

FORMALDEHYDE AND OTHER VOC EXPOSURES FROM CONSUMER PRODUCTS

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ABSTRACT

Formaldehyde (CH₂O) and other volatile compounds (VOCs) are presently considered ubiquitous in indoor as well as outdoor atmospheres. Indoor levels of these contaminants are thought to originate from various construction materials and consumer products commonly found in public buildings, offices, and personal residences.

A large-scale environmental chamber has been designed to study volatile organic emission rates from various materials. The chamber is 28.4 m³ in volume and has environmental control of air change rate, temperature, and humidity. The air change rate (N) can be regulated from 0.2 to 1.5 A/h; temperature and humidity have a wide range of control. The chamber can be used to simulate a "real room" situation. A consumer product can be loaded into the chamber at a normal loading-to-volume ratio (L) (m²/m³) and the resulting volatile outgassing can be measured by monitoring the ambient air within the chamber. A small scale chamber (0.24 m³ in volume) has also been designed and is being evaluated for measurement of VOC emission rates. Correlation data between the small and large chambers for formaldehyde emissions from pressed wood products have been studied.

Various consumer products, including pressed wood materials, synthetic carpet, and fabric office partitions, have been studied for formaldehyde and other volatile organic emissions using the chamber techniques. Formaldehyde and other VOCs have been monitored using real-time measurements and solid sorbents collection followed by thermal desorption GC/MS analysis.

INTRODUCTION

Volatile organic compounds including formaldehyde are considered a ubiquitous class of pollutants being found in modern indoor air environments. Formaldehyde levels in indoor air have been studied by the U.S. Consumer Product Safety Commission (CPSC) and the Department of Housing and Urban Development (HUD). These studies have shown that the formaldehyde levels typically range from 10 ppb to 1000 ppb depending on the type of structure and materials of construction (Singh et al, 1982; National Academy, 1981; HUD, 1981). Considering all types of structures, formaldehyde exposure appears to be the highest in pre-manufactured housing. Ambient levels have also been studied in traditional homes. A recent study showed that homes greater than five years old and without urea-formaldehyde foam insulation had indoor formaldehyde levels ranging from 20 ppb to 50 ppb (Hawthorn et al, 1985). Formaldehyde levels in office buildings have been surveyed in the metro Atlanta area, and levels ranging from 10 ppb to 70 ppb with an average of 30 ppb have been measured (Black, 1985). Control levels of outside formaldehyde levels within the Atlanta area ranged from 10 ppb to 30 ppb, indicating an indoor/outdoor ratio of approximately 2.

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Other VOCs have been studied by various researchers in residential and public buildings (Wallace et al, 1984; Hartwell et al, 1984; Molhave et al, 1979; Seifert et al, 1982). Some of the various compounds found include acetone, 1,1,1-trichloroethane, hexane, heptane, benzene, methylene chloride, toluene, and xylene. One of the major studies on VOCs was the EPA Total Exposure Assessment Methodology Study where integrated VOC ambient air samples and human breath samples were monitored (Wallace et al, 1984; Hartwell et al, 1984). Indoor concentrations of the VOCs were greater than outdoors with indoor /outdoor ratios typically averaging from 2-20.

The indoor levels of these pollutants can originate from numerous construction and consumer products. One of the primary sources of formaldehyde is pressed wood products such as particleboard, plywood, and medium density fiberboard. Other sources include coatings, plastics, paper products, foam insulation, and textile materials. Other volatile organics may originate from building materials and products such as adhesives, cleaning agents, dry-cleaned clothes, deodorizers, textile and synthetic furnishings, copy-machine chemicals, paints, paint strippers, etc. Another significant source of VOCs is both mainstream and sidestream tobacco smoke.

While formaldehyde and other VOCs are being found ubiquitously in indoor structures, their levels are very low and are difficult to interpret with respect to human health complaints. However, there appears to be a concern that VOCs can contribute to symptoms associated to poor indoor air quality, typically known as the "tight building syndrome" (Molhave, 1985). These human health symptoms can include upper respiratory distress, headache, sore throat, fatigue, nausea, and mucous membrane irritation. Hence, the study of VOCs commonly found within indoor environments is an important research effort.

An important research tool for studying these organic emissions from various construction and consumer products is an environmental chamber. This research tool provides a means of determining organic emission rates from selected sources under controlled environmental conditions that can be set to simulate a "real-world" situation. The measurement of organic emissions can also be related to an impact on the ambient indoor air quality. Emission sources to be studied can be loaded into an environmental chamber at a normal loading ratio (m^2 of product to m^3 air volume) and emission rates ($mg/m^2 \cdot hr$) and ambient air concentrations (ppmv or ppbv or pptv) can be measured at known environmental conditions (temperature, humidity, and air change rate). Loading ratios and environmental conditions can be set to achieve real-world levels or they can be altered to study the effects of changing parameters. Single as well as multiple emission sources can be studied.

Numerous environmental chamber studies have been conducted in the study of formaldehyde releases from pressed-wood products (Matthews et al, 1985; Black et al, 1985; Grot et al, 1985). The implementation of HUD rule 3280.308, which established formaldehyde emission standards for particleboard and hardwood, plywood paneling used in pre-manufactured housing requires that wood products be certified using a large scale chamber methodology under standard environmental conditions (HUD, 1984). The use of environmental chamber methodology for the study of other VOC emissions has been minimum to date.

Environmental chamber studies have been conducted using both a large scale environmental chamber (LSTC) ($28.4 m^3$) and a small scale environmental chamber (SSTC) ($0.24 m^3$) for the study of VOC emissions from numerous construction and consumer products. Correlation studies of emission rates as determined using the SSTC and LSTC have been studied for formaldehyde emissions. Other VOC emissions have been studied in both chambers and chamber measurements have been related to real-world situations.

EXPERIMENTAL

Large Scale Test Chamber (LSTC)

The LSTC chamber, as illustrated in Figure 1, is constructed of aluminum interior panels and galvanized steel external panels filled with 10 cm of insulating styrofoam. The internal volume of the large scale chamber is $28.5 m^3$ as measured from internal dimensions of $5.4 m \times 2.4 m \times 2.2 m$. Volume occupied by the inside equipment is approximately $0.06 m^3$, which gives a final adjusted volume of $28.4 m^3$.

External preconditioned air is drawn through the chamber using a variable speed blower. The external air initially passes through a dehumidifier and then through a 10 cm bed of adsorbent, molecular sieve, and charcoal. Following purification, the air is forced through

a metal orifice plate by the blower and enters a calibrated positive displacement gas meter for volume measurement.

After passing through the dry gas meter, the dry, clean air is delivered to the chamber through a diffuser tube located along the middle of the back wall. The tube consists of 1.1 m long x 3.8 m OD PVC pipe with numerous 0.6 ID holes for gas diffusion. This air supply system allows clean air to uniformly diffuse throughout the chamber. A 8.3 cm ID hole located in the opposite wall (front) is open for air escape.

Temperature and humidity are controlled within the chamber with an electric baseboard heater, heat exchanger, and humidifier. The heat exchanger maintains its coil temperature above the dew point of the water so that condensation will be eliminated. The standard baseboard heater was modified by replacement of a simple contact point thermostat with a more durable hydrostatic type. The humidifier is controlled with a humidistat which was initially covered with a plastic faceplate. Removal of the faceplate enabled more rapid diffusion of water vapor into the humidistat and subsequently reduced the time between humidifying cycles. The humidifier mist is directed toward the back wall of the chamber where air velocity and mixing are greatest. This allows better control of humidity levels.

Mixing inside the chamber is achieved with a standard fan set on medium speed. The fan is placed behind the heater. The heated air is blown against a wedge-shaped aluminum baffle that creates an atmospheric swirling effect throughout the chamber. This air movement, together with that created by the fan within the heat exchanger, enables the air inside the chamber to pass at a uniform rate over the wood products being tested.

A hygrothermograph is used to continuously record temperature and relative humidity levels. Calibration is performed weekly using a sling psychrometer.

A metal rack, located in the center of the chamber, is constructed for horizontal placement of consumer products. The hygrothermograph, a thermometer, and a certified hygrometer are placed on a metal rack for environmental measurements.

Sampling lines into the large scale chamber are minimized in length and are made of 6.4 mm PTFE tubing. One sampling port is located 2.2 m from the rear wall of the chamber and 1.1 m above the inside floor. The other is located 3.3 m from the inside back wall and 1.1 m from the inside floor.

Small Scale Test Chamber (SSTC)

The SSTC is constructed of 2 cm plywood. The interior is lined with 0.6 cm PTFE sheeting, and the exterior surface is sealed with epoxy paint. Figure 2 presents an interior/exterior description. Entry to the chamber is achieved through a hinged, top lid which was sealed with beveled neoprene stripping. A polyethylene rack is placed in the center of the chamber. The rack was constructed of equidistant and parallel posts which allowed vertical placement of the specimens with adequate air circulation between them.

Chamber supply air originates from the LSTC preconditioned air. The SSTC is actually placed inside the LSTC to take advantage of the existing controlled environmental conditions (T and RH). A small oil-free GAST vacuum pump is used to push air through the SSTC. Air is metered into the chamber using a calibrated flowmeter equipped with flow controller. Air exiting the chamber is directed outside the LSTC so that contaminated air cannot reenter the SSTC. All entrance, exit, and sampling lines are constructed of PTFE tubing.

Entering air is diffused into the SSTC through a 1.3 cm OD x 53 cm long PTFE tube with numerous holes. A plexiglas baffle and small mixing fan are used to achieve adequate air mixing and circulation in the chamber.

Temperature and relative humidity are normally at pre-set conditions. Temperature and humidity are monitored using a calibrated hygrothermograph with a continuous read-out.

The internal dimensions of the SSTC are 63 cm wide x 61 cm high with an internal volume of 241 L. The internal equipment occupied a volume of 2 L for an adjusted internal volume of 239 L.

Ambient Formaldehyde Determinations

During LSTC and SSTC studies, the concentration of ambient CH₂O was determined using two methods: a modification of NIOSH P and CAM 125 and a CEA continuous formaldehyde monitor, both based on colorimetric analyses.

The modified P and CAM method involved air collection in tandem 20 mL midget impingers with a 1% sodium bisulfite (NaHSO₃) collection medium. Pre- and post-calibrations were performed on each pump for each specific sample collection. Pre- and post-calibration data indicated that the constant flow device in some pumps was subject to a high failure rate when used with impingers. This was assumed to be due to excessive moisture. Subsequently, pumps were evaluated prior to use with respect to their performance efficiency.

Sources of error were minimized in the impinger method by pipetting a known volume (10 ml) of 1% NaHSO₃ into the impinger flask. The final volume was corrected for evaporation by weighing impingers before and after use. For a one-hour sampling period of an atmosphere at 23°C and 50% relative humidity, the loss of the 1% NaHSO₃ formaldehyde absorbing solution averaged 0.7 ml. Initial use of 20 ml was discontinued after the solution was repeatedly drawn out of the impinger flask.

Chamber air was sampled for 60 minutes at a calibrated 1 L/min flow rate. Samples were retained in the impingers and aliquots were analyzed within 24 hours of sample collection using the chromotropic acid, spectrophotometric method. The detection limit for a 60-minute sampling time at 1 L/min was 0.020 ppm (using S/N of 2).

A CEA continuous monitor was also used to measure ambient CH₂O concentrations within the LSTC. The operating procedures were similar to those supplied by the instrument manufacturer.

Other VOC Determinations

The VOCs were collected on 2,6 diphenylene oxide polymer which had been subjected to an extensive cleanup procedure. The adsorbent was Soxhlet extracted in methanol for 24 hours and dried under a nitrogen stream. Two hundred mg were packed into glass sampling tubes which had been washed and baked at 270°C. The ends of the tubes were plugged with unsilanized glasswool that had been solvent washed and baked at 270°C. After packing, the sampling tubes were baked in a gas chromatographic oven at 270°C under a helium flow for at least 18 hours. The tubes were sealed in airtight containers for storage and traveling.

The VOC samples were collected with calibrated personal sampling pumps over a four-hour period. All samples were collected in duplicate. Analysis was by thermal desorption/capillary gas chromatography/mass spectrometry (TD/GC/MS). The thermal desorber was equipped with a cryofocusing unit. Analysis conditions were as follows:

Column: bonded, SE54, capillary column, 0.32 mm x 25 mm with a 0.5 µm film-thickness
Desorption Conditions: 250°C for 8 minutes
GC Temperature Program: 30-300°C, t₁ = 1, R = 8, t₂ = 15
Scan Conditions: 42-500 amu in 0.7 sec

Compound identification was primarily by mass spectral matching with the National Bureau of Standards Library. Authentic standards were used whenever available.

RESULTS AND DISCUSSION

Preliminary Chamber Studies

Prior to experimental chamber testing of consumer products, the efficiencies of chamber operating parameters were evaluated. It was desirable to maintain constant and reproducible operating conditions during product testing and to identify and eliminate any controllable sources of experimental error. Parameters evaluated included control of temperature and relative humidity, air movement within the chamber, confirmation of air change rate, and determination of formaldehyde recovery within the chamber.

Temperature and humidity control were easily achieved with minor modifications of the original design. Following these equipment modifications and refinement of equipment locations in the LSTC, accurate and reproducible environmental conditions were obtained. Relative humidity was controlled within $\pm 4\%$ and temperature within $\pm 2^\circ\text{C}$.

Adequate mixing inside the chamber was accomplished with the fan and baffle system previously described in the "Experimental" section. Air distribution was monitored with ventilation smoke tubes at 50% RH, 23°C, and air change rates of 0.53 A/h and 1.1 A/h. A high degree of swirling occurred, and there were no observable dead spots or channeling effects. Analysis precision between air samples collected simultaneously at the two sampling ports was very good (3% RSD for a data set of 10). This confirmed adequate mixing during product testing.

Verification of LSTC air change rates were made using a carbon monoxide decay procedure. The two calibrated rates used throughout this study were 0.53 A/h and 1.1 A/h. The dry gas meter was calibrated using these results with airflow rates of 8.4 ft³/min and 16.9 ft³/min, respectively.

Formaldehyde recovery in the LSTC was determined at two separate concentrations, 0.1 ppm and 0.4 ppm. Chamber operating conditions of 50% RH and 23°C were constant with air change rates of 0.53 A/h and 1.1 A/h. A known concentration of formaldehyde was introduced into the chamber using a formaldehyde generator. Formaldehyde concentration in the chamber was continuously monitored using the CEA continuous monitor instrument. Once a steady state level of formaldehyde was reached, the chamber formaldehyde concentrations were determined using sodium bisulfite impinger collection followed by chromotropic acid, spectrophotometric method. Two measurements were made for each concentration level and each air change rate.

Recoveries were excellent averaging:

92.5% at 0.1 ppm at 0.53 A/h;
92.0% at 0.4 ppm at 0.53 A/h;
93.2% at 0.1 ppm at 1.1 A/h; and
90.6% at 0.4 ppm at 1.1 A/h.

Considering the experimental error of the technique (estimated at 8%), the CH₂O loss within this specific LSTC under the described conditions was minimal. Recovery studies for other VOCs have not yet been completed.

Airflow face velocities were measured in linear ft/min inside the LSTC. The measurements were made with a hot wire anemometer and were recorded as maximum readings obtained as the probe was held at various angles. The LSTC conditions were held constant at 23°C and 50% RH while measurements were taken at 0.53 A/h and 1.1 A/h.

Velocities measured 30-40 ft/min in the area of the sample. Velocities were high around the periphery of the chamber with the highest values at the end of the chamber where the floor fan was located. A velocity of 600 ft/min was measured directly in front of the mixing fan and 800 ft/min toward the middle of the inlet diffuser tube.

There were no significant changes in velocity measurements at 0.53 A/h and 1.1 A/h in the central area of the chamber. This indicated that the velocities were primarily determined by the mixing fan, not the air change rate.

Pre-conditioned air from the LSTC was used as the supply air to the SSTC. This technique worked very well. The LSTC temperature was lowered to compensate for a small heating effect of the air delivery system to the SSTC. The SSTC environmental conditions were monitored with a calibrated hygrothermograph and were constant within $\pm 4\%$ RH and $\pm 2^\circ\text{C}$. The air change rate was controlled using a calibrated flowmeter and flow controller.

Formaldehyde recovery in the SSTC was determined using two air exchange rates 2.2 A/h and 4.4 A/h at 0.1 ppm and 0.4 CH₂O levels. The CH₂O spiked LSTC air was used as source gas for the SSTC. Formaldehyde recoveries were 95% or greater for all conditions studied:

95% at 0.1 ppm at 2.2 A/h;
100% at 0.4 ppm at 2.2 A/h;
96.2% at 0.1 ppm at 4.4 A/h; and
95.0% at 0.4 ppm at 4.4 A/h.

The values were obtained after correcting for the LSTC CH₂O recoveries.

The SSTC, in general, operated extremely well without any significant operation problems during the span of these studies.

CONSUMER PRODUCT TESTING

Wood Products

Formaldehyde emission characteristics of two wood products, a particleboard underlayment and a plywood paneling, were studied using both a large scale test chamber (LSTC) and a small scale test chamber (SSTC). Emission rates and ambient formaldehyde concentrations were studied at a number of different air change to loading ratios (N/L) both in the SSTC and LSTC, and correlations between the resulting data were studied. In addition, the emission data from both chambers were compared to published theory on the effects of ventilation and loading ratios on ambient formaldehyde levels.

The two wood products were placed into conditioning upon arrival. Their formaldehyde emissions were monitored from the initial arrival time until they appeared to reach a steady-state formaldehyde emission level (defined as less than 5% change of the ambient formaldehyde level over a three-day period). A wood loading of $0.42 \text{ m}^2/\text{m}^3$ was studied in the LSTC at conditions of 50% RH and 25°C to monitor the ambient formaldehyde level. After a period of 15 days, the underlayment emissions stabilized at 0.20 ppm and after a period of 89 days, the paneling emissions stabilized at 0.18 ppm.

The wood product emissions were studied at 50% RH and 25°C and experimental test parameters are given in Table 1. Loadings (measured in m^2) were cut from representative panels of the products and were kept in conditioning when not being used in the LSTC. The 0.5 A/h was studied first, followed by the 1.0 A/h. Each specific N/L setting was monitored for a two to three day period within the LSTC. The board edges were sealed with paraffin.

Following LSTC testing, the wood product pieces were cut to achieve the loadings required for the SSTC. These pieces were cut directly from those pieces used in the LSTC testing. There were six different subsets prepared for the SSTC testing of each product. The SSTC experimental parameters are given in Table 2. Each N/L setting was monitored one to two days for each subgroup.

Summaries of measured ambient CH_2O levels and calculated emission rates are given in Tables 3-4 for the LSTC and SSTC, respectively. Formaldehyde emission rates were calculated according to the equation:

$$\text{ER (mg/m}^2\cdot\text{hr)} = \frac{(\text{CH}_2\text{O, ppm)} (\text{chamber air flow, m}^3/\text{hr})}{(0.814 \text{ ppm/mg/m}^3) (\text{Product area, m}^2)} \quad (1)$$

Each data point is an average of six determinations.

Graphical representations of measured CH_2O concentrations versus calculated emission rates were studied for the LSTC and SSTC. A summary of the correlation coefficients from this data is given in Table 5. In general, a linear relationship (with negative slope) exists between the measured CH_2O concentrations and the calculated emission rates for both products in both chambers. The correlations to the LSTC were very similar for both the underlayment and paneling product. Correlations were higher when the air change rate was held constant, and the correlation was consistently higher at $N=1.0$ for both products.

The CH_2O concentration versus emission rates data show more variation in the SSTC for both wood products, but the basic linear relationship does exist. This relationship was also observed by using data obtained with a constant loading and differing air change rates (0.5 to 4.4). These data are presented in Table 5 as "A loading," "C loading," and "D loading." The A denotes the lowest loading ($0.70 \text{ m}^2/\text{m}^3$), D denotes the highest loading ($4.4 \text{ m}^2/\text{m}^3$), and C is a middle loading ($2.9 \text{ m}^2/\text{m}^3$). Correlations of this data were variable. For the higher loadings of the paneling products, there were no linear relationships between emission rates and measured concentrations. The underlayment product, in contrast, showed its highest correlation in the SSTC at the highest loading.

Correlations between the LSTC and SSTC data were observed by graphically representing LSTC emission rate versus SSTC emission rate obtained by using all the N/L values. Figures 3-1 show these relationships, and a summary of the correlation coefficients is given in Table 6. These data were obtained using six representative sets of wood product for SSTC testing. Initially, only one set was used and the obtained correlations were very low for the paneling product. In order to evaluate the possible effect of homogeneity on the chamber correlations, six separate testing groups of both products were measured in the SSTC

experiment, and the average concentration data was used in calculating an average emission rate. These values are those presented in the Table 6 correlations. Table 7 shows the correlation differences obtained when one sampling set versus six sampling sets were used in the SSTC data. The correlation change for the underlayment product was very slight; however, the increase in correlation for the paneling product was very significant. In order to achieve equivalent N/L values in the LSTC and SSTC, much smaller product sizes were used in the SSTC testing (for N/L=3.1, only 3.7% of the LSTC loading was used in the SSTC). If product homogeneity is an experimental factor, the 3.7% chosen may not have been truly representative of that loading studied in the LSTC. The data shown in Table 7 indicate that the LSTC vs SSTC correlations significantly increased for the paneling product as more representative loadings were studied in the SSTC.

Consumer Product Testing

Two consumer products, which were present in a public school and an office building and were thought to be a source of indoor air contaminants, were evaluated in the environmental chambers. The first product was a standard fabric-covered modular office partition. A five story office complex of approximately 18,000 ft²/floor area had been recently renovated with mid-high and ceiling-high office partitions to create individual work stations. Following installation of the partitions, numerous employee complaints began to surface, which included burning eyes, mucous membrane irritations, fatigue, and headaches. An ambient air study of the building indicated formaldehyde levels from 0.2 to 0.8 ppm and numerous other volatile organic compounds at ppb levels. A suspect office partition was then studied in the LSTC at environmental conditions and air change to loading rate as close as possible to that existing within the building. These data are shown in Table 8. The chamber formaldehyde ambient level was within 25% of the level found within the building area from which the partition had been removed. Similar other VOCs were detected as had been in the building air. This study indicated that the partitions were a source of a considerable level of indoor air pollutants. These particular partitions were removed and monitored formaldehyde levels within the building dropped significantly down to less than 0.1 ppm within a two-week period. New office partitions were supplied and installed. Formaldehyde levels within the building were below 0.1 ppm; however, significant amounts of other volatile organics were present. A representative partition of the new shipment was similarly studied in the LSTC. The formaldehyde level and other VOCs present agree with those being found within the office structures (Tables 8 and 9). Present studies are now being conducted of the decay in VOC emissions of these partitions as a function of time.

The second product to be studied was a synthetic carpet removed from a public school where health complaints had originated following installation of the carpet. The carpet was six months old when studied for organic emissions. The carpet was studied in the SSTC at a N/L value and environmental conditions similar to that existing within the building. The formaldehyde level was nondetectable at less than 20 ppb. Certain other VOCs were detected in low ppb levels. These VOCs are listed in Table 10. These compounds are now being considered as possible irritants within the school building.

CONCLUSIONS

Environmental chamber methodology provides a means of characterizing organic emissions from potential sources. Valid organic emission studies can be made in a well-design environmental chamber if environmental controls allow pre-established conditions to be consistent and reproducible; if an appropriate sample selection and preconditioning process is followed; and if an accurate sampling and analytical methodology is used. Environmental chamber studies can aid in identification of potential sources of air pollutants and also can indicate their potential impact on the ambient indoor air quality.

The LSTC provides a realistic approach to environmental chamber methodology, since environmental conditions (T, RH, and air change rate) can be adjusted to match those found in a "real-building" situation. The product loading can also be studied at realistic settings. The SSTC, in contrast, can only accommodate very small sizes and necessitates an unrealistic loading. In order to achieve adequate N/L (air change to loading ratios) in the SSTC, higher than normal air change rates must be used.

In studies of formaldehyde emissions, it is noticeable that emission rates are numerically different when the same wood product is studied in the LSTC and SSTC and emission rates compared. The correlation of LSTC vs SSTC emission rates on the products studied indicate variable correlations, based on loading and air change rates. Further studies on these findings are warranted.

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TABLE 1
Experimental Parameters for LSTC Studies

<u>N (A/Hr)</u>	<u>L (m²/m³)</u>	<u>N/L</u>	<u># of Pieces</u>	<u>wood sizes (m x m)</u>
0.5	0.16	3.10	2	(A) - see below
0.5	0.33	1.50	3	(B) - see below
0.5	0.67	0.75	5	(C) - see below
0.5	1.00	0.50	8	(D) - see below
1.0	0.16	6.30	2	(A) same
1.0	0.33	3.00	3	(B) same
1.0	0.67	1.50	5	(C) same
1.0	1.00	1.00	8	(D) same
(A) =	1.22 x 1.22	1.22 x 0.68		
(B) =	1.22 x 2.43	1.22 x 1.22	1.22 x 0.15	
(C) =	1.22 x 2.43	1.22 x 2.43	1.22 x 1.22	
	1.22 x 2.43	1.22 x 2.43	1.22 x 1.22	
	1.22 x 1.22	1.22 x 0.30		
(D) =	1.22 x 2.43	1.22 x 2.43	1.22 x 1.22	
	1.22 x 1.22	1.22 x 1.22	1.22 x 1.22	
	1.22 x 1.22	1.22 x 0.66		

TABLE 2
Experimental Parameters for SSTC Studies

<u>N (A/Hr)</u>	<u>L (m²/m³)</u>	<u>N/L</u>	<u># of Pieces</u>	<u>wood sizes (cm x cm)</u>
0.5	0.70	0.71	2	(A) - see below
0.5	1.46	0.34	3	(B) - see below
0.5	2.90	0.17	5	(C) - see below
0.5	4.40	0.11	8	(D) - see below
1.0	0.70	1.40	2	(A) same
1.0	1.46	0.68	3	(B) same
1.0	2.90	0.34	5	(C) same
1.0	4.40	0.22	8	(D) same
2.2	0.70	3.10	2	(A) same
2.2	1.46	1.50	3	(B) same
2.2	2.90	0.75	5	(C) same
2.2	4.40	0.50	8	(D) same
4.4	0.70	6.30	2	(A) same
4.4	1.46	3.00	3	(B) same
4.4	2.90	1.50	5	(C) same
4.4	4.40	1.00	8	(D) same
(A) =	20.5 x 20.5	20.5 x 20.5		
(B) =	24.0 x 24.0	24.0 x 24.0	24.0 x 24.0	
(C) =	24.0 x 24.0	20.5 x 20.5	28.3 x 28.3	
	28.3 x 28.3	15.2 x 26.5	15.2 x 26.5	
(D) =	24.0 x 24.0	24.0 x 24.0	20.5 x 20.5	
	28.3 x 28.3	28.3 x 28.3	26.3 x 26.3	
	26.3 x 26.3	26.3 x 26.3		

TABLE 3
Summary of LSTC Data

N/L Value	Particleboard Underlayment		Plywood Paneling	
	avg. ppm	avg. ER	avg. ppm	avg. ER
(constant N=0.5)				
0.50	0.234	0.144	0.292	0.180
0.75	0.204	0.188	0.222	0.204
1.50	0.104	0.195	0.107	0.201
3.10	0.072	0.276	0.062	0.239
N/L Value				
(constant N=1.0)				
1.00	0.245	0.303	0.172	0.214
1.50	0.166	0.308	0.148	0.274
3.00	0.087	0.327	0.076	0.284
6.30	0.046	0.359	0.043	0.334

ER = Emission Rate (mg/m²hr)

TABLE 4
Summary of SSTC Data

N/L Value	Particleboard Underlayment		Plywood Paneling	
	avg. ppm	avg. ER	avg. ppm	avg. ER
(constant N=0.5)				
0.11	1.553	0.225	0.826	0.119
0.17	1.170	0.254	0.581	0.126
0.34	1.107	0.369	0.460	0.199
0.71	0.613	0.565	0.312	0.288
N/L Value				
(constant N=1.0)				
0.22	1.002	0.288	1.044	0.302
0.34	0.826	0.357	0.811	0.350
0.68	0.562	0.472	0.409	0.335
1.40	0.440	0.807	0.261	0.479
N/L Value				
(constant N=2.2)				
0.50	0.756	0.479	0.485	0.307
0.75	0.377	0.358	0.384	0.365
1.50	0.279	0.516	0.231	0.414
3.10	0.181	0.729	0.119	0.480
N/L Value				
(constant N=4.4)				
1.00	0.410	0.519	0.218	0.275
1.50	0.305	0.578	0.216	0.410
3.00	0.212	0.781	0.110	0.406
6.30	0.165	1.326	0.077	0.623

ER = Emission Rate (mg/m²hr)

TABLE 5
Summary of Chamber Concentrations versus Emission Rate

<u>LSTC Data</u>	<u>Particleboard, (r2) Underlayment</u>	<u>Plywood, (r2) Paneling</u>
N=0.5	0.74	0.71
N=1.0	0.82	0.82
Total N	0.26	0.55
<u>SSTC Data</u>		
N=0.5	0.89	0.80
N=1.0	0.81	0.59
N=2.2	0.23	0.99
N=4.4	0.72	0.63
Total N	0.52	0.43
Only A Loading (low)	0.47	0.73
Only C Loading	0.64	0.14
Only D Loading (high)	0.87	0.056

TABLE 6
LSTC vs SSTC Correlations

<u>Product</u>	<u>N/L Range</u>	<u>r2, correlation</u>
Particleboard	0.5 - 3.1	0.613
Underlayment	1.0 - 6.3	0.921
	0.5 - 6.3	0.522
<hr/>		
Plywood	0.5 - 3.1	0.882
Paneling	1.0 - 6.3	0.942
	0.5 - 6.3	0.620

TABLE 7
LSTC vs SSTC Correlations as a Function of SSTC Sample Sets

<u>Product</u>	<u>N/L Range</u>	<u>r2, correlation 1 SSTC Samp. Set</u>	<u>r2, correlation 6 SSTC Samp. Set</u>
Particleboard			
Underlayment	0.5 - 3.1	0.590	0.613
	1.0 - 6.3	0.878	0.921
Plywood			
Paneling	0.5 - 3.1	0.574	0.882
	1.0 - 6.3	0.776	0.942

TABLE 8
Comparison of Building and LSTC Air Formaldehyde Levels
Using a Modular Office Partition as the Emission Source

	<u>RH</u> (%)	<u>T</u> (°C)	<u>Air Change</u> (A/hr)	<u>Loading</u> (ft ² /ft ³)	<u>CH₂O</u> (ppb)
Initial Partitions	42	22	0.3	0.08	780 (Building)
	42	22	0.3	0.08	620 (LSTC)
Replacement Partitions	40	23	0.3	0.08	75 (Building)
	40	23	0.3	0.08	102 (LSTC)

TABLE 9
VOCs Found Both within the Office Building and LSTC Using a
Modular Office Partition as the Emission Source

Organic Species

Chloromethane
Methylene chloride
Benzene
Tetrachloroethene
Ethylbenzene
p-Xylene
o-Xylene
1,2,4-Trimethylbenzene
2-Butene
Propanamide
1,2-Diethylcyclobutane
3-Methyl-1-pentanol
2-Butenenitrile
Heptane
2,2-Dimethyl-1-pentanol
5-Methyl-1-heptane
4-Chlorooctane
3-Methylheptane
trans-1,2-Dimethylcyclohexane
cis-1,4-Dimethylcyclohexane
2-Propyl-1-heptanol
Ethylbutanoate
cis-1,3-Dimethylcyclohexane
Butyl acetate
2,2,4-Trimethylheptane
3,4-Dimethyl-1-octene
2,2,3,3-Tetramethylhexane

Organic Species

2,5-Dimethyloctane
1-Methylethylbenzene
2,3,7-Trimethyloctane
4-Carene
5,6-Dimethylundecane
2,2,3,4-Tetramethylpentane
2,5,6-Trimethyloctane
3,7-Dimethyl-1,3,6-octatriene
2,2-Dimethylundecane
1,7,7-Trimethylbicyclo [2.2.1]
hept-2-ene
2,6-Dimethyloctane
Undecane
4,5-Dimethylnonane
1,3,3-trimethylbicyclo
[2.2.1] heptan-2-ol
4,7-Dimethylundecane
1-Azabicyclo [3.1.0] hexane
2,6,11-Trimethyldodecane
1,2,3,5,6,7,8,8a-Octahydro-1,
8a-dimethyl-7-(1-methyl-ethenyl)
naphthalene
1,2,3,4,4a,5,6,8a-Octahydro-
7-methyl-4-methylene-1-(1-
methylethyl) naphthalene
2,6 Bis (1,1-dimethylethyl) phenol

TABLE 10
VOCs Detected in the SSTC Studies of Synthetic Carpet A

Compounds Detected

chloroform
benzene
toluene
xylenes
tetrachloroethane
N-methylacetamide
1,2 dichloroethane
butylacetate
acetic acid
1,2,4 benzene tricarboxylic acid
hexadecanoic acid
propylcyclohexane
hexanone
2-propenone
octane
decane
heptadecane

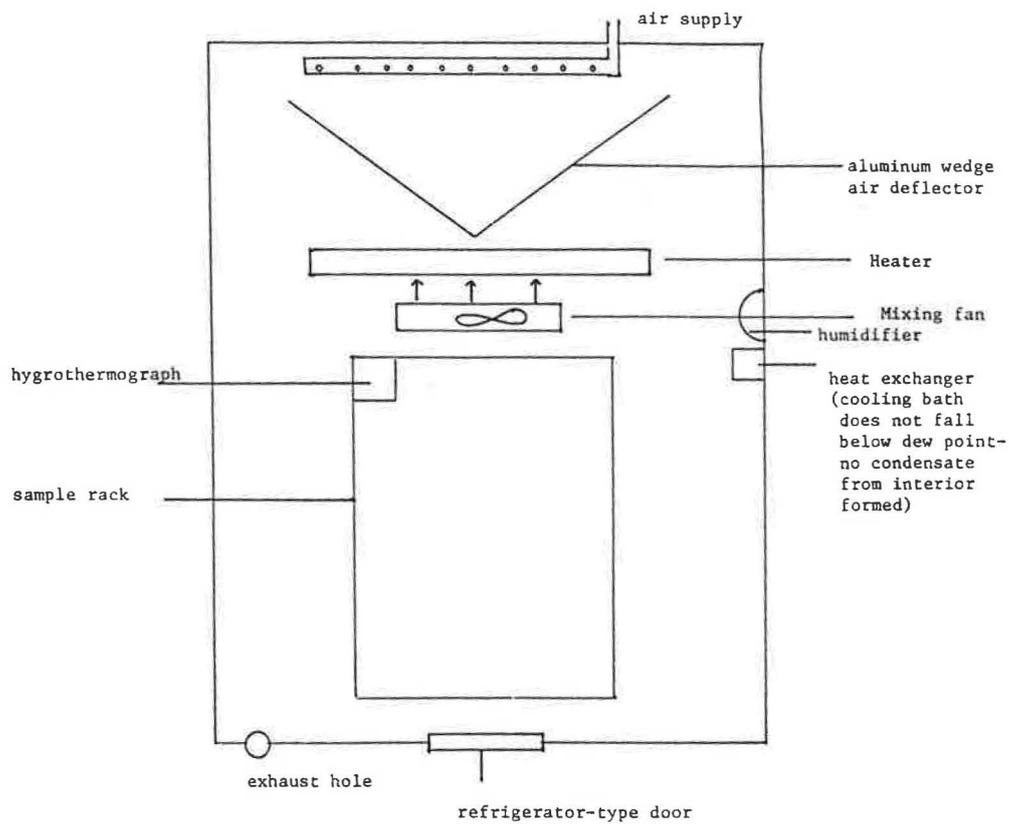


Figure 1. Top view of large-scale test chamber (interior)

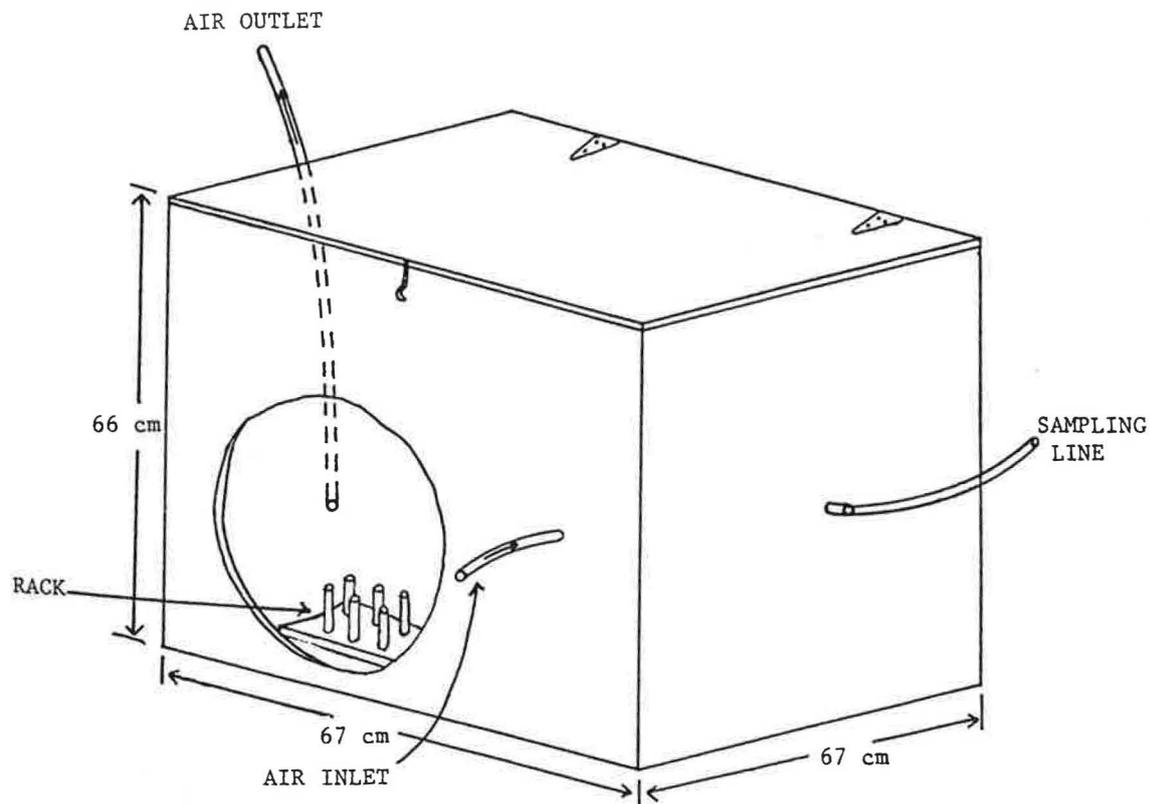


Figure 2. Small-scale test chamber (exterior)

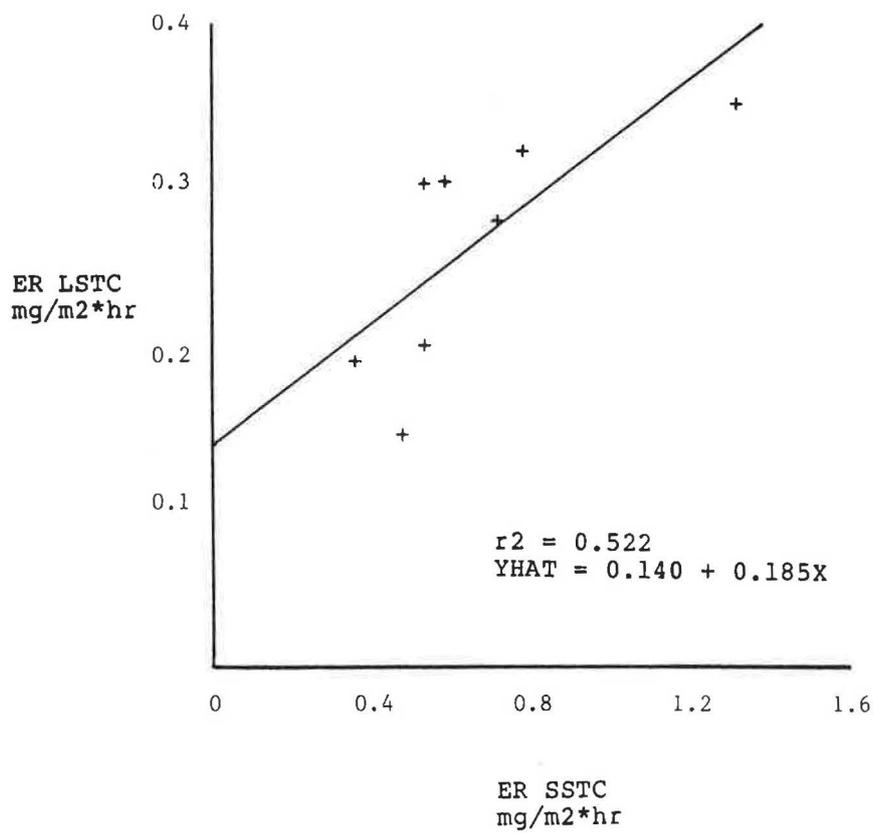


Figure 3. LSTC emission rate vs. SSTC emission rate correlation/
particleboard underlayment (all N/L values)

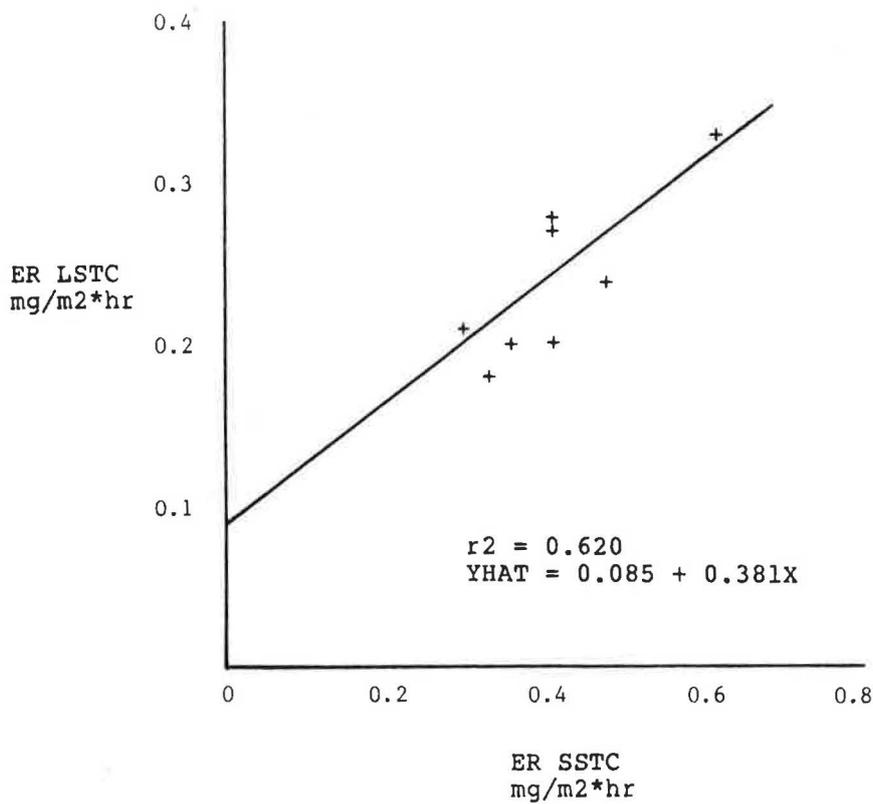


Figure 4. LSTC emission rate vs. SSTC emission rate correlation/
plywood paneling (all N/L values)