engineer.aeerl .epa.gov)

Investigation of Contact Vacuuming for Remediation of Fungally Contaminated Duct Materials - Environmental fungi can become a potential IAQ problem when adequate moisture and nutrients are present in building materials. Because of their potential to rapidly spread contamination throughout a building, ventilation system materials are of particular significance as potential microbial contamination sources. Current recommendations are to discard fibrous glass insulation that appears to be wet or moldy. Unfortunately, this advice is not always followed. Instead, cleaning is sometimes used to remediate fibrous glass duct liner that is contaminated with microbial growth. The objectives of this research program were to: 1) determine, under dynamic test conditions, whether fungal spore levels on HVAC duct material surfaces could be substantially reduced by thorough vacuum cleaning, 2) evaluate whether subsequent fungal growth could be limited or contained by mechanical cleaning, and 3) provide data concerning the advisability of cleaning duct materials. The constant high RH environment to which the test materials were exposed during this study was selected as a favorable growth environment that is frequently found in the Southeastern U.S. The results showed that following cleaning, the levels of the two test fungi, *A. versicolor* and *P. chrysogenum*, recovered to precleaning levels within 6 weeks. Therefore, mechanical cleaning by contact vacuuming alone was able to only temporarily reduce the surface fungal load. The current guidelines to discard contaminated materials should be followed. Source: Environment International, 23, 6, 751-762, 1997 (EPA Contact: John Chang, 919-541-3747, jchang@engineer. aeerl.epa.gov.)

Personal Computer Monitors: A Screening Evaluation of Volatile Organic Emissions from Existing Printed Circuit Board Laminates and Potential Pollution Prevention Alternatives - The printed circuit board is a vital operating component in many electronic products. They can be found in personal computers (PC), telephones, fax machines, and copiers. Offgassing from the boards is most prominent during the initial break-in period when electrical heating occurs. This is especially true in the case of PC monitors where internal operating temperatures can range from 60 to 70° C. In this evaluation, four types of printed circuit board laminates commonly found in PC monitors were tested to determine if an alternative laminate would be less emitting than conventional laminates: 1) glass/lignin-containing epoxy; 2) glass/epoxy; 3) paper/phenol; and 4) paper/reformulated phenolic. The purpose of the screening evaluation was to determine if the glass/lignin-containing epoxy resin and the reformulated phenolic laminates would be less emitting than conventional laminates (paper/phenol). Glass/epoxy laminates were included in the evaluation because they exist primarily in central processing units. The test results qualitatively showed that the glass/epoxy laminates and the glass/lignin-containing epoxy resin laminates emit fewer volatile compounds than the two paper/phenolic resin-based laminates. Source: EPA Report. (EPA Contact: Kelly W. Leovic, 919-541-7717, kleovic@engineer.aeerl. epa.gov)

Predicting the Emissions of Individual VOCs from Petroleum-Based Indoor Coatings - The indoor use of petroleum-based coating materials may cause elevated VOC concentrations. This paper presents a newly developed mass transfer model for estimating emissions of individual VOCs from freshly coated surfaces. Results of a four-step validation show that the predicted individual VOC emissions are in good agreement with experimental data generated in small chambers and an IAQ test house. The values of the parameters introduced in this model are all easily obtained and thus its utilization can provide indoor air quality professionals with emission rate estimates for individual VOCs without having to conduct costly dynamic chamber testing. Source: Atmospheric Environment, Vol. 32, No. 2, pp. 231-237, 1998. (EPA Contact: Zhishi Guo, 919-541-0185, zguo@engineer. aeerl.epa.gov)

Radon Measurement and Diagnostic Guidance for Large Buildings - This manual is designed to assist architects, engineers, and building owners, operators, and maintenance staff to incorporate radon mitigation into building design, construction, commissioning, operation, and maintenance. This guidance for evaluating building ventilation dynamics, building air system balance (including leakage rates of typical residential, commercial, and public structures), and HVAC components and their effect on radon dilution and indoor air should be of significant benefit in improving IAQ. Source: EPA Report, EPA-600/R-97-064a and b (NTIS PB97-189716 and -724), July 1997 (EPA Contact: Marc Y. Menetrez, 919-541-7981 mmenetrez@engineer.aeerl. epa.gov)

Results of a Pilot Study to Evaluate the Effectiveness of Cleaning Residential Heating and Air Conditioning Systems and the Impact on IAQ and System Performance - To evaluate the effectiveness of heating and air-conditioning (HAC) system cleaning in residences and its impact on IAQ and system performance, a nine-home pilot field study was conducted in the Research Triangle Park area of NC during the summer of 1996. All the homes in the study had central (whole-house) cooling systems and forced air distribution systems with sheet metal ducts. Background air monitoring and sampling were performed at each home for 3 days, then the air distribution ducts and air handler components were professionally cleaned by the National Air Duct Cleaners Association (NADCA) using methods and equipment commonly used by industry. Source removal was performed by mechanical cleaning, and chemical biocides were not used. The homes were monitored again for 2 to 4 days following cleaning. The impact of mechanical cleaning without the use of chemical biocides on the levels of bacteria in samples collected from surfaces of the HAC system was highly variable. Fungal levels on HAC system duct surfaces were generally higher than bacterial levels. Mechanical cleaning without the use of chemical biocides had the most impact on the ducts with the highest levels of fungi and noticeably reduced the level of fungi on ductwork surfaces in most houses. Results suggest that, although the source of particulate matter in the HAC system was effectively removed, the magnitude of the impact of HAC system cleaning on particle concentrations could not be quantitatively determined due to the presence of other indoor sources, occupant activity, and outdoor particle sources. Airborne fiber concentrations were low at all houses, precluding an assessment of the impact of HAC system cleaning on this parameter.

Measurements related to performance of the HAC system suggest that cleaning may improve system performance. The medium volume dust sampler developed for this study was shown to be an effective tool for quantitatively assessing HAC system cleaning effectiveness. Source: EPA Report, EPA-600/R-97-137, December 1997 (EPA Contact: Russell N. Kulp, 9 1 9 - 5 4 1 - 7 9 8 0 , rkulp@engineer.aeerl.epa. gov)

The Application of Pollution Prevention Techniques to Reduce Indoor Air Emissions From Engineered Wood Products - The objective of this research was to investigate P2 options to reduce indoor emissions from a type of finished engineered wood. Emissions were screened from four types of finished engineered wood and alternative, lower emitting substitutes were identified as potential alternatives for the higher emitting compounds. Three types of coatings were found to have significantly lower emission factors of summed VOCs and formaldehyde relative to heat-curable acid-catalyzed alkyd-urea coatings; these included a two-component waterborne polyurethane; a UV-curable acrylate; and a UV- and heat-curable multi-functional acrylate-free emulsion. These coatings also had comparable performance characteristics to the heat-curable acid-catalyzed alkyd-urea coatings. All three wood coatings are currently available in the market place. Three types of engineered fiber panels were identified as having significantly lower emission factors of summed VOCs and formaldehyde relative to those for particleboard; these included MDF made with MDI resin; a wheatboard panel made with MDI resin; and a panel made from recycled corrugated cardboard. All three fiber panels are in the market place and are used to construct a wide variety of interior products. See related article on page 8.

Source: EPA Report (EPA Contact: Kelly W. Leovic, 919-541-7717, kleovic@engineer.aeerl. epa.gov)

The Possible Role of Indoor Radon Reduction Systems in Back-Drafting Residential Combustion Appliances - A computational sensitivity analysis was conducted to identify the conditions under which residential active soil depressurization (ASD) systems for indoor radon reduction might most likely exacerbate or create back-drafting of natural-draft combustion appliances. Parameters varied included: house size; normalized leakage area; exhaust rate of exhaust appliances other than the ASD system; and the amount of house air exhausted by the ASD system. Even with a reasonably conservative set of assumptions, it is predicted that ASD systems should *not* exacerbate or create back-drafting in most of the U.S. housing stock. However, even with a more forgiving set of assumptions, it is predicted that ASD systems *could* contribute to back-drafting in some fraction of the housing stock – houses tighter than about 1 to 2 cm^2/m^2 – even in large houses at minimal ASD exhaust rates. It is not possible to use parameters such as house size or ASD system flow rate to estimate reliably the risk that an ASD system might contribute to back-drafting in a given house. Spillage/back-draft testing should be needed for essentially all installations. Source: *Indoor Air*, 7: 206-214, 1997 (EPA Contact: D. Bruce Henschel, 919-541-4112, bhenschel@engineer. aeerl. epa.gov)

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GLOSSARY OF ACRONYMS

ACH - Air Exchange Per Hour
ASD - Active Soil Depressurization
DNPH - Dinitrophenylhydrazine
DOE - Department of Energy
GAC - Granulated Activated Carbon
GPAFE - Gas-phase Air Filtration Equipment
HAC - Heating and Air Conditioning
HAP - Hazardous Air Pollutants
HB - Hardboard
HBVSST - hardboard coated and cured with a stain, and a
   heat-curable acid-catalyzed alkyd-urea sealer and topcoat
HUD - Housing and Urban Development
HVAC - Heating, Ventilation, and Air Conditioning
IAQ - Indoor Air Quality
IEMB - Indoor Environment Management Branch
I/O - Indoor/Outdoor
MDI - Methylene diisocyanate
MEK - Methylethylketone
MFD - Medium Density Fiberboard

MSDS - Material Safety Data Sheet
NOPES - Nonoccupational Pesticide Exposure Study
NRMRL - National Risk Management Research Laboratory
OA - Outdoor Air
OAQPS - Office of Air Quality Planning and Standards
PB - Particleboard
PBVST - particleboard coated and cured with a heat-curable
   acid-catalyzed alkyd-urea sealer and topcoat
PC - Personal Computer
PCO - Photocatalytic Oxidation
PF - Phenol - Formaldehyde
P2 - Pollution Prevention
PVB - Veneered Particleboard
RH - Relative Humidity
RTI - Research Triangle Institute
TVOC - Total Volatile Organic Compound
UF - Urea - Formaldehyde
UV - Ultraviolet
VOC - Volatile Organic Compound