Section 4, Chapter 1
AIR TOXICS MONITORING

INTRODUCTION

The Ohio Air Quality Development Authority funded the second phase of this project which involved the continuation of the monitoring program outlined in Section 2 Chapter 1 for the 1999 – 2000 school year. In addition to monitoring for $PM_{2.5}$ the second phase involved the evaluation of exposures to air toxics at the elementary schools participating in this study. These sites offered the opportunity to obtain a compressive time series of indoor, outdoor, and personal exposures to air toxics at three unique locations within central and southeast Ohio.

Past research using the Total Exposure Assessment Methodology (TEAM) approach has shown a significant difference between indoor and outdoor concentrations of volatile organic compounds (VOCs) when an indoor contaminant source is present.[1] The TEAM approach was first used in the 1980s to determine individual indoor, outdoor, and personal VOC exposures. The most often cited finding of TEAM is that a person can spend more than 80 percent of his or her day indoors. This finding is significant when combined with two other key conclusions: (1) relatively high outdoor VOCs can make substantial contributions to indoor levels, and (2) in homes where there are no indoor sources of individual compounds, the indoor concentration can be driven by outdoor VOC levels.

Evidence from Pellizari suggests that stagnant and non-stagnant air plays different but major roles in how outdoor air affects indoor air quality.[2] On stagnant days, the concentrations of pollutants indoor and outdoor both increased, showing a correlation between outdoor and indoor air concentrations of VOCs. On non-stagnant days, the ratio of indoor to outdoor contaminant concentrations was lower. This was thought to be due to a combination of factors, including the presence of major indoor sources (e.g., a smoker at one of the test sites), and a lack of significant outdoor sources in the study area. Personal sampling was accompanied by a diary of daily events,

through which it was found that VOC levels were dependent not only on where a person spent most of the day, but also on the activities in which he or she engaged. A person's exposure to benzene, for instance, was far greater when the person had visited a gas station that day than on days the person had not done so. These findings have been confirmed by recent studies completed in at least three countries and seven U.S. states.[3]

In the late 1980s another significant project explored sources and factors affecting indoor and outdoor air quality. Cohen et al. studied the Kanawha Valley region of West Virginia to determine the impact of the sizeable regional chemical industry on human exposure to VOCs.[4] Extrapolation from high VOC dose data suggests the possibility of asthma and cancer attributable to low-level, chronic VOC exposures. The Kanawha study was geographically situated so that higher than normal levels of air toxins could be detected. The close proximity of residential areas to pollutant sources resulted in the possibility of elevated VOC exposures to the nearly 250,000 residents who lived in the valley.

The Kanawha Valley study is also important with respect to the current research because it utilized passive occupational monitors to obtain air samples; however, the Kanawha Valley dosimeters were used only for ambient sampling. Indoor and outdoor ambient samples alone do not accurately represent the total exposure that a person receives from a full day of activities. Personal monitoring, wherein a sampling device is located within a one foot radius of the nose and mouth, is needed to assess the exposure a person receives from his or her normal routines. The Kanawha monitor was functionally identical to the dosimeter employed in this study—the 3M 3500 series organic vapor monitor, or OVM. This device samples VOCs at empirically determined rates through a membrane face, where they are subsequently deposited onto a thin activated charcoal pad. This technique is still in wide use and has been relied upon most recently in the Finish EXPOLIS-Helsinki work, where Tenax TA was used with active sampling to assess personal exposures.[5] Since the Kanawha Valley work, several additional studies have been completed utilizing an OVM. The USEPA Region V NHEXAS, Germany's GerES II, and the Arizona NHEXAS project all employed the 3M 3500 OVM to collect VOC data that met predetermined limits of quality assurance and quality control.[6]

It should be noted that earlier TEAM studies and Pellizzari's study both employed active sampling, using Tenax GC for air contaminant trapping.

Despite their methodological differences, the Kanawha Valley work, Pellizzari's 5 states study, and the TEAM studies reached essentially the same conclusions. Factors like airtight building construction, extensive time spent inside, and outdoor ambient pollutant levels, make indoor VOC sources important to determining total personal VOC exposures.

There are currently 188 hazardous air pollutants (HAPs) regulated as such by the U.S. Environmental Protective Agency. These compounds have been associated with a wide variety of adverse health effects, including neurological, reproductive, cancer, and developmental problems. In addition, many of these chemical compounds pose environmental problems. In the spring of 1999, the USEPA released an air toxics concept paper that outlined protocols being developed for monitoring air toxics.[7] Currently, the USEPA has identified the following fifteen VOCs as problematic air pollutants in urban settings (Table IV.1.1), and more are likely to be added.

Table IV.1.1. USEPA Draft List of 15 VOCs of Concern in Urban Settings

acrylonitrile
benzene
1,3-butadiene
chloroform
1,2-dibromoethane
hexachlorobenzene
1,3-dichloropropene
1,2-dichloropropane
1,2-dichloroethane
ethylene oxide
methylene chloride
1,1,2,2-tetrachloroethane
tetrachloroethylene
trichloroethylene
vinyl chloride

The stated goal of the USEPA project is to reduce air toxics to 25 percent of 1993 levels.[8] As techniques for easy and accurate air quality tests improve, testing in nonindustrial environments has increased. In an effort to monitor these chemicals, the USEPA's program proposed to set up a national system to assess air quality so that the air quality in the United States could be quantified. Clearly, any technological advances that allow for more extensive monitoring at lower unit cost should be of interest to the USEPA. For this reason, the use of OVMs may prove important in helping the USEPA monitor pollutant levels at a multitude of locations, thereby advancing data procurement that may eventually be used for source reduction purposes.

The health significance of exposures to indoor and ambient pollution is far from clear. Direct exposure data is logistically, and therefore economically, difficult to obtain. Therefore regulators use epidemiological methods to study at-risk populations, such as school age children. Children are more susceptible to air pollution, due to the ratio between their size and contaminants and their stage of development (i.e. high growth rate and lower body mass to pollutant ratio).[9] Children maybe more susceptible than adults to suffering adverse effects from VOCs due to intensive growth and organ system development, and different metabolic responses to these chemicals. Despite such facts, there has been little research on the risks posed specifically to children by most chemicals. The majority of exposure research has focused on adult occupational exposures to industrially important organic compounds. Some common illnesses suspected to be linked to VOC (and particulate) pollutants include asthma, cancer, learning disorders, and pulmonary disorders.[10] These studies have shown that the most significant negative effects from low-level VOC exposures is irritation and discomfort.[11] Exposure to ambient levels of some pollutants has been shown to have detrimental health effects on children.[12]

The goal of this project was to determine VOC levels in elementary schools in various settings and to explain how personal, indoor, and outdoor ambient samples relate to variables such as season, population density, and geographic region. The implications of the study results are multidimensional. First, the study provides a picture of the state of air quality in schools. Second, the study information can be used by regulating entities to determine whether current levels of VOCs are of potential concern. Third, the data collected can be used to determine the difference among VOC concentrations in inner-city, suburban, and rural areas in Ohio, as well as the differences between outdoor and indoor concentration of the target compounds at each school. Results of this study can be used as the basis for further examination of the utility and feasibility of passive dosimeter technology for ambient air pollution assessments. Work to date has shown good agreement between active and passive sampling devices[13], and because of positive outcomes from rigorous testing the 3M OVM is emerging as the long term passive sampler of choice in U.S.[14]

OBJECTIVES

This work was conducted as part of a comprehensive project examining multiple parameters of air pollution in Ohio. The objectives were:

- To focus on the potential and actual health risk(s) associated with air pollution in Ohio;
- To investigate the health effects of the proposed National Ambient Air Quality Standards for ozone and fine particulate matter ($PM_{2.5}$);

- To collect information and data that measures the correlation between potential air pollution exposures and health;
- To evaluate current or real-time collection of health data, especially for sensitive sub-populations;
- To compare populations, in different geographic areas; and
- To conduct monitoring for a set of VOCs as identified by the USEPA in the *Urban Air Toxics Strategy* to have the greatest potential effect on the public and the environment in urban areas.

To achieve project compliance with the last objective, the following actions were taken with respect to air toxics monitoring:

- Environmental measurements of VOC levels were made during the school year (September 1999 to May 28, 2000). Weekly VOC measurements (indoor, outdoor, and personal) were conducted at each site, beginning in November 1999, and ending with the close of the school year (May, 2000); and
- VOC measurements included benzene, 1-3-butadiene, carbon tetrachloride, chloroform, methylene chloride, 1,1,2,2-tetrachloroethane, and trichloroethylene.

Health status of the affected population was examined as part of the larger study, But those findings are not considered with this section of the report. Actions taken during the sampling period toward the above mentioned objectives, and their results, form the basis for this section of the report.

SAMPLING AND ANALYTICAL PROCEDURES

Passive Dosimeters

Using ambient indoor or outdoor data alone to extrapolate personal exposure to VOCs has distinct limitations. One's exposure will be determined by his or her daily routine and VOCs associated with those activities. The overall daily exposure is highly influence by microenvironments. Consequently personal monitoring is the preferred method for determining potential exposures.

Due to technological limitations personal monitoring has historically been difficult, often limited by cost. In addition, because of their size, personal samplers interfere with the subject's daily routine.[15] Before the advent of the passive sampler, personal sampling units consisted of an air pump hooked to a sampling filter that removed VOCs from the air. These air sampling units were relatively noisy, large, and hindered day-to-day activities.[16] With the refinement of passive dosimeters however, many of these issues have become

less important. Modern passive monitoring devices have no moving parts, are lightweight, and small enough to offer minimal interference.

A passive dosimeter is defined by Montalvo as "an air sampler requiring no pumps, handling of chemicals, or wearing of cumbersome apparatus such as impingers."[17] A passive dosimeter collects the species of interest via natural diffusion, and then traps them within the sampler by a sink (sampling media). In contrast, an active sampler brings the species of interest into contact with the sampling media by force using convection or pumping.[18] The theoretical design of a passive dosimeter is simple. The dosimeter consists of a draft shield (also know as a windscreen), a static diffusion layer, and a primary sink. Sometimes a secondary sink, or backup, is used when there are sampling atmospheres that could contain a high enough concentration of the species to cause breakthrough.[19] The basic design of the 3M passive dosimeter utilized in this study is shown in Figure IV.1.1.

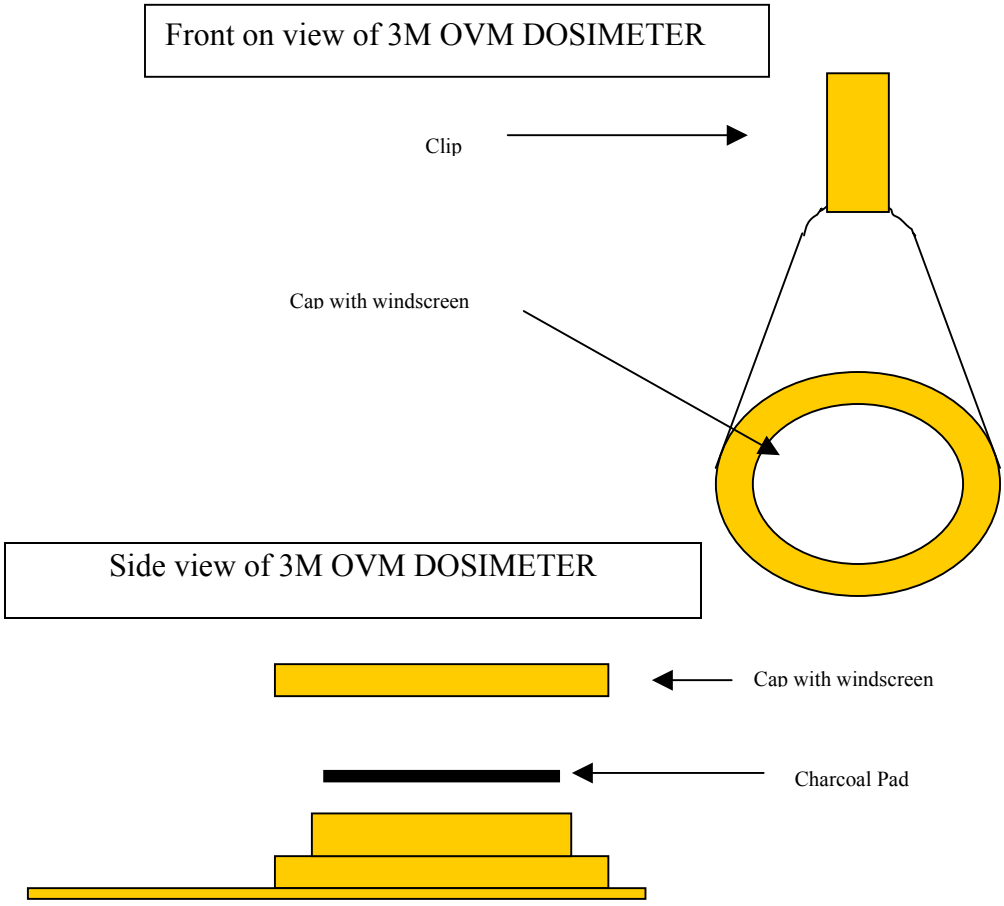

Figure IV.1.1. Diagram of a 3M Passive Organic Vapor Monitor

Drawbacks to dosimeters are that they require longer sampling times because the dosimeter's sampling rate is a function of diffusion. Therefore, for the low parts-per-billion concentrations measured in most nonindustrial indoor air work, dosimeters require a longer placement time to acquire an adequate sample to be analyzed.[20] Despite the drawbacks of personal passive dosimeters, they deliver consistent results and are viewed as dependable devices and were actively used in this project.

Each VOC will demonstrate a different rate of diffusion into a passive dosimeter, and that rate is directly affected by atmospheric conditions.[21] The three most important atmospheric conditions are temperature, humidity, and pressure. These can change the diffusion rates of the compound and cause problems with the ability of the sink to collect and hold the species being sought.[22] Another issue of concern is the effect of face velocity on the passive dosimeter. Extremely stagnant air conditions can lead to a depletion of the species of interest in the air directly outside of the sampler inlet. The result is erroneously low results, a situation that can be avoided by selecting a location with adequate airflow. Stagnant air is seldom an issue when performing personal sampling, but stagnation can still be problematic if the subject is immobile for long periods of time (e.g. sitting at a desk).[23]

In contrast to the dosimeter, the USEPA has developed and used its own methodology for collecting ambient air samples. This method employs a SUMMA™ canister device to collect an air sample. These devices are rugged and can be reused, but there are some aspects that limit their use in research. The primary disadvantages are the issues of artifacts, sample size, and sampling time. Some chemicals are more difficult to remove from the canister than others, and some chemicals actually bond to the inside of the canister, requiring physical means (such as scrubbing) to remove the material from the sides. Currently, canisters are cleaned using negative pressure and steam heating. Another limitation is that canisters are too large to collect personal exposure data and, like pump operated active samplers, will interfere with personal monitoring. The primary advantage of a canister is the precision in which it captures a known volume of air enabling the extraction and analysis of multiple samples.

A study by Daughtrey et al.[24] compares canister and sorbent sampling media samplers. The study used USEPA method TO-14, which is specific to the use of canisters for air sampling in order to analyze their samples. Using a duplicate analysis from the same canister, the results show that the difference between the two methods was insignificant. Canister cleanliness limits the detection limit of such devices below the TO-14 acceptance standard of 2.0 ppb per unit volume (0.2-2 ppb by concentration for target analytes). Thus, the lower limit of detection for canisters is higher than that of sorbent samplers.

The GC/FID method is used primarily when analyzing canister samples, and the GC/MS method is used primarily with sorbent material samples. The relative accuracy between the GC/FID and GC/MS method is excellent. Although very popular in industrial applications, sorbent sampling media has distinct disadvantages for ambient work, such as artifact issues in the presence of ozone and/or high humidity, and logistical problems related to all active sample collection.

In summary, there are several factors that need to be considered when attempting to utilize a passive dosimeter for an ambient or personal air sampling project. For this research, a passive dosimeter containing a charcoal pad is appropriate because charcoal is adequate for collecting volatile organics. Other considerations are the conditions at the sampling location and magnitude of airflow at the site. In all cases of sampling in this study, these factors were judged to be of minor concern and passive dosimeters were considered suitable for use in the study. A commercially available passive dosimeter (3M 3500 Organic Vapor Monitor, St. Paul, Minnesota) was utilized to perform indoor and outdoor ambient sampling as well as personal sampling. This dosimeter was extensively and rigorously evaluated by,Morandi et al. [25] Stock et al.[26] and Cohen et al.[27] and found suitable for use as an ambient sampler.

Sampling Protocol

Sampling was carried out for an eight-month period, beginning in January 2000 and continuing through August 2000. Although initial study objectives called for sampling to be conducted throughout the entire nine-month school term, start-up difficulties associated with procuring, installing, and operating the analytical instrument prevented acceptable data acquisition before January 2000.

To analyze the regional differences in concentration of chemical compounds in various residential settings, the study was conducted at three sites representing an urban, suburban and rural location. Koebel Elementary School, located in Columbus, Ohio, was selected to represent an urban location. The suburban site was represented by New Albany Elementary School, located northeast of Columbus, Ohio. Athens Elementary School, located in Athens, Ohio, was included to represent a rural site. A detailed description of the sampling locations is presented in Section 1 Chapter 2 (Research Methods). From all three schools a total of 183 indoor, 230 outdoor, and 180 weekly personal samples were collected during the sampling period (n=593).

For ambient samples, one dosimeter was placed inside the classroom and a second was located outside the school building at each site. Both of these samples were placed four to five feet about the floor/ground within the

breathing zone height of most of the children. The indoor sample was placed near the $PM_{2.5}$ ambient monitor (refer to Section 2 Chapter 1). The outdoor monitor was placed near a major entrance to the school under the roof line to protect it from the rain or snow. The indoor and outdoor samples were collected continuously from Monday morning through Friday afternoon ("weekly" samples), with weekend samples being collected from Friday afternoon until Monday morning respectively ("weekend" samples). Therefore, the approximate sampling period for the ambient samplers was 103 hours for weekly samples and 65 hours for weekend samples. In addition, two samplers were located immediately adjacent to each other ("co-located") at outdoor locations to determine variability in sample collection. Post-exposure, indoor, and outdoor samplers were closed and refrigerated at less than 10° C.

Personal samplers were attached to students selected at random each weekday between 7:30 and 8:00 am and worn until approximately 3:30 to 4:00 pm. The same sampler was utilized for five consecutive days for a total run time between 37.5 and 40 hours per week. At the end of each sampling day, personal OVMs were capped and refrigerated at less than 10° C for use the following day.

Every week at each site, one or two field blanks were also generated. Ambient blanks were created by opening a tube each Monday morning and immediately recapping the tube and refrigerating for transport on Friday. The weekly personal blanks were opened each morning and immediately recapped, then refrigerated. At the end of each sampling week, all samplers were transported in a cooler to a laboratory for analysis.

Analysis

Dosimeter Sample Extraction Procedures

All samples were kept refrigerated at less than 10° C and processed within two weeks of their arrival to the laboratory. OVMs were desorbed by removing the charcoal filters using PTFE coated tweezers and placing them into a 2.0 ml amber crimp vial (HP part #5181-3376). A gastight 1.0 ml syringe (Hamilton Co., #1001) was used to aspirate 1.0 ml of 99.9 + pure carbon disulfide (Aldrich Chemical, #42,464-1, Lot #LU 06855LU) into the vial. The vial was then capped using a crimping tool (HP part #9301-0720) and crimp caps (HP part #5181-1211) physically verifying cap tightness to ensure an adequate seal. The vial was then placed in an ice water bath and sonicated for forty minutes. Dosimeter extraction was based on a procedure described by Stock et al.[28], except that sample vials were sonicated instead of shaken on a rotary plate shaker. After desorbtion, 200 µl of sample was removed from the vial using a 250-µl syringe (Microliter, #725) with a set-stop

and placed in a second amber 2 ml vial containing a vial insert (HP part #631-9330). Using a 25-µl syringe (Microliter, #702), 10µl of a 100µg/µl internal standard mix (Bestek Corp., #30074; see below) was added to the vial. The vial was then crimp-capped and immediately placed into an HP 6890 series auto sampler (HP part #G2613A and G2614A) for analysis.

GC/MS Configuration

Samples were qualitatively and quantitatively analyzed using a Hewlett-Packard 6890 gas chromatograph coupled to a Hewlett-Packard 5973 mass spectrometer. Analytes were separated with a 90 m x .32 mm i.d. HP-VOC special performance capillary column coated to a 1.8 µm liquid film thickness (HP, #19091R-319). Run parameters are shown in Table IV.1.2 and were similar to those utilized by Stock et al.[29] for analysis of 3M dosimeters employed as ambient samplers.

Briefly, an injector port temperature of 180 °C was used with an initial oven temperature of 35 °C and an eight minute hold, followed by a ramp rate of 8 °C/min to 180 °C, and then 20 °C/min to a final temperature of 270 °C with a seven minute hold. The unit was run splitless for the first two minutes to load the sample, then run split 40:1. An initial inlet pressure of 3.0 psi was utilized for two minutes, and was increased at 10 psi/min to a final pressure of 25 psi. The mass spectrometer was programmed "off" for the first five minutes and again from 11.7-12.7 minutes into each run, to allow for carrier solvent passage. Total run time for each analysis cycle was 37.6 minutes.

Table IV.1.2. Gas Chromatography/Mass Spectrometer Settings

GC/MS Parameter	Parameter Setting
Mode	
-Port temperature	180°C
-volume	1 ml
-split	splitless first 2.0 min split 40 to 1 after 2.0 min
Inlet Pressure	
-initial	3.0 p.s.i. with 2 min hold
-ramp rate	10 p.s.i./min
Oven Temperature	
-Initial	35°C with 8 min hold
-ramp rate	8°C/min to 180°C, then 20°C/min
-final	270°C with 7 min hold
-Detector Off	0-5.0 min, 11.68-12.74 min
-Total Run Time:	37.6 min

Quality Control

Sample Chain of Custody, Holding, and Processing

Samples were kept in refrigerators at the sampling sites, then transported by project employees via private car to the analysis laboratory. All samples were kept refrigerated at less than 10° C at the laboratory and processed within two weeks of their arrival. Field sampling sheets were used to determine hours and minutes of actual exposure for each OVM based on recorded times. Completed sample transfer sheets are available for inspection in room E318 A, Grover Center, Ohio University, Athens, Ohio.

Standards and Quantitation

A VOC standards mix (Ultra Scientific, #DWM-588) was used for VOC quantification through the creation of standard 5 point minimum curves. The

mix is marketed for USEPA Method 8260B. That method is primarily used in air and water sampling to determine VOCs from a variety of solid matrices, including halogenated and non-halogenated organics. For that reason the VOCs employed in that method were deemed appropriate for use in this study. All of the compounds in the mix could not be discriminated by the column, desorption solvent, and run parameters used in this study. Table IV.1.3 lists the 60 compounds included in the standards mix and the 45 chemicals this method was able to resolve.

Table IV.1.3. VOCs Available to USEPA Method 8260 B in Standard Mix, Quantified, and Semi-Quantified

Compound Name	Standard Mix n=60	Quantified n=20*	Semi-Quantified** n=25
Benzene	X	X	
Bromobenzene	X		X
Bromochloromethane	X	X	
Bromodichloromethane	X		X
Bromoform	X		X
Bromomethane	X		
n-Butylbenzene	X		
Carbon tetrachloride	X	X	
Chlorobenzene	X	X	
Chlorodibromomethane	X		X
Chloroethane	X		
Chloroform	X	X	
Chloromethane	X		
2-Chlorotoluene	X		
4-Chlorotoluene	X		
1,2-Dibromo-3-chloropropane	X		X
1,2-Dibromoethane	X		X
Dibromomethane	X		X
1,2-Dichlorobenzene	X	X	
1,3-Dichlorobenzene	X	X	
1,4-Dichlorobenzene	X		
Dichlorodifluoromethane	X		
1,1-Dichloroethane	X	X	
1,2-Dichloroethane	X		X
1,1-Dichloroethene	X	X	
trans-1,2-Dichloroethene	X		X
cis-1,2-Dichloroethene	X		X

Compound Name	Standard Mix n=60	Quantified n=20*	Semi-Quantified** n=25
1,2-Dichloropropane	X		X
1,3-Dichloropropane	X		X
2,2-Dichloropropane	X		X
cis-1,3-Dichloropropene	X		X
trans-1,3-Dichloropropene	X		X
1,1-Dichloropropene	X		X
Ethylbenzene	X	X	
Hexachlorobutadiene	X		X
Isopropylbenzene	X		
4-Isopropyltoluene	X		
Methylene chloride	X	X	
Naphthalene	X	X	
n-Propylbenzene	X		X
sec-Butylbenzyne	X		
Styrene	X	X	
1,2,3 tert-Butylbenzyne	X		X
1,1,1,2-Tetrachloroethane	X		X
1,1,2,2-Tetrachloroethane	X	X	
Tetrachloroethylene	X		X
Toluene	X	X	
1,2,3-Trichlorobenzene	X		X
1,2,4-Trichlorobenzene	X		X
1,1,1-Trichloroethane	X	X	
1,1,2-Trichloroethane	X	X	
Trichloroethylene	X	X	
Trichloromonofluoromethane	X		X
1,2,3-Trichloropropane	X		
1,2,4-Trimethylbenzene	X		
1,3,5-Trimethylbenzene	X		X
Vinyl chloride	X		
o-Xylene	X	X	
m-Xylene	X	X	
p-Xylene	X	X	

* m- and p-Xylene co-elute and so are considered as a single compound for the purposes of categorization.

** See text for criteria of “Semi-quantified” compounds

Approximately monthly, standard curves were generated using the 60 compound standard mix. The mix is received at a concentration of 2,000µg/ml. Ten points were used to generate a calibration curve, with concentrations of 20, 10, 5, 2, 1, 0.5, 0.2, 0.1, 0.05, and 0.005 µg/ml being prepared. First, the 2,000µg/µl VOC mix was diluted to 20µg/µl by taking 10µl of the VOC mixture and adding it to 990µl of 99.9 + pure carbon disulfide, for a total volume of 1,000µl. Using this 20µg/µl VOC mix solution, the other dilutions were made per Table IV.1.4.

Table IV.1.4. Dilutions for Standard Curve Generation

Curve concentrations in µg/µl	Dilution ratio from starting solution	Starting solution concentration in µg/ml	Volume made in µl	Dilution ratio from stock solution
20	1/100	2000	1000	1/100
10	1/2	20	1000	1/200
5	1/4	20	1000	1/400
2	1/10	20	1000	1/1000
1	1/20	20	1000	1/2000
0.5	1/2	1	1000	1/4000
0.2	1/5	1	1000	1/10000
0.1	1/10	1	1000	1/20000
0.05	1/20	1	1000	1/40000
0.005	1/200	1	1000	1/400000

All dilutions were made to a final volume of 1,000 µl. Vials containing the standard mix were then run through the GC/MS using the method described earlier. After the initial analysis was completed, HP ChemStation software was utilized to analyze the curve data and assign a concentration.

To best assess mass spectrometer response, four compounds were utilized in each processed sample as internal standards. These compounds, pentafluoro-benzene, 1,4-diflouro-benzene, chlorobenzene d5, and 1,4-dichlorobenzene d4, are available as a mixture (Bestek Corp., # 30074). The internal standard mix was purchased at 2,500µg/µl, and was diluted to the concentration desired for spiking the vials before sampling using 99.9 + pure carbon disulfide (Aldrich Chemical, # 42,464-1, Lot # LU 06855LU). One milliliter of internal standard mix is made at 100µg/µl by taking 40µl of 2,500µg/ml internal standard and diluting it with 960µl of CS_2.

Both calibration and environmentally collected sample results were reviewed for probability of match in a set of steps recommended by Hewlett-Packard[30] in a procedure termed "Qediting". Qedited results were then entered into a spreadsheet to calculate the amount of a VOC in the air in $\mu g/m^3$ and parts per billion (ppb), employing exposure time and 3M supplied sampler desorption coefficient and sampling rate for a given chemical.[31] Of the 45 standard components detectable in this study, there were 20 for which 3M OVM desorption coefficients and sampling rate data were available. Where 3M data was available concerning sampler desorption coefficient and sampling rate for a given chemical, those values were employed in the calculation. These are indicated as "Quantified" in Table IV.1.3. An additional 25 chemicals in the standard mix were identified and semi-quantitatively reported using the average desorption coefficient (0.915) and average sampling rate (30.9 ml/min) calculated for all chemicals for which 3M reported such parameters (n = 127). These are indicated as "Semi-quantified" in Table IV.1.3. Thus, of the 60 compounds in the standard mix, 45 can be resolved by the GC/MS method used, 20 can be positively quantified, and 25 can be semi-quantified.

As noted earlier, sampling sheets submitted with each passive dosimeter and Qedited analytical results were entered into a spreadsheet to calculate the amount of a VOC in $\mu g/m^3$ and ppb. To do so, Qedited data from the GC/MS was converted from µg/ml total volume to $\mu g/m^3$ concentration in the air per Equation IV.1.1.

Equation IV.1.1. Calculation of Dosimeter Concentration in $\mu g/m^3$

$$(X_1 - X_0)/(T*De*Ra*1e\text{-}6) = C$$

Where:
X_1 = the sample reading from the GC/MS (µg/ml)
X_0 = the sample reading from the blank (µg/ml)
T = sampling time (minutes)
De = desorption coefficient for the compound
Ra = sampling rate (ml/min)
C = concentration of VOC in air in $\mu g/m^3$
MW = molecular weight of compound
ppb = amount present in ppb

Conversion from $\mu g/m^3$ to ppb was accomplished using Equation IV.1.2.

Equation IV.1.2. Conversion to ppb

$$(C\ 1e\text{-}6*\ 0.02445)/(MW*1e9) = ppb$$

Limit of Detection

The limit of detection (LOD) is the lowest standard concentration reproducibly generating a signal above the background noise of the GC/MS (after removing laboratory blank values). The standard deviation, mean, max, median, and correlation coefficient were calculated for standard curve data using Microsoft Excel 2000. Table IV.1.5 lists the compounds used in this study (OH) compared to the Kanawha Valley (KV) and Total Exposure Assessment Methodology (TEAM) studies, and compares the LODs by chemical for the thirteen compounds shared by the three studies.

Table IV.I.5. Limits of Detection (LOD) in Ohio 3 School Study as Compared to KV and TEAM Studies

Limits of Detection			
Compound	**µg /m^3 LOD OH[a]**	**µg /m^3 LOD KV[b]**	**ug/m^3 LOD TEAM[c]**
o-xylene	0.18	1.8	0.13
m & p-xylene	0.7	1.8	0.13
1,3-dichloro-benzene	0.18	1.9	0.17
trimethyl benzene	0.18	2	0.00
tetrachloroethylene	0.16	1.8	0.29
benzene	0.01	7.1	0.12
ethylbenzene	0.18	1.8	0.13
carbon tetrachloride	0.17	8.3	0.37
trichloroethylene	0.18	4.1	0.37
styrene	0.16	1.9	0.12
chlorobenzene	0.02	4.3	0.21
1,2-dibromoethane	0.18	8.5	0.00
trichlorobenzene	0.35	11.1	0.00

[a] Limit of detection for this study based on GC/MS analysis of passive OVMs in µg/m^3
[b] Limit of detection for the Kanawha Valley study in µg/m^3
[c] Limit of detection for the TEAM study in µg/m^3

The KV study defined their LOD as "the lowest concentration standard for which a signal was obtained, correcting for desorption efficiency and volume."[32] For this study the LOD was taken as the lowest standard concentration for which a signal that did not fall below background noise of the instrument. Thus, the definitions of LOD between KV and this project are similar. The TEAM study calculated its limit of detection based on the volume of sample collected and the instrumental LOD.[33] By using the TEAM study

sampling time (12 hours), sampling rate (30 ml/min), and instrumental LOD reported for each compound (originally reported in ng/canister), an LOD in $\mu g/m^3$ was calculated to generate the LODs reported in Table IV.1.5. Results are within expected ranges and thus the comparisons of Table IV.1.5 are appropriate.

Quality control and data integrity are important in any study purporting to represent a populations' exposure to a given contaminant. In their 2001 assessment of data quality in the NHEXAS (Region V) study, Pellizzari et al.[34] reported median detection limits of 7 of the 13 compounds in Table IV.1.5. that were considerably higher than this study, the TEAM project, or even their earlier work. For example, benzene reportedly had a lower quantification limit of 740 ug/m^3 in air. The authors noted two significant factors in this regard: 1) two identical GC/MS systems employed for VOC analysis generated remarkably different relative standard deviations (for example , 34% versus 6.8% for benzene), and 2) the precision and analysis of benzene, specifically, did not meet the NHEXAS data quality goals. These findings are important in light of some of the difficulties seen in work utilizing charcoal pads in passive dosimeters for benzene collection. It should also be noted that the less precise GC/MS system was employed for the majority (>75%) of the NHEXAS (Region V) VOC samples.

RESULTS AND DISCUSSION

Results have been tabulated and tested for significance in Table IV.1.6. The significance of these values is best appreciated relative to other studies of a similar nature. For this reason, the results will be discussed and compared to the findings of the New Jersey TEAM report[35], Pellazari's 5 states study[36], and the Kanawha Valley report.[37] These studies reported considerably fewer compounds than this report, so the majority of the discussion in the following sections will be limited to the thirteen compounds shared by these projects. In addition, results from several more recent studies will also be used to benchmark values obtained in this study. These recent studies include; the National Human Exposure Assessment Survey (NHEXAS) conducted in Arizona[38] and in USEPA Region V[39] from 1995-1997, the German environmental survey (GerES II)[40] conducted from 1990-1992, and EXPOLIS-Helsinki, Finland[41] study conducted from 1995-1997.

Table IV.I.6. Statistical Comparison of Personal and Indoor to Outdoor Concentrations of VOCs for the Entire Study Period

Compound	Average personal exposure µg /m^3 (n=180) [b]	Standard Deviation (n=180) [b]	Indoor average ambient concentration µg /m^3 (n=549) [c]	Standard Deviation (n=549) [c]	Outdoor average ambient concentration µg /m^3 (n=693) [d]	Standard Deviation (n=693) [d]	probability personal < outdoor	probability indoor < outdoor	probability both < outdoor
o-xylene	3.62	11.44	1.99	2.13	1.00	1.11	< 0.001	< 0.001	< 0.001
m & p-xylene	5.93	18.79	3.5	4.17	1.69	2.08	< 0.001	< 0.001	< 0.001
1,3-dichloro-benzene	36.11	103.98	42.67	122	1.22	3.41	< 0.001	< 0.001	< 0.001
trimethyl benzene	0.5	0.73	0.36	0.31	0.19	0.19	< 0.001	< 0.001	< 0.001
tetrachloroethylene	1.05	1.63	1.16	3.21	0.47	0.46	< 0.001	< 0.001	< 0.001
benzene	3.88	8.76	2.59	2.92	2.50	2.73	0.01	0.01	< 0.001
ethylbenzene	3.17	8.02	2.09	2.52	0.93	1.22	< 0.001	< 0.001	< 0.001
carbon tetrachloride	1.24	1.69	1.04	0.84	1.17	0.9	0.11	0.76	0.08
trichloroethylene	0.72	1.89	1.79	13.54	0.56	4.5	0.1	0.01	< 0.001
styrene	0.97	2.38	0.17	0.75	0.05	0.3	< 0.001	< 0.001	< 0.001
chlorobenzene	0.15	0.26	0.09	0.39	0.15	0.85	0.27	0.83	0.23
1,2-dibromoethane	0.03	0.21	0.01	0.02		0.03	0.04	0.12	< 0.001
trichlorobenzene	0.03	0.08	0.01	0.04	0.03	0.05	0.01	0.97	0.01
TVOC[e]	57.39		57.45		9.96				

[a] These values are less than the limit of detection
[b] The total number of personal samples collected during this study at all three schools combined
[c] The total number of indoor ambient samples collected during this study at all three schools combined
[d] The total number of outdoor ambient samples collected during this study at all three schools combined
[e] The total volatile organic compound amount for the entire study for the selected compounds

One approach to examining VOC data is through the sum of VOC species present. Molhave et al. define Total Volatile Organic Compounds as "…the total mass of measured VOCs per unit volume of air, exclusive of very volatile (e.g., formaldehyde) organic compounds."[42] TVOCs are therefore a simple, integrated measure of VOCs irrespective of the individual toxicity of any particular species within the whole. As an indicator of health effects, a TVOC concentration is inherently flawed because the potency of individual VOCs to elicit irritating symptoms varies by orders of magnitude.[43] Nevertheless, the TVOC measure is frequently used as a risk index for health and comfort, particularly in indoor air quality remediation cases.[44]

In general, very low TVOCs were found in this study. Like several other studies examining background, or baseline, concentrations of VOCs in nonproblematic settings, levels found in this study were in the low ug/m^3 range. For example, the USEPA's ongoing Building Assessment and Survey Evaluation (BASE) of 100 nonproblematic U.S. office buildings reported toluene, 1,1,1-trichloroethane, benzene, and xylenes among the most frequently measured VOCs in studied locations.[45] These Ohio findings echo such results, frequently finding these species at levels on par with the BASE data (i.e., at concentrations < 100 ug/m^3, usually much lower).

The significance of exposures to VOC mixtures at low levels is unclear. As mentioned, the BASE study concentrations have been collected from office buildings devoid of any indoor air quality (IAQ) issues. In his study of 50 'normal' Finnish homes, Kostiainen routinely found speciated VOC concentrations at less than 5 ug/m^3.[46] Of the 48 compounds he quantified, the TVOC average for the healthy homes was 123 ug/m^3 (121 ug/m^3, median), as compared with the TVOC average for the 45 compounds quantified and semi-quantified in this study of 57 ug/m^3 (see Table IV.1.6). Kostiainen reported that in 38 'sick' homes included in his study, specific VOC species were two to three higher than 'normal' homes. In contrast to that study, Weschler et al.[47] determined more than forty individual VOCs which combined to generate TVOCs in excess of 3,000 ug/m^3 in facilities exhibiting "sick building syndrome" (SBS). It is noteworthy that in both studies, speciated concentrations were 10,000-100,000 times lower than current OSHA Permissible Exposure Limits[48] or American Council of Governmental Industrial Hygienists Threshold Limit Values[49] established for workplace exposures to these chemicals.

Since the application of occupational limits to the concentrations detected in this study is inappropriate, and in lieu of other binding standards pertaining to low level VOCs in indoor air, interpretation of the findings of this study must be guarded. Hodgson et al.[50] reported that European nations were moving toward IAQ guidelines analogous to radiological health concept of "as low as reasonably achievable" (ALARA). They also summarized a recommendation by Seifert of 250 ug/m^3 as an "acceptable level" of VOCs in

indoor air, and another suggestion by Molhave of a maximal TVOC limit of 300 ug/m^3, with no one species exceeding 20 percent of the total. If such limits were presently in place, none of the three schools studied in this project would be considered to have IAQ issues.

Data in the following sections should be considered as representing VOC levels at the high end of ambient concentrations. OVM charcoal absorbent pads were typically found to contain trace levels of benzene. For example the 32 blank OVMs processed for Athens had an average benzene level of 0.38 ppm with a standard deviation of 0.48 ppm. Similar difficulties were reported by Stock et al. in their initial evaluation of the 3M OVM.[51] Benzene was also a quantification problem in the NHEXAS, Region 5 study[52] which used 3M OVMs.

Although reported the values reported in the following tables were corrected with respect to the values obtained on the field blanks the inherent variability in the contaminant levels on the charcoal pads could result in artificially elevated reported levels of benzene. Caution in the interpretation of concentration maxima in particular is therefore warranted. Work is presently underway exploring the use of tube axial and radially diffusive samplers with much reduced levels of benzene or its artifacts. Using thermal desorption, these samplers have the added advantage of not requiring the use of carbon disulfide possibly containing further sources of benzene contamination.

Co-located Field Sampler Comparisons

Outdoor duplicate samples were run January through March at all study locations, and the relative standard deviation were calculated for co-located samplers. The relative standard deviation of a co-located measurement is an assessment of the uncertainty in a single measurement. Table IV.I.7 shows the results of correlations of study of badges over the entire sampling period, by date and school. The average relative standard deviation at each school is approximately 0.31, and is acceptably low in all cases. These results, examined in light of the limits of detection data, can be interpreted as demonstrating an adequate level of precision for the OVMs as ambient samplers.

Table IV.1.7. Results for Co-located OVM Badges
Relative Standard Deviation (RSD) for Co-located Badges at Schools
January 3rd to April 3rd, 2000

Date	Athens[a] RSD	Koebel[b] RSD	New Albany[c] RSD
January 3rd-7th	0.20	0.38	
January 7th-10th	0.06		
January 10th-14th	0.22	0.06	0.10
January 14th-17th			0.06
January 17th-21st			0.02
January 21st-24th			0.15
January 24th-28th			0.19
January 28th-31st			0.25
Jan. 31st-Feb. 4th	0.20	0.76	0.40
February 4th-7th	0.35		0.37
February 7th-11th	0.24	0.35	
February 11th-14th	0.47		0.44
February 14th-18th	0.23	0.49	0.40
February 18th-21st	0.22	0.14	0.61
February 21st-25th	0.15	0.28	0.32
February 25th-28th			0.44
Feb. 28th-March 3rd		0.25	0.25
March 3rd-6th	0.26	0.03	0.19
March 6th-10th		0.33	0.23
March 10th-13th	0.62	0.01	0.37
March 13th-17th	0.65	0.49	0.53
March 17th-20th	0.65		0.38
March 20th-24th	0.06		
March 24th-27th	0.41		
March 27th-31st	0.37		
March 31st-April 3rd	0.40		
Average	0.32	0.30	0.30

[a] Sample set for Athens where n = 18 sample pairs
[b] Sample set for Koebel where n = 12 sample pairs
[c] Sample set for New Albany where n = 19 sample pairs

Graphical depiction of co-located results are presented in Figures IV.1.2-A, -B, and -C for four of the fifteen compounds that the USEPA has indicated are of potential long-term interest.[53] Results are shown for the three sampling locations of this study, along with best line of fit regressions for the data for each chemical.

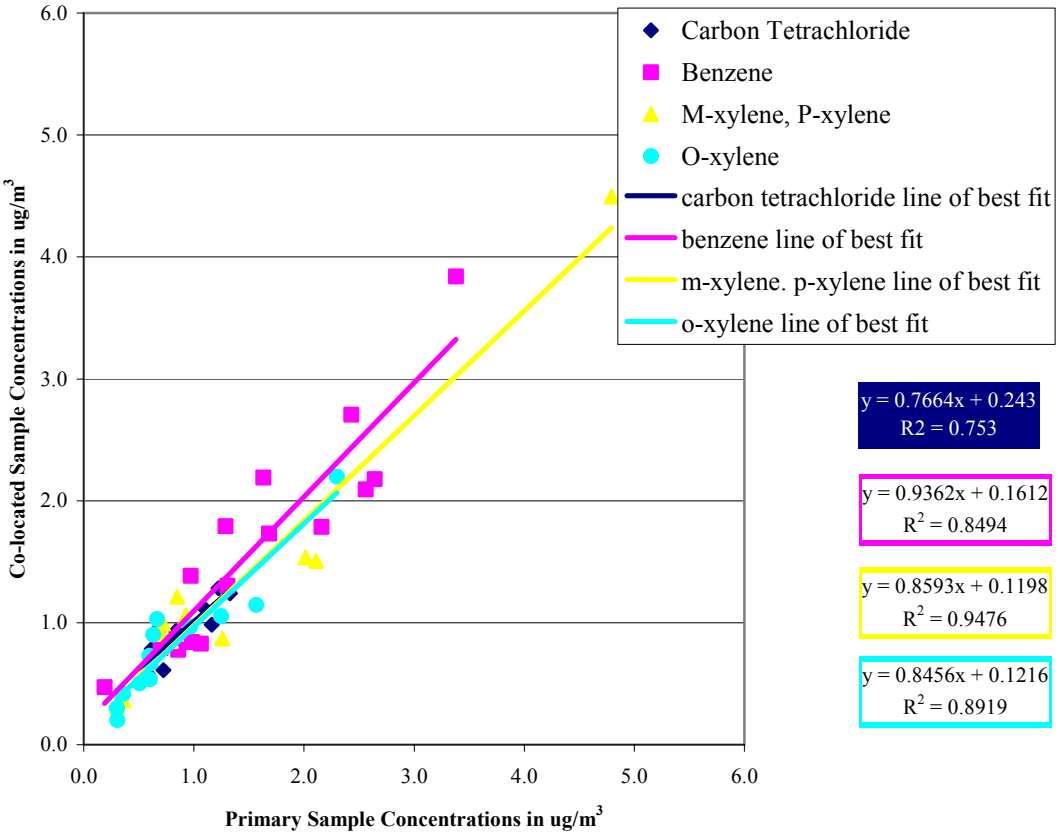

Figure IV.1.2A
Co-locate Data for Four Compounds at Athens

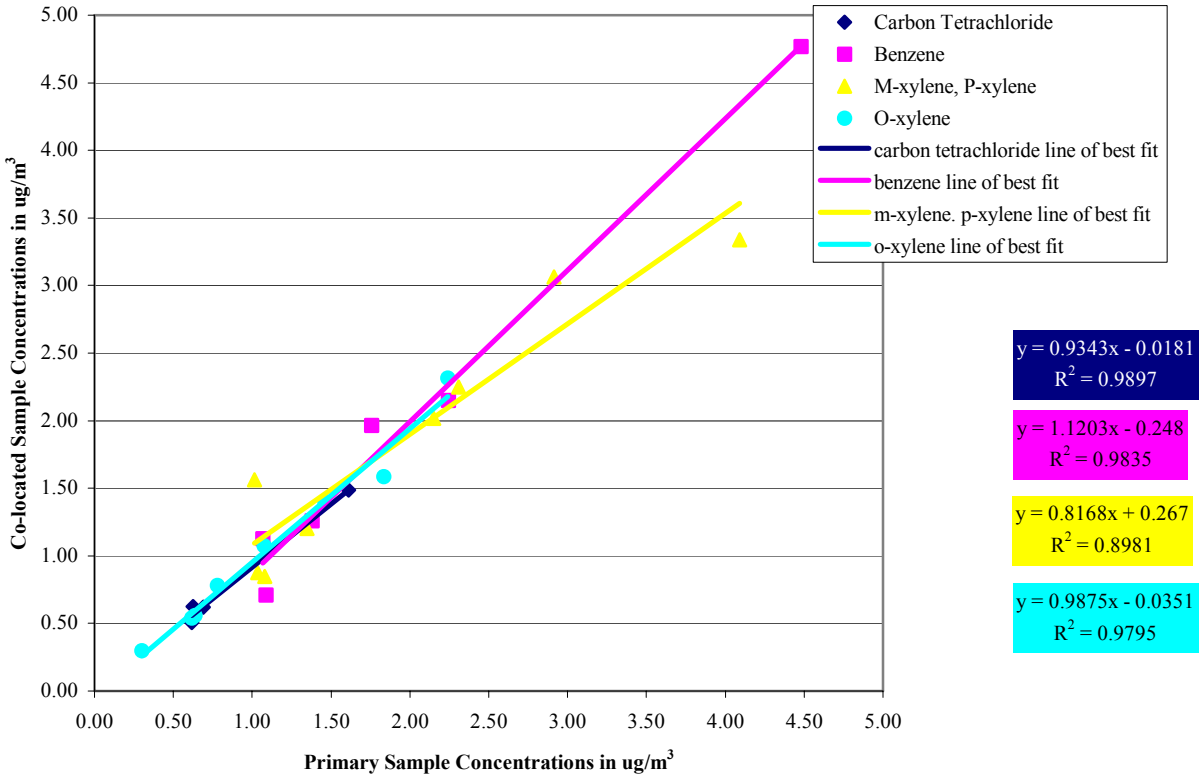

Figure IV.1.2B
Co-locate Data for Four Compounds at Koebel

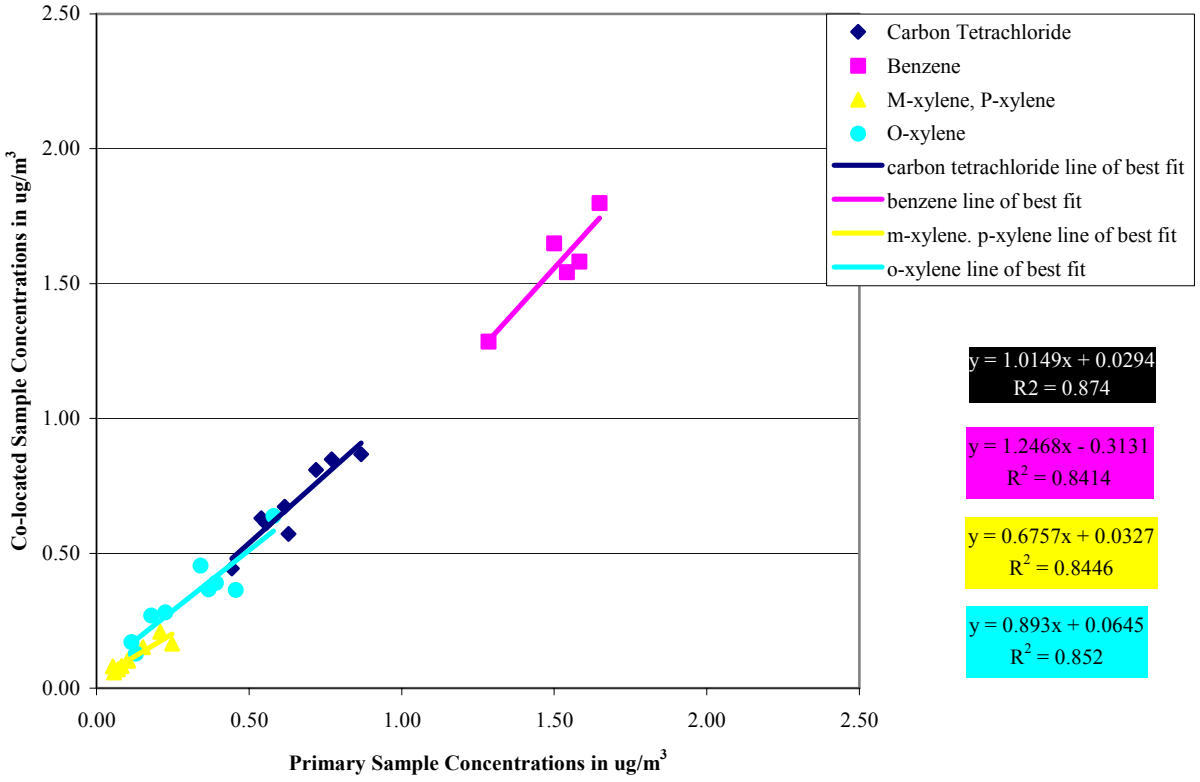

Figure IV.1.2C
Co-locate Data for Four Compounds at New Albany

Indoor to Outdoor Comparisons

Table IV.1.8 compares the percentage of samples above the LOD for this study against several similar studies conducted in the US and Findland. For comparison purposes, the table reports only those compounds measured in all the studies. This study found a greater percentage of detectable compounds than than all the other studies referenced in Table IV.1.8.

Table IV.1.8. Percent of Measurements with Concentrations Greater Than LOD : Comparison with other studies

	Indoor (%)						Outdoor (%)					
Compound	OH[a]	AZ[b]	KV[c]	Reg V[d]	TEAM[e]	EX[f]	OH	AZ	KV	Reg V	TEAM[g]	EX
o-xylene	99		60		85	93	95		0		65	68
m & p-xylene	98		100		>90	99	94		71		>90	87
1,3-dichloro-benzene	96		49		60		70		0		18	
trimethyl benzene	95		80		ND[h]	7	78		9		ND	64
tetrachloroethylene	95		17	57	90		93		0	50	60	
benzene	95	49	26	99	75	71	91	34	0	100	48	85
ethylbenzene	93		66		90	94	84		3		30	63
carbon tetrachloride	93		26		10		92		0		<1	
trichloroethylene	88		34	36	30		66		0	26	18	
styrene	61		11		45	50	19		0		8	7
chlorobenzene	56		63		ND		43		0		ND	
1,2-dibromoethane	8		29		ND		4		0		ND	
trichlorobenzene	4		23		ND		6		0		ND	

[a] OH -results from this study
[b] AZ – results from the NHEXAS Arizona study
[c] KV -results from the Kanawha Valley study
[d] Reg V- results from the NHEXAS Region V. study
[e] Indoor Values taken from “night personal air” samples from TEAM study in Elizabeth-Bayonne, NJ
[f] EX- results from the EXPOLIS Helsinki study
[g] Outdoor Values taken from “night outdoor air” samples from TEAM Study in Elizabeth-Bayonne, NJ
[h] ND = not determined

The results depicted in Table IV.1.8 are most likely explained by differences in analytical methods among the studies. For example the KV study utilized 3M 3500 series charcoal pad dosimeters analyzed by GC/FID while the TEAM study utilized Tenax-GC tubes analyzed by GC/MS. This project utilized 3M 3500 series charcoal pad dosimeters analyzed by GC/MS. As shown previously in Table 5, LODs for this project are comparable to

TEAM study LODs, and significantly lower than the KV study LODs. In addition this study used a long sample duration, up to four days, which decrease the LODs.

Tables IV.I.9A, -B, and -C, display indoor VOC concentrations for the thirteen shared compounds for Athens, Koebel, and New Albany, respectively. These tables can be compared to outdoor levels (Tables IV.1.10-A, -B, and -C) and to personal values (Tables IV.1.11-A, -B, and -C) for the same sites. For most of the compounds, the arithmetic average concentrations are greater than median values, indicating skewed concentration distributions. This is typical for distributions of indoor air pollutants and air pollutants in general.[54] Casual comparison of the three data table series indicates that personal exposures are generally in excess of indoor values, which are, in turn, higher than outdoor values.

Elevated levels of 1,3-dichlorobenzene reflected in Table IV.1.9A merit some discussion, as no conclusive explanation adequately addresses their existence. Possible causes of these values were explored with school personnel at Athens, 1,3-dichlorobenzene is an active ingredient in insecticides (MW=147, BP=174 degrees C). No conformation was obtained of insecticide spraying during the spring of 2000 at Athens. Consequently the elevated levels of this chemical in indoor samples from Athens can neither be wholly explained nor dismissed.

Table IV.1.9A. Summary Statistics for Indoor VOC Samples (ug/m^3) for Athens

Compound	Mean	Std. Dev.	Max	Median
o-xylene	2.65	2.76	13.67	1.47
m & p-xylene	4.96	5.68	28.66	2.67
1,3-dichloro-benzene	117.80	191.53	697.65	4.43
trimethyl benzene	0.35	0.29	1.45	0.28
tetrachloroethylene	0.68	0.85	5.09	0.36
benzene	3.94	4.09	22.62	2.56
ethylbenzene	3.11	3.40	17.15	1.80
carbon tetrachloride	0.98	0.87	3.42	0.77
trichloroethylene	0.24	0.35	1.71	0.10
styrene	0.13	0.15	0.81	0.10
chlorobenzene	0.19	0.67	5.16	0.06
1,2-dibromoethane	0.01[a]	0.02	0.09	0.00[a]
trichlorobenzene	0.02[a]	0.05	0.34	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.9B. Summary Statistics for Indoor VOC samples (ug/m^3) for Koebel

Compound	Mean	Std. Dev.	Max	Median
o-xylene	1.51	1.11	5.92	1.23
m & p-xylene	2.41	1.87	10.11	1.91
1,3-dichloro-benzene	1.24	0.64	3.41	1.25
trimethyl benzene	0.50	0.37	2.42	0.42
tetrachloroethylene	2.50	5.54	28.72	0.75
benzene	2.57	2.19	9.48	1.82
ethylbenzene	1.30	1.24	6.35	1.06
carbon tetrachloride	1.04	0.80	4.21	0.73
trichloroethylene	3.63	24.63	182.95	0.21
styrene	0.10	0.15	0.76	0.06
chlorobenzene	0.04[a]	0.06	0.23	0.00[a]
1,2-dibromoethane	0.00[a]	0.03	0.18	0.00[a]
trichlorobenzene	0.01[a]	0.03	0.09	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1. 9C. Summary Statistics for Indoor VOC samples (ug/m^3) for New Albany

Compound	Mean	Std. Dev.	Max	Median
O-xylene	1.78	1.98	12.52	1.18
M & P-xylene	3.08	3.55	22.45	2.06
1,3-dichloro-benzene	8.78	9.28	54.05	5.61
Trimethyl benzene	0.25	0.22	1.08	0.18
tetrachloroethylene	0.49	0.74	4.62	0.27
benzene	1.39	1.19	5.48	1.20
Ethylbenzene	1.82	2.05	12.65	1.18
carbon tetrachloride	1.09	0.84	3.70	0.78
trichloroethylene	1.69	2.54	14.28	0.66
styrene	0.25	1.21	10.03	0.07
chlorobenzene	0.04[a]	0.05	0.18	0.00[a]
1,2-dibromoethane	0.01[a]	0.03	0.18	0.00[a]
trichlorobenzene	0.01[a]	0.02	0.11	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.10A. Summary Statistics for Outdoor VOC Samples (ug/m^3) for Athens

Compound	Mean	Std. Dev.	Max	Median
o-xylene	1.38	1.72	7.26	0.62
m & p-xylene	2.36	3.38	14.52	0.85
1,3-dichloro-benzene	3.10	6.41	26.26	0.08
trimethyl benzene	0.20	0.20	0.82	0.14
tetrachloroethylene	0.48	0.55	2.94	0.34
benzene	3.55	4.16	18.05	1.73
ethylbenzene	1.38	1.90	8.29	0.49
carbon tetrachloride	1.14	1.00	3.74	0.81
trichloroethylene	0.15	0.21	0.79	0.06
styrene	0.11	0.61	4.57	0.00[a]
chlorobenzene	0.10	0.16	0.89	0.00[a]
1,2-dibromoethane	0.00[a]	0.01	0.06	0.00[a]
trichlorobenzene	0.03	0.05	0.23	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.10B. Summary Statistics for Outdoor VOC Samples (ug/m^3) for Koebel

Compound	Mean	Std. Dev.	Max	Median
o-xylene	1.26	0.98	4.74	1.07
m & p-xylene	2.15	1.72	8.62	1.77
1,3-dichloro-benzene	0.31	0.35	1.61	0.21
trimethyl benzene	0.30	0.23	1.27	0.24
tetrachloroethylene	0.53	0.43	1.96	0.42
benzene	2.90	2.78	15.04	1.97
ethylbenzene	1.04	1.19	5.54	0.86
carbon tetrachloride	1.16	0.98	5.57	0.81
trichloroethylene	1.45	9.21	68.46	0.13
styrene	0.03	0.07	0.40	0.00[a]
chlorobenzene	0.15	0.77	5.72	0.00[a]
1,2-dibromoethane	0.00[a]	0.02	0.11	0.00[a]
trichlorobenzene	0.01[a]	0.02	0.09	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.10C. Summary Statistics for Outdoor VOC Samples (ug/m^3) for New Albany

Compound	Mean	Std. Dev.	Max	Median
o-xylene	0.37	0.26	1.33	0.31
m & p-xylene	0.55	0.45	2.13	0.39
1,3-dichloro-benzene	0.24	0.40	2.93	0.16
trimethyl benzene	0.07	0.07	0.27	0.06
tetrachloroethylene	0.41	0.53	2.89	0.27
benzene	1.06	0.82	4.12	0.97
ethylbenzene	0.38	0.31	1.37	0.30
carbon tetrachloride	1.20	0.96	4.34	0.80
trichloroethylene	0.09	0.12	0.50	0.07
styrene	0.01	0.04	0.25	0.00[a]
chlorobenzene	0.20	1.41	11.60	0.00[a]
1,2-dibromoethane	0.01[a]	0.04	0.33	0.00[a]
trichlorobenzene	0.02	0.07	0.50	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.11A. Summary Statistics for Personal VOC Samples (ug/m^3) for Athens

Compound	Mean	Std. Dev.	Max	Median
o-xylene	7.39	19.31	83.27	1.66
m & p-xylene	12.40	31.73	132.07	2.51
1,3-dichloro-benzene	102.50	163.11	606.25	1.66
trimethyl benzene	0.53	0.90	3.68	0.28
tetrachloroethylene	0.89	1.33	6.00	0.58
benzene	7.38	14.02	60.00	1.94
ethylbenzene	6.07	13.13	47.72	1.92
carbon tetrachloride	1.18	1.33	5.92	0.85
trichloroethylene	0.49	0.73	3.30	0.40
styrene	1.07	1.51	4.86	0.31
chlorobenzene	0.26	0.38	1.68	0.15
1,2-dibromoethane	0.02[a]	0.07	0.30	0.00[a]
trichlorobenzene	0.03[a]	0.09	0.36	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.11B. Summary Statistics for Personal VOC Samples (ug/m^3) for Koebel

Compound	Mean	Std. Dev.	Max	Median
o-xylene	2.57	3.23	12.88	1.92
m & p-xylene	3.83	4.67	19.03	2.88
1,3-dichloro-benzene	1.90	1.69	6.03	2.09
trimethyl benzene	0.81	0.83	2.74	0.70
tetrachloroethylene	1.61	2.13	8.14	1.13
benzene	3.59	4.46	14.86	2.37
ethylbenzene	2.76	3.60	14.49	1.90
carbon tetrachloride	1.82	2.55	11.08	1.53
trichloroethylene	0.34	0.37	1.23	0.28
styrene	1.93	3.88	16.46	0.76
chlorobenzene	0.11	0.17	0.51	0.00[a]
1,2-dibromoethane	0.09	0.37	1.58	0.00[a]
trichlorobenzene	0.02[a]	0.06	0.21	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Table IV.1.11C. Summary Statistics for Personal VOC samples (ug/m^3) for New Albany

Compound	Mean	Std. Dev.	Max	Median
o-xylene	1.05	0.77	2.71	1.07
m & p-xylene	1.77	1.41	5.57	1.48
1,3-dichloro-benzene	3.73	2.44	9.68	3.77
trimethyl benzene	0.21	0.18	0.56	0.16
tetrachloroethylene	0.77	1.33	6.55	0.49
benzene	0.94	0.69	2.82	0.85
ethylbenzene	0.87	0.76	2.89	0.73
carbon tetrachloride	0.81	0.80	2.95	0.56
trichloroethylene	1.26	2.99	14.05	0.29
styrene	0.09	0.12	0.38	0.00[a]
chlorobenzene	0.08	0.15	0.60	0.00[a]
1,2-dibromoethane	0.01[a]	0.04	0.17	0.00[a]
trichlorobenzene	0.04[a]	0.09	0.31	0.00[a]

[a] These values indicate concentrations less than the limit of detection

Statistical comparison of the means of the three data types (personal, indoor and outdoor) for the three schools is summarized in Tables IV.1.12A, -B, and -C. These comparisons also support the observation of personal exposures greater than indoor concentrations, and indoor values exceeding outdoor values. For both Athens (Table IV.1.12A) and New Albany (Table IV.1.12C), indoor ambient levels were statistically greater than outdoor

concentrations ($p < 0.001$). Koebel indoor levels also tended to be higher than outdoor levels ($p < 0.10$). When sampling results from the schools were pooled by sample category (Table IV.1.6), all but four of the thirteen compounds (carbon tetrachloride, chlorobenzene, 1,2-dibromoethane, and trichlorobenzene) demonstrated this relationship ($p<0.10 - 0.001$). Both 1,2-dibromomethane and trichlorobenzene concentrations were typically below the LOD of the method (Table IV.1.5) but are included in Table IV.1.6 for consistency.

Table IV.1.12A. Statistical Comparison of Personal and Indoor to Outdoor Concentrations of VOCs for Athens

Compound	Average personal exposure µg /m³ (n=60) [b]	Standard Deviation (n=60) [b]	Indoor average ambient concentration µg /m³ (n=183) [c]	Standard Deviation (n=183) [c]	Outdoor average ambient concentration µg /m³ (n=231) [d]	Standard Deviation (n=231) [d]	probability personal < outdoor	probability indoor < outdoor	probability both < outdoor
o-xylene	7.39	19.31	2.65	2.76	1.38	1.56	0.007	< 0. 001	0.007
m & p-xylene	12.4	31.73	4.96	5.68	2.36	3.04	0.006	< 0. 001	0.006
1,3-dichloro-benzene	102.5	163.11	117.8	191.53	3.1	5.73	< 0. 001	< 0. 001	<. 001
trimethyl benzene	0.53	0.9	0.35	0.29	0.2	0.19	0.001	< 0. 001	0.001
tetrachloroethylene	0.89	1.33	0.68	0.85	0.48	0.5	0.004	< 0. 001	0.004
benzene	7.38	14.02	3.94	4.09	3.55	3.73	0.009	0.015	0.024
ethylbenzene	6.07	13.13	3.11	3.4	1.38	1.73	0.002	< 0. 001	0.002
carbon tetrachloride	1.18	1.33	0.98	0.87	1.14	0.91	0.249	0.81	0.858
trichloroethylene	0.49	0.73	0.24	0.35	0.15	0.2	< 0. 001	< 0. 001	< 0. 001
styrene	1.07	1.51	0.13	0.15	0.11	0.53	< 0. 001	0.156	0.156
chlorobenzene	0.26	0.38	0.19	0.67	0.1	0.14	< 0. 001	0.015	0.015
1,2-dibromoethane	0.02[a]	0.07	0.01[a]	0.02	0.00[a]	0.01	0.011	< 0. 001	0.011
trichlorobenzene	0.03[a]	0.09	0.02[a]	0.05	0.03	0.05	0.179	0.844	0.872
TVOC[e]	140.21		135.04		13.98				

[a] These values are less than the limit of detection
[b] The total number of personal samples collected per school during this study
[c] The total number of indoor ambient samples collected per school during this study
[d] The total number of outdoor ambient samples collected per school during this study
[e] The total volatile organic compound amount for the entire study for the selected compounds

Table IV.1.12B. Statistical Comparison of Personal and Indoor to Outdoor Concentrations of VOCs for Koebel

Compound	Average personal exposure µg /m³ (n=60) [b]	Standard Deviation (n=60) [b]	Indoor average ambient concentration µg /m³ (n=183) [c]	Standard Deviation (n=183) [c]	Outdoor average ambient concentration µg /m³ (n=231) [d]	Standard Deviation (n=231) [d]	probability personal < outdoor	probability indoor < outdoor	probability both < outdoor
o-xylene	2.57	3.23	1.51	1.11	1.26	0.91	0.001	0.001	< 0.001
m & p-xylene	3.83	4.67	2.41	1.87	2.15	1.61	0.002	0.014	< 0.001
1,3-dichloro-benzene	1.9	1.69	1.24	0.64	0.31	0.35	< 0.001	< 0.001	< 0.001
trimethyl benzene	0.81	0.83	0.5	0.37	0.3	0.23	< 0.001	< 0.001	< 0.001
tetrachloroethylene	1.61	2.13	2.5	5.54	0.53	0.4	0	< 0.001	< 0.001
benzene	3.59	4.46	2.57	2.19	2.9	2.6	0.064	0.668	0.043
ethylbenzene	2.76	3.6	1.3	1.24	1.04	1.14	0	0.001	< 0.001
carbon tetrachloride	1.82	2.55	1.04	0.8	1.16	0.94	0.011	0.605	0.007
trichloroethylene	0.34	0.37	3.63	24.63	1.45	8.28	0.943	0.1	0.094
styrene	1.93	3.88	0.1	0.15	0.03	0.06	< 0.001	< 0.001	< 0.001
chlorobenzene	0.11	0.17	0.04	0.06	0.15	0.69	0.597	0.967	0.577
1,2-dibromoethane	0.09	0.37	0[e]	0.03[a]	0.00[a]	0.02[a]	0.038	0.194	0.007
trichlorobenzene	0.02[a]	0.06	0.01	0.03[a]	0.01[a]	0.02[a]	0.055	0.085	0.005
TVOC[e]	21.39		16.88		11.28				

[a] These values are less than the limit of detection
[b] The total number of personal samples collected per school during this study
[c] The total number of indoor ambient samples collected per school during this study
[d] The total number of outdoor ambient samples collected per school during this study
[e] The total volatile organic compound amount for the entire study for the selected compounds

Table IV.1.12C. Statistical Comparison of Personal and Indoor to Outdoor Concentrations of VOCs for New Albany

Compound	Average personal exposure µg /m^3 (n=60) [b]	Standard Deviation (n=60) [b]	Indoor average ambient concentration µg /m^3 (n=183) [c]	Standard Deviation (n=183) [c]	Outdoor average ambient concentration µg /m^3 (n=231) [d]	Standard Deviation (n=231) [d]	probability personal < outdoor	probability indoor < outdoor	probability both < outdoor
o-xylene	1.05	0.77	1.78	1.98	0.37	0.25	< 0.001	< 0.001	< 0.001
m & P-xylene	1.77	1.41	3.08	3.55	0.55	0.44	< 0.001	< 0.001	< 0.001
1,3-dichloro-benzene	3.73	2.44	8.78	9.28	0.24	0.35	< 0.001	< 0.001	< 0.001
trimethyl benzene	0.21	0.18	0.25	0.22	0.07	0.06	< 0.001	< 0.001	< 0.001
tetrachloroethylene	0.77	1.33	0.49	0.74	0.41	0.47	0.015	0.057	0.001
benzene	0.94	0.85	1.39	1.19	1.06	0.8	0.917	0.003	0.003
ethylbenzene	0.87	0.76	1.82	2.05	0.38	0.29	< 0.001	< 0.001	< 0.001
carbon tetrachloride	0.81	0.8	1.09	0.84	1.2	0.86	0.994	0.593	0.59
trichloroethylene	1.26	2.99	1.69	2.54	0.09	0.1	0.001	0	< 0.001
styrene	0.09	0.12	0.25	1.21	0.01	0.03	< 0.001	0.004	< 0.001
chlorobenzene	0.08	0.15	0.04	0.05	0.2	1.24	0.82	0.933	0.765
1,2-dibromoethane	0.01[a]	0.04	0.01[a]	0.03	0.01[a]	0.04	0.578	0.793	0.459
trichlorobenzene	0.04[a]	0.09	0.01[a]	0.02	0.02	0.06	0.057	0.991	0.057
TVOC[e]	11.63		20.67		4.6				

[a] These values are less than the limit of detection
[b] The total number of personal samples collected per school during this study
[c] The total number of indoor ambient samples collected per school during this study
[d] The total number of outdoor ambient samples collected per school during this study
[e] The total volatile organic compound amount for the entire study for the selected compounds

Both the TEAM and KV studies concluded that indoor levels were higher than outdoor levels, and so would contribute more significantly to personal exposure to VOCs than outdoor air. As observed in this study, personal exposures and indoor concentrations of VOCs were higher than outdoor concentrations throughout the entire study. This result supports earlier findings that indoor air quality has a greater impact on personal exposures to VOCs than outdoor air quality, and extends that conclusion to the elementary school setting.

Personal to Indoor Comparisons

Lioy et al.[55] found no correlation between personal and outdoor samples in their Elizabeth/Bayonne study, and the results or this study echo those findings. However, in their comparison of personal and indoor sampling data,

strong correlations were experienced. In this study the same relationships were also found. Figures IV.1.3A, -B, and –C show the relationship between personal and indoor concentrations for benzene. Fairly large correlation coefficients (R) were experienced at all three schools, ranging from 0.74 at Koebel down to 0.41 at New Albany.

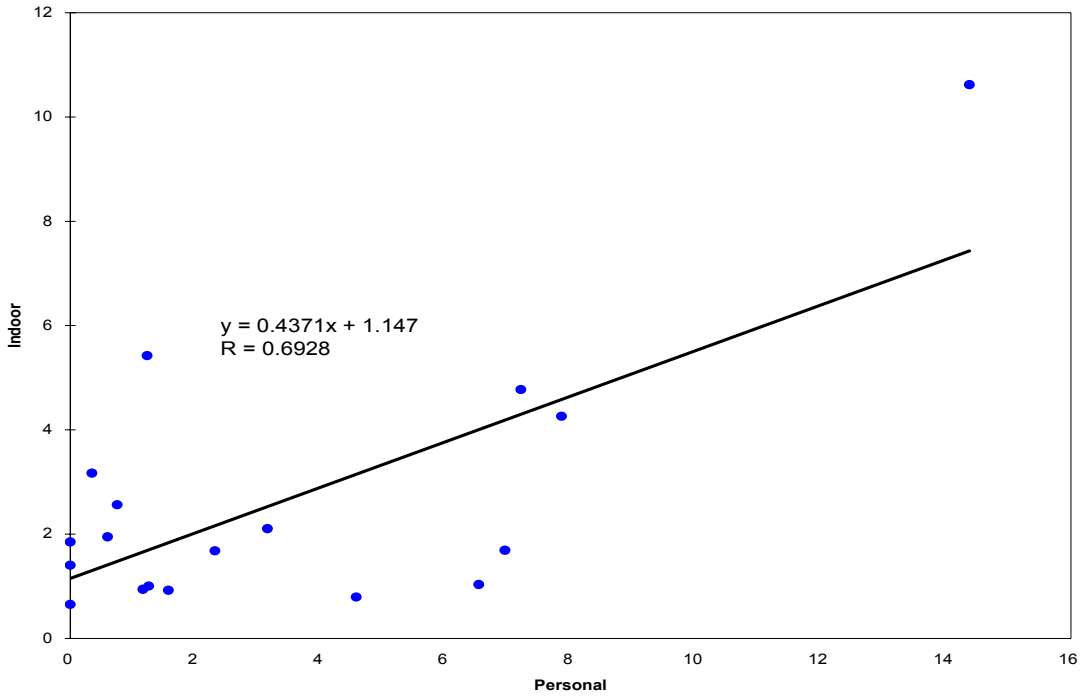

Figure IV.1.3A. Indoor Concentrations vs. Personal Exposures for Benzene at Athens ($\mu g/m^3$)

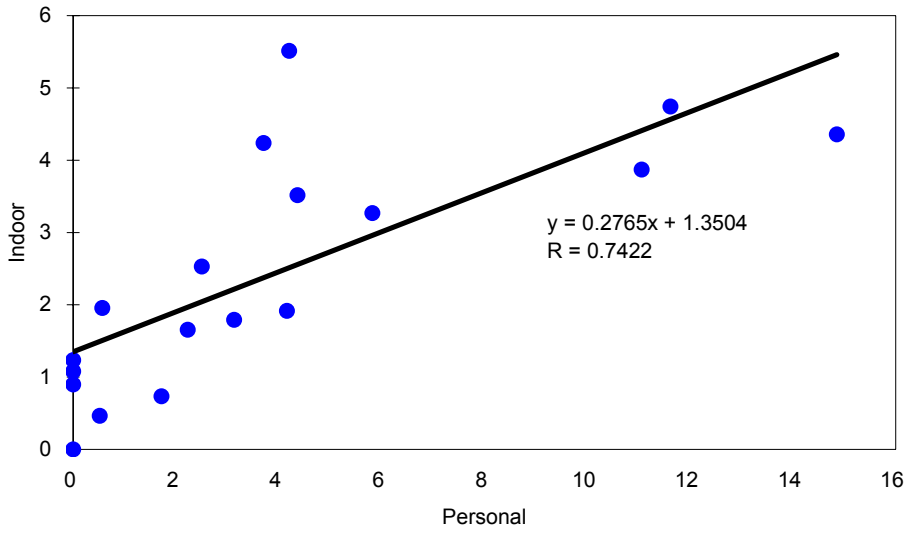

Figure IV.1.3B. Indoor Concentrations vs. Personal Exposures for Benzene at Koebel ($\mu g/m^3$)

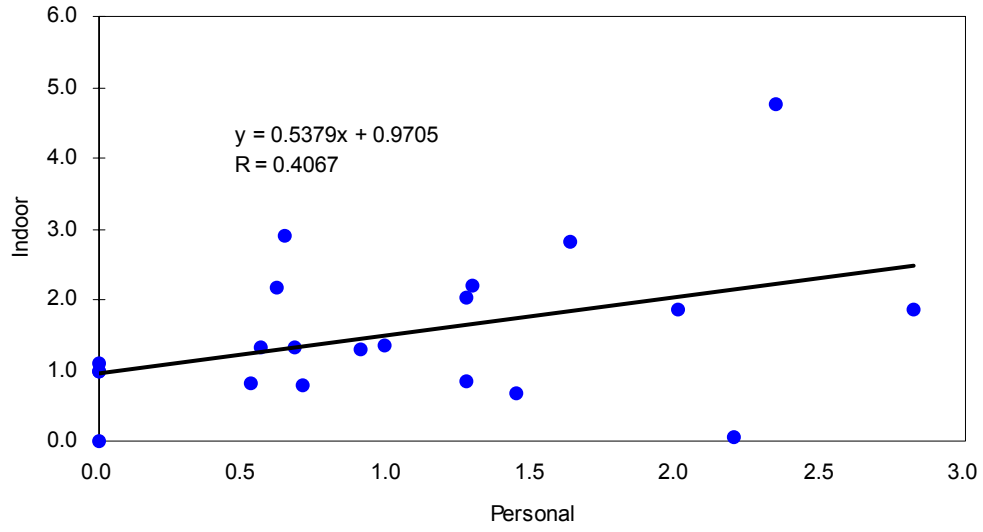

Figure IV.1.3C. Indoor Concentrations vs. Personal Exposures for Benzene at New Albany ($\mu g/m^3$)

Seasonal Comparisons

Sampling results for most species were not impacted by daily or weekly increases in temperature or relative humidity. Figures IV.1.4A, -B, and –C plot outdoor temperature and relative humidity averages against concentrations of o-xylene, and show no association between this chemical and either of the weather variables. Comparisons have been made for trichloroethylene and benzene with similar results. Because of their redundancy those graphs are not presented.

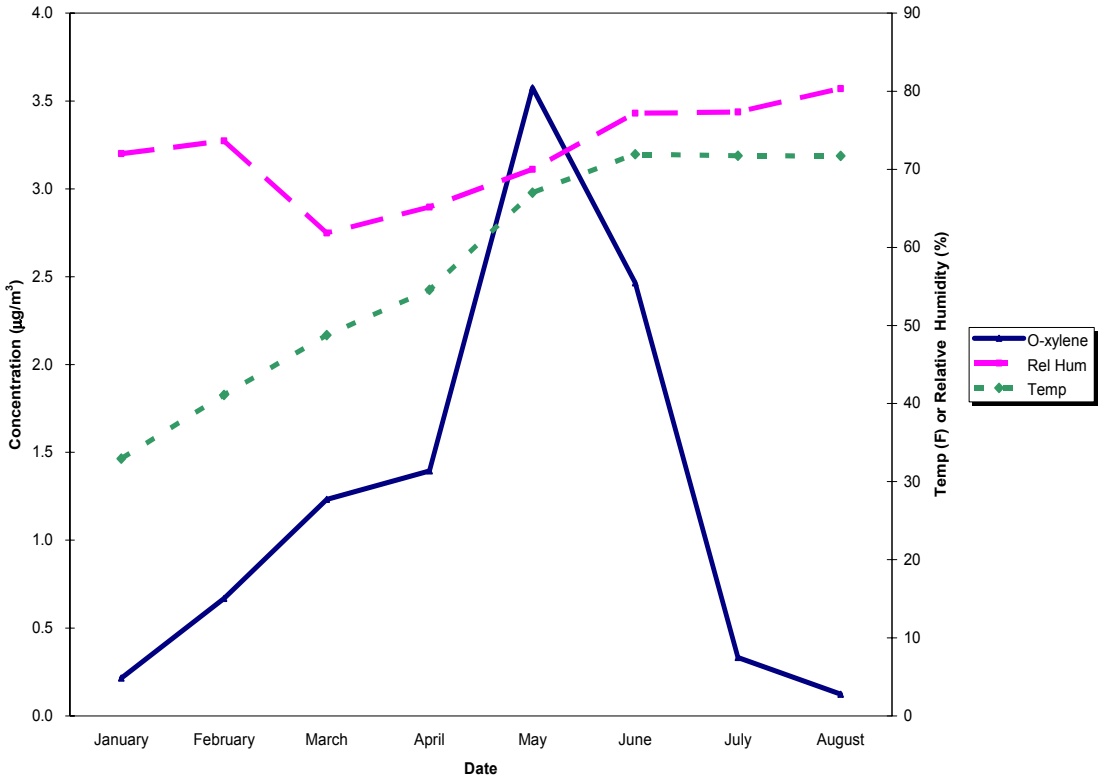

Figure IV.1.4A. Athens Monthly Averaged Outdoor O-Xylene Concentrations[a]

[a] Units are Fahrenheit, percent and ug/m^3 for temperature, relative humidity and concentration, respectively

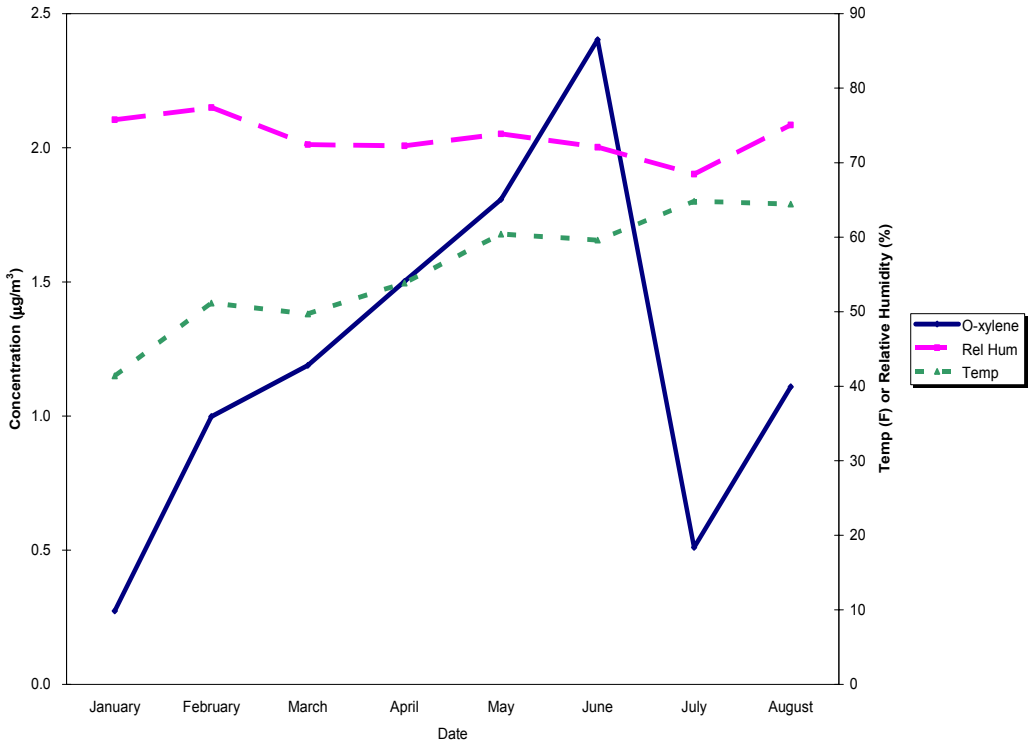

Figure IV.1.4B. Koebel Monthly Averaged Outdoor O-Xylene Concentrations[a]

[a] Units are Fahrenheit, percent and ug/m^3 for temperature, relative humidity and concentration, respectively

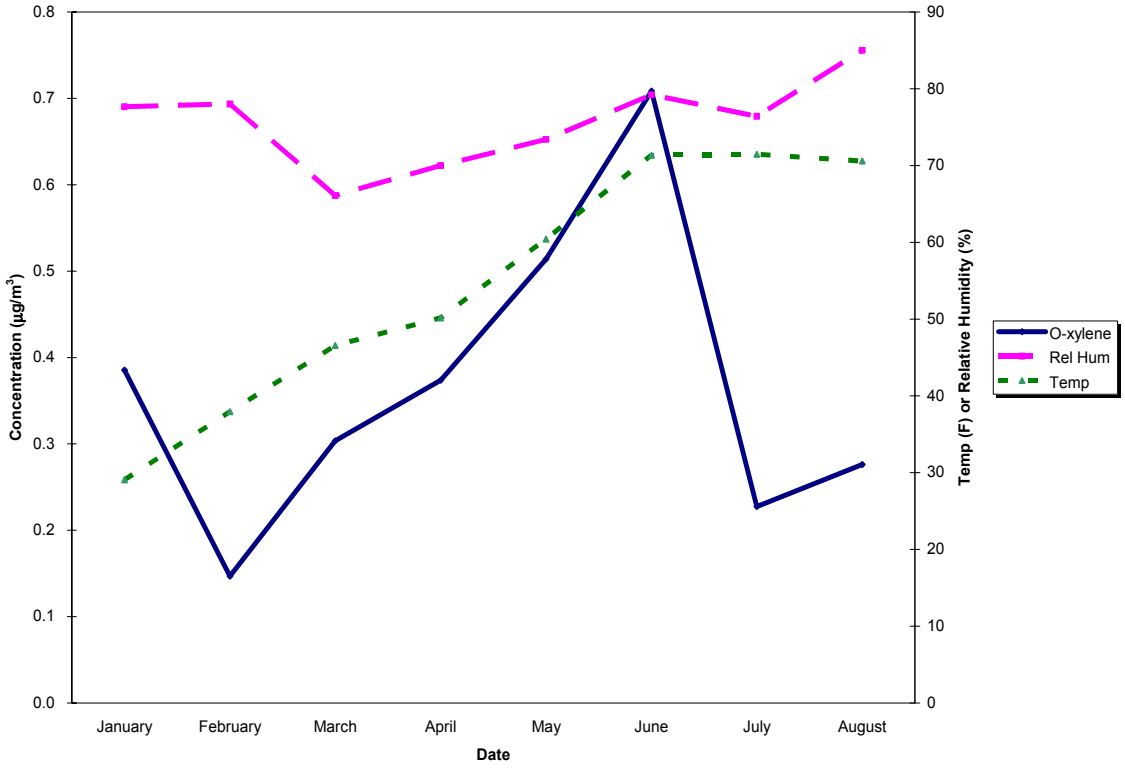

Figure IV.1.4C. New Albany Monthly Averaged Outdoor O-Xylene Concentrations[a]

[a] Units are Fahrenheit, percent and ug/m^3 for temperature, relative humidity and concentration, respectively

Although specific VOC concentrations were not distinctly affected by weekly temperature or airborne moisture, this study shows a significant seasonality to VOC prevalence. Higher levels of most chemical species occurred in spring months as compared to either winter or summer. Table IV.1.13 displays a summary of seasonal trends by sample type for each school. Owing to 1,3-dichlorobenzene concentrations, Athens had significantly higher overall levels of VOCs than either Koebel or New Albany. When 1,3-dichlorobenzene was removed from the dataset, Koebel showed the highest VOC levels but Athens VOC levels were still higher than New Albany.

Table IV.1.13. Seasonality Trends in TVOC for All Schools and All Sample Types ($\mu g/m^3$)

Athens		**Winter**	**Spring**	**Summer**
	Personal	7.53	272.88	N/A [a]
	Indoor	5.45	297.32	41.24
	Outdoor	5.21	23.25	3.93
Koebel				
	Personal	5.78	33.88	N/A
	Indoor	7.61	24.53	15.72
	Outdoor	6.19	16.99	8.56
New Albany				
	Personal	10.92	12.34	N/A
	Indoor	16.33	32.13	10.56
	Outdoor	3.73	6.45	3.29
Seasonal trend averaged for all three schools				
	Personal	8.08	106.37	N/A
	Indoor	9.80	117.99	22.51
	Outdoor	5.05	15.56	5.26
Overall Seasonal trend for all sample types				
	Average TVOC	7.64	79.97	13.88

[a] No personal data was collected during the summer since school was not in session at the elementary schools

As detailed earlier, inquiries were made of site personnel at Athens elementary but the source of 1,3-dichlorobenzene could not be determined. Its presence could be due to the use of insecticides in the school. 1,3-dichlorobenzene is an active ingredient in insecticides. To enable a more precise determination of abnormally high levels of a given compound, a contemporaneous diary of activities in the classroom, as well as a diary of the activities of the student wearing the personal sampler, could be kept. Such

diaries would create a precise data log to be associated with chemicals used in the classroom, thereby enhancing the ability to determine sources of VOC contaminants.

As foretold by the speciated data, TVOC levels were highest in the spring season at all three sites. This was unexpected since the winter months would typically have the least fresh air available indoors, resulting in higher indoor levels from anthropogenic sources. Higher personal exposures were likewise expected due to cold weather keeping the children indoors, and the likelihood that the schools were saving energy by limiting the supply of fresh outdoor air.

Seifert et al.[56] studied 12 Berlin households over the course of a 12 month period, employing passive dosimeters to collect bi-monthly samples (i.e., 26, two-week periods). In most of the residences, TVOCs in winter months exceeded summer values by a margin of 3:1. TVOCs were employed as a parameter measure to indicate general influence of seasonal conditions on all VOC concentrations. Although no average or median values were reported by season, the authors cite Krause et al.[57] who, in a study of sixty VOCs in some 500 German homes, reported a mean TVOC value of 400 ug/m^3 and a 50-percentile value of 330 ug/m^3. As compared with this study (Table 13), German 50-percentile residential values of TVOCs were approximately 40, 4, and 24 times greater than the Ohio winter, spring, and summer TVOC values, respectively. Seifert attributed the higher average TVOC concentrations in his study to specific activities taking place in the homes, such as renovation work, use of felt markers, cleaning agents, correction fluids, and adhesives. Lewis, in a study of ten homes in winter in Boise, Idaho, also found indoor contributions of various VOCs to be the significant cause for the higher VOC concentrations detected.[58]

Given the magnitude of the differences seen between Seifert's work and the current study, it is also possible that sampling differences were responsible for higher levels seen in Germany in winter months and in Ohio in late spring. For example, Chen et al.[59] studied the relationship of VOC vapor pressure to temperature at time of sampling, and found that elevated temperatures increased specific airborne concentrations significantly. Since no temperature data is available from Seifert et al. it can only be postulated that potentially higher indoor temperatures may have had some effect on sampling rates of the badges. In this study, it is possible that sampling rates in late spring were increased owing to elevated indoor temperatures during atypical hot days occurring prior to the use of building air conditioning.

Pellizzari's TEAM study produced a seasonality comparison between winter and summer seasons.[60] In that study, winter VOC levels for most target compounds were two to three times higher than summer levels. For both Elizabeth/Bayonne, NJ, as well as Los Angeles, the majority of chemicals common to both studies were more frequently measured in indoor settings

during winter months than in indoor locations during summer months. Over all geographical areas incorporated into that study, indoor to outdoor concentrations were statistically different ($p = 0.05$) in 58 of the 280 matched pairs examined. However, in some locations all studied chemicals during Fall months were higher indoors than outdoors (Elizabeth/Bayonne, NJ), or a large percentage (13/19 at Antioch/ W. Pittsburg, CA.) were greater indoors as compared to outdoors. Thus it seems that what few studies have been done comparing indoor to outdoor concentrations indicate indoor values are greater in colder months than warmer months. Clearly, Athens and Koebel data contradicts those findings whereas New Albany data affirms them.

Figures IV.1.5A, -B, and –C show the monthly averaged concentrations for selected VOCs at each school. These figures illustrate the rise in concentration, that was experienced for a majority of the VOCs measured, during the spring months. The concentrations also tended to drop during the summer months for both indoor and outdoor samples (personal samples were not taken during the summer months).

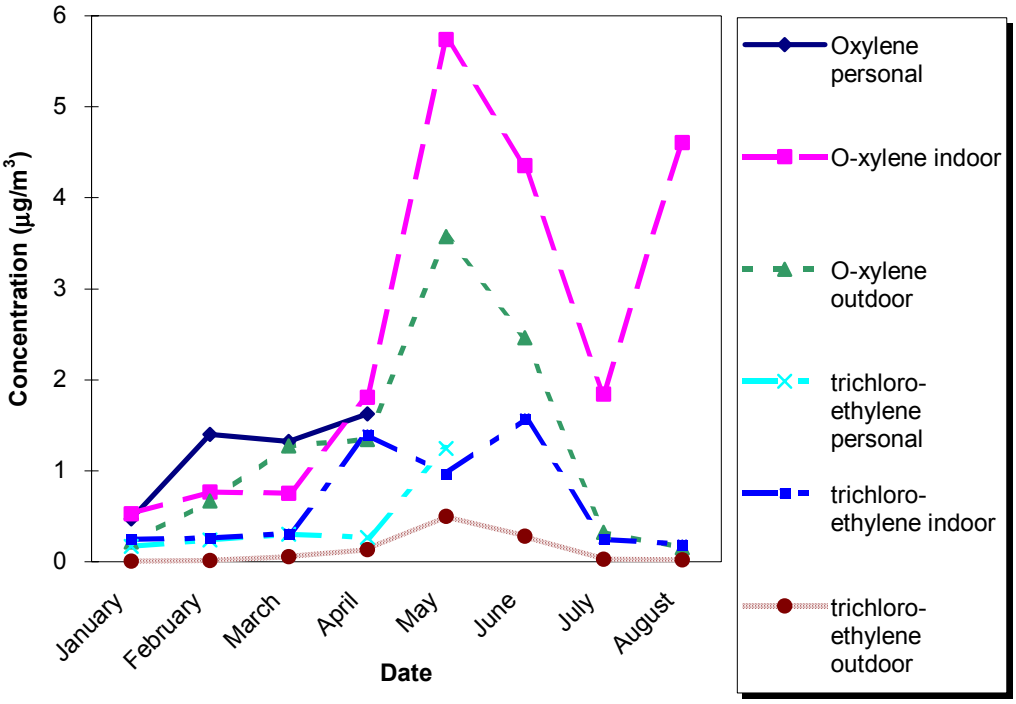

Figure IV.1.5A. Athens Comparison of Indoor Outdoor and Personal Monthly Averaged VOC Levels.

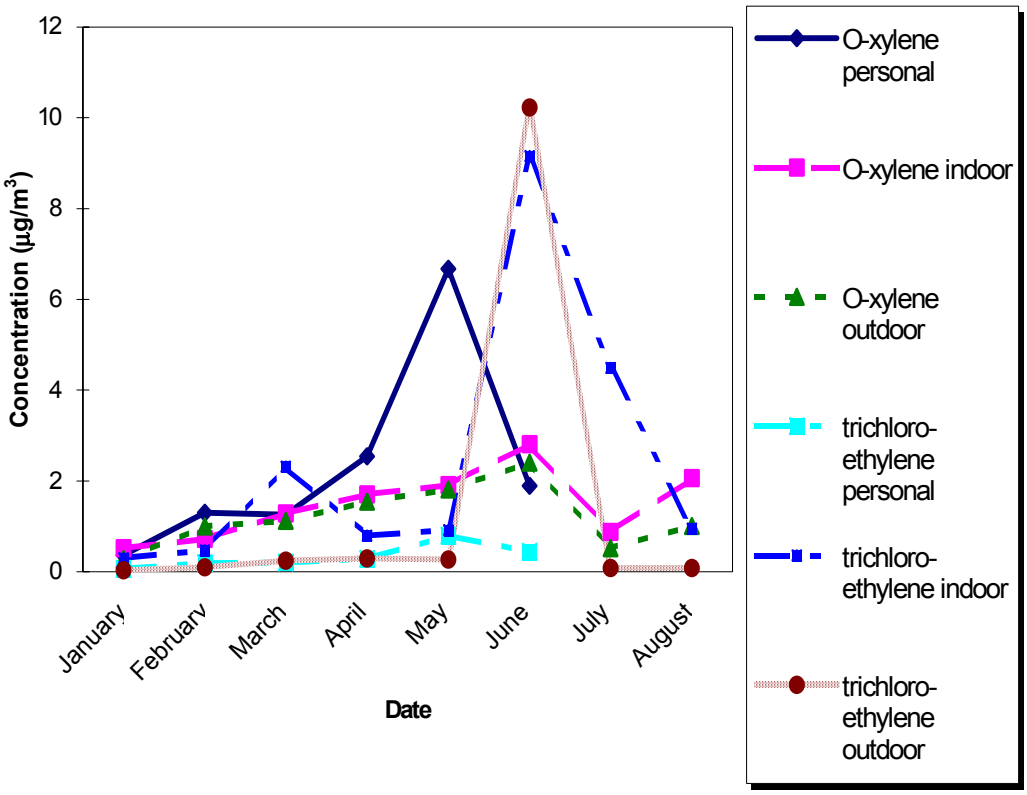

Figure IV.1.5B. Koebel School Comparison of Indoor Outdoor and Personal Monthly Averaged VOC Levels.

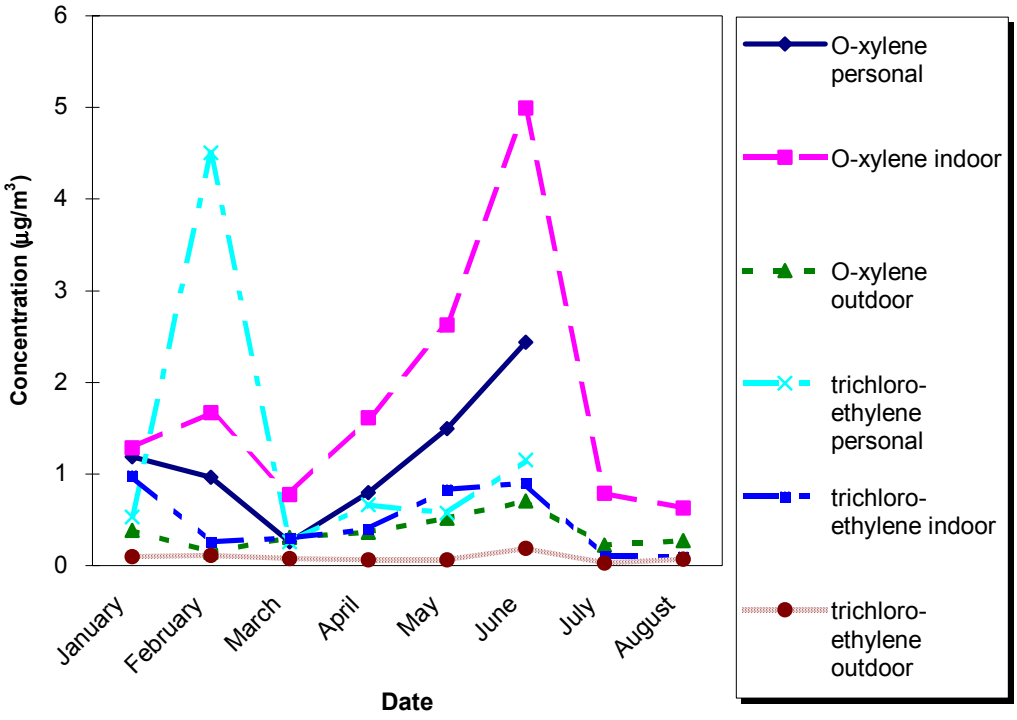

Figure IV.1.5C. New Albany Comparison of Indoor Outdoor and Personal Monthly Averaged VOC Levels.

Weekend

Figures IV.1.6A, -B, and -C show weekday and weekend concentrations at each site for a typical sample result, o-xylene. What seems notable is the similarity between the concentrations regardless of site. For this chemical and most others, the location variable (rural, suburban, and urban) had no major impact on VOC concentration. Weekend levels were not consistently higher or lower than weekday concentrations.

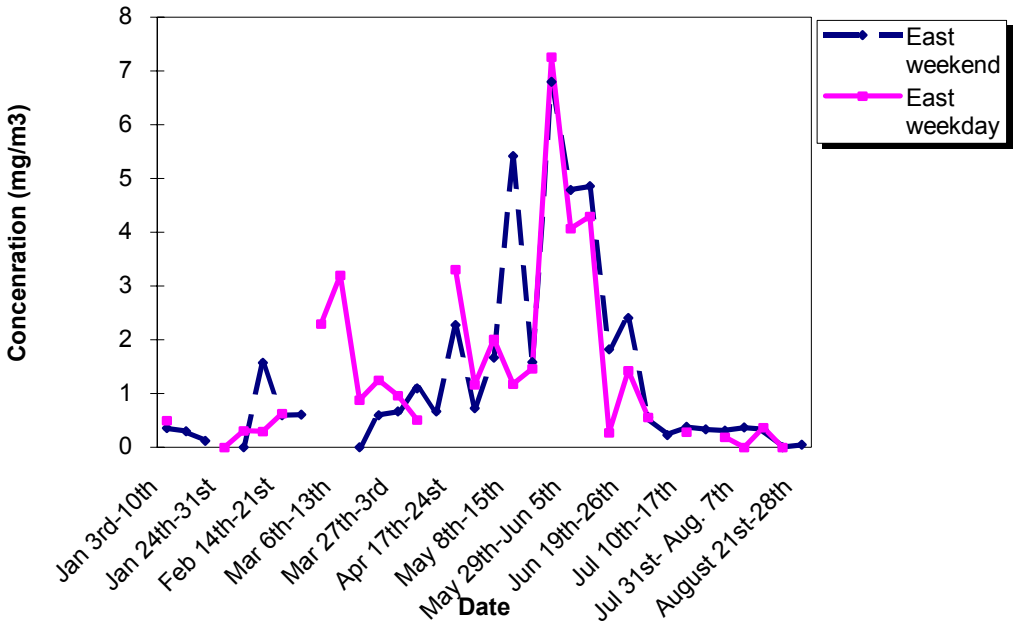

Figure IV.1.6A. Weekday and Weekend Comparison of O-xylene Concentrations at Athens

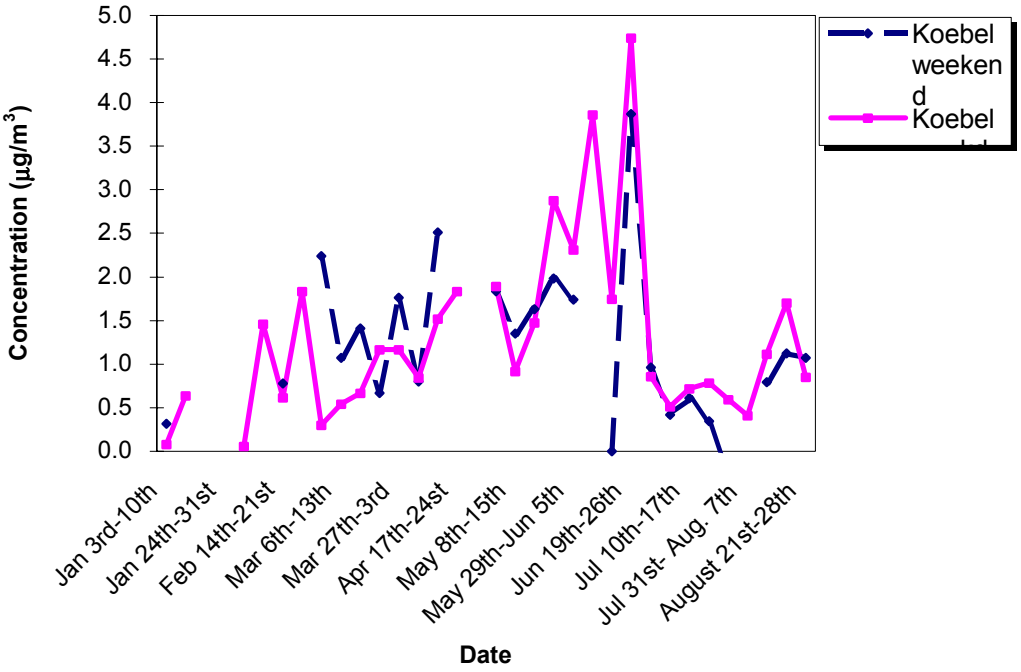

Figure IV.1.6B. Weekday and Weekend Comparison of O-xylene Concentrations at Koebel School

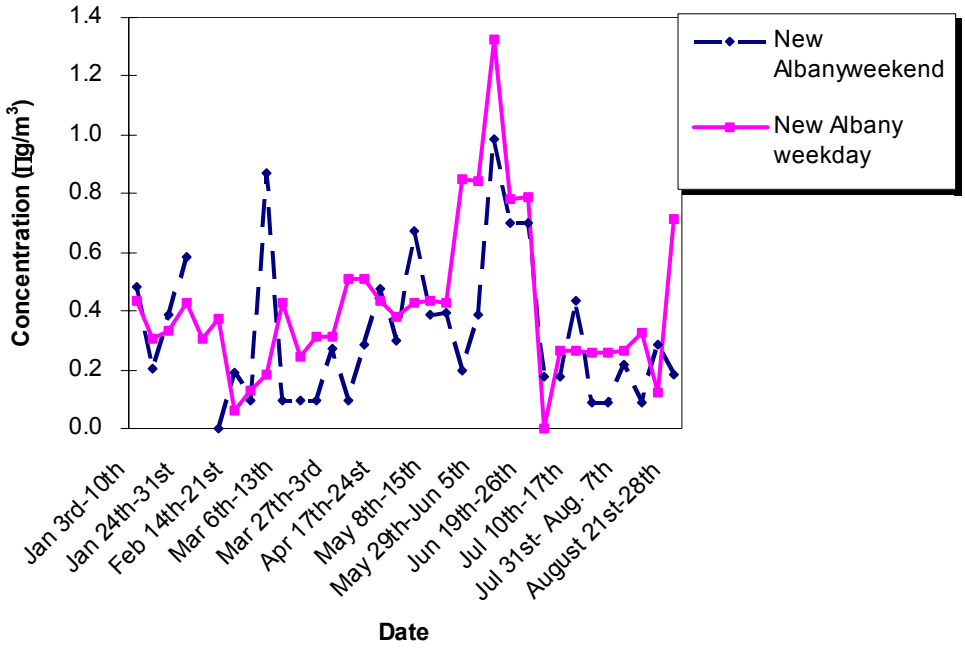

Figure IV.1.6C. Weekday and Weekend Comparison of O-xylene Concentrations at New Albany

Regional Geographical Variation

A higher percentage of samples with detectable VOC levels was found in Los Angeles than in Elizabeth/Bayonne, NJ.[61] For the eight compounds shared by this study and those two locations (o-xylene, m,p-xylenes, m,p-dichlorobenzenes, tetrachloroethylene, ethylbenzene, carbon tetrachloride, trichloroethylene, and styrene), the Ohio median data from New Albany show overall lower VOC measures as compared with Los Angeles summertime data (Tables IV.1.14A and -B). This same relationship held for median Ohio concentrations relative to the New Jersey summertime study sites. New Albany was chosen for comparison because its designation as a suburban site is most similar to the Los Angeles and New Jersey sites. Only two compounds from Region V data [62] are applicable to this geographic comparison (tetracholoroethylene and trichloroethylene). As can be seen from Tables IV.1.14A and –B, the Ohio values are very similar with the values reported for the USEPA Region V for trichloroethylene indoors and significantly lower for the other comparisons.

As demonstrated earlier in Table IV.1.8, in 9 of 13 chemical specific indoor comparisons, this study found higher percentages of detectable VOCs than did the Kanawha Valley study[63], and 13 of 13 such comparisons were greater than in the TEAM evaluations of Pellizzari.[64] This study found higher outdoor concentrations in all cases as compared to both the KV and Pellizzari work. Differences in methodology have already been noted between the three studies, as has the issue with elevated blanks for benzene. It is presumed that the analytical differences account for the observed higher levels of speciated VOCs in this study compared to the other two studies, and that the differences are not attributable to geographic differences. Indeed, since the center of the KV study was only 60-130 nautical miles from the Ohio study sites, large outdoor differences would not be expected. This is in accord with the conclusion of Pellizzari[65] that no statistically significant different concentrations were measured in their study of heavily industrialized and control locations.

Separate comparisons of our study results with other New Jersey data for geographic variation is not possible and does not appear necessary, as all study locations in that report were taken from just three homes in Elizabeth and Bayonne, NJ.[66] Furthermore, it appears that these same data may have been included in Pellizzari's report.

Table IV.1.14A. New Albany Concentrations[a] versus Los Angeles, New Jersey Summer and Region V. (Indoor)

Compound	LA Summer	NJ Summer	Region V	New Albany
O-xylene	2.6	5.9		1.18
m & p-xylene	8.2	14		2.06
1,3-dichloro-benzene	1.0	2.6		5.61
tetrachloroethylene	1.7	4.7	1.9	0.27
ethylbenzene	2.2	5.4		1.18
carbon tetrachloride	.71	1.4		0.78
trichloroethylene	.51	3.9	0.56	0.66
styrene	.60	1.8		0.07

[a] all values in ug/m^3

Table IV.1.14B. New Albany Concentrations[a] versus Los Angeles, New Jersey Summer and Region V. (Outdoor)

Compound	LA Summer	NJ Summer	Region V	New Albany
o-xylene	2.1	3.4		0.31
m & p-xylene	7.8	9.0		0.39
1,3-dichloro-benzene	.72	1.2		0.16
tetrachloroethylene	1.3	1.8	1.2	0.27
ethylbenzene	2.0	2.5		0.30
carbon tetrachloride	.63	.97		0.80
trichloroethylene	.11	1.4	0.32	0.07
styrene	.57	.44		0.00[b]

[a] all values in ug/m^3

[b] This value indicates a concentrations less than the limit of detection

VOC and PM 2.5 Correlations

For the majority of chemicals in this study, there is no, or only slight, correlation between their concentrations and $PM_{2.5}$. This finding is summarily illustrated in Figure IV.1.7, comparing $PM_{2.5}$ with all VOCs (TVOCs).

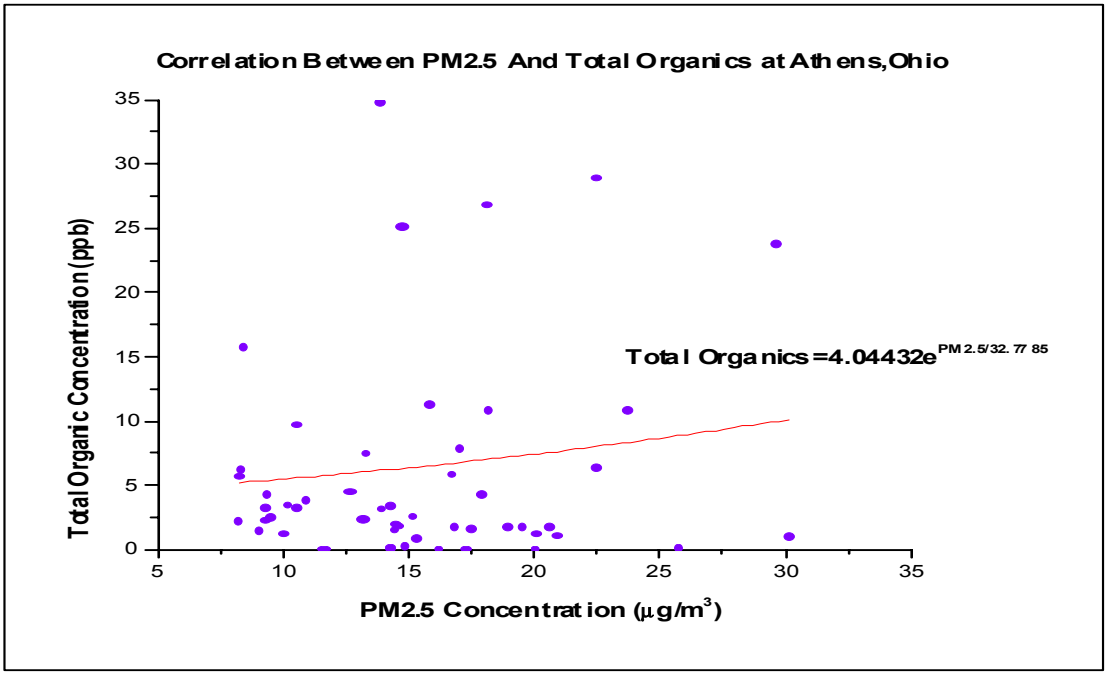

Figure IV.1.7. TVOC and $PM_{2.5}$ Relationship

One notable exception to the overall TVOC and speciated VOC trend is that of benzene and $PM_{2.5}$. As in Figure IV.1.8, there is an increase in this particular VOC with particulate concentration. It is tempting to attribute this association to fuels but no other such relationship was seen with other fuel constituents. Chemically related species with similar chemical properties include the xylenes, where no such trend was detected.

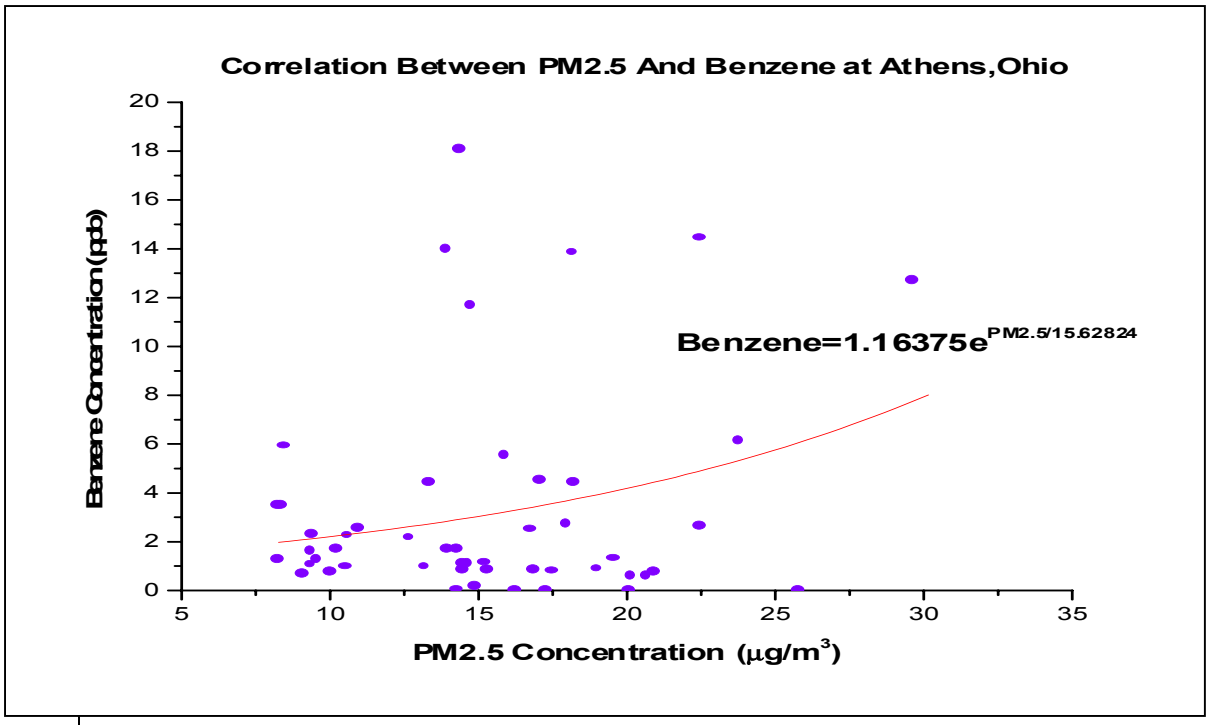

Figure IV.1.8. Benzene and $PM_{2.5}$ Relationship

SUMMARY

Indoor, outdoor, and personal concentrations of 45 volatile organic compounds were simultaneously assessed in separate semi-rural, suburban, and inner city schools in Ohio over an eight-month period. Samples were collected with passive dosimeters analyzed by gas chromatography and mass spectrometry.

Results showed overall levels of exposures in the parts per billion range with rare excursions approaching parts per million. Indoor concentrations typically exceeded outdoor levels, and personal exposures were generally the highest of the three levels analyzed. Of the three locations studied, it was found that the rural setting had the highest TVOC levels. This was unexpected and contradicts the intuitive expectation that the inner city site, with ostensibly greater local emissions, would contain the highest levels of TVOCs. This finding indicates that location may not always determine the concentration of VOCs present at a site, and that local variability may play a greater role in contaminant levels present. This study further confirms earlier work showing

that indoor and personal sample VOC concentrations are higher than outdoor concentrations.

Many studies have examined VOC concentrations, but this study is one of a very few to examine ambient and personal VOC concentrations in elementary schools. This work is also notable in that it employed a passive dosimeter for the assessment of these low-level organic contaminants. Despite difficulties with elevated background concentrations of benzene on some dosimeters, passive dosimeters show promise for ambient air monitoring.

Because of the success of this study in using passive dosimeters to assess indoor air quality, further work to explore the utility of this methodology should be considered. Compared with conventional methods, passive dosimeters are much easier to deploy and return from field sampling locations, have high accuracy and versatility, low unit cost, and no maintenance expenses. Passive dosimeter sampling can be initiated as quickly as dosimeters can be provided to the study site, and sampling can be carried out by laypersons with virtually no scientific training. For all these reasons, research aimed at establishing passive dosimeters as primary ambient air pollution monitors for VOCs should be considered.

NOTES

1. P. J. Lioy, L. Wallace & E. O. Pellizzari, Indoor/outdoor, and personal monitoring and breath analysis relationship for selected volatile organic compounds measured at three homes during New Jersey TEAM – 1987; *Journal of Exposure Analysis and Environmental Epidemiology* 1.1(1991):45-61.

2. E. D. Pellizzari, T. D. Hartwell, R. L. Perritt, C. M. Spaeacino, L. S. Sheldon, H. S. Zelon & R. W. Whitmore, Comparison of indoor and outdoor residential levels of volatile organic chemicals in five U.S. geographic areas; *Environment International* 12 (1986): 619-623; E. D. Pellizzari, K. Perritt, T. D. Hartwell, L. C. Micheal, C. M. Sparacino, L. S. Sheldon, R. Whitmore, C. Leninger, H. Zelon, W. Handy & D. Smith, *Total exposure assessment methodology (TEAM) study: Elizabeth and Bayonne, New Jersey, Devils Lake, North Dakota and Greensboro, North Carolina*. (Washington, DC: U.S. Environmental Protection Agency, 1987) A/600/6-87/002b.

3. E.D. Pellizzari, R.L. Perritt, & C.A. Clayton, National human exposure assessment survey (NHEXAS): exploratory survey of exposure among population subgroups in EPA Region V; *Journal of Exposure Analysis and Environmental Epidemiology* 9 (1999): 49-55; B. Seifert, K. Becker, K. Hoffmann, C. Krause & C. Schulz, The German environmental survey 1990/1992 (GerES II): a representative population study, *Journal of Exposure Analysis and Environmental Epidemiology* 10 (2000): 103-114; S.M. Gordon, P.J. Callahan, M.G. Nishioka, M.C. Brinkman, M.K. O'Rourke, M.D. Lebowitz, and D.J. Moschandreas, Residential environmental measurements in the National Human Exposure Assessment Survey (NHEXAS) pilot study in Arizona: preliminary results for pesticides and VOCs; *Journal of Exposure Analysis and Environmental Epidemiology* 9 (1999): 456-470; R.D. Edwards, J. Jurvelin, K. Koistenen, K. Saarela, & M. Jantunen, VOC source identification from personal and residential indoor, outdoor, and workplace microenvironment samples in EXPOLIS-Helsinki, Finland; *Atmospheric Environment* 35 (2001):4529-4841.

4. M. A. Cohen, P. B. Ryan, Y. Yanagisawa & J. D. Spengler, Indoor/outdoor measurements of volatile organic compounds in the Kanawha Valley of West Virginia, *Journal of the Air Pollution Control Association* 39 (1989): 1086-1093.

5. R.D. Edwards, J. Jurvelin, K. Saarela, & M. Jantunen, VOC concentrations measured in personal samples and residential indoor, outdoor, and workplace microenvironments in EXPOLIS-Helsinki, Finland; *Atmospheric Environment* 35 (2001):4531-4543.

6. E.D. Pellizzari, D.J. Smith, C.A. Clayton, L. Michael, & J.J. Quackenboss, An assessment of the data quality for NHEXAS-Part I: exposure to metals and volatile organic chemicals in Region 5; *Journal of Exposure Analysis and Environmental Epidemiology* 11 (2001): 140-154; Seifert et al., The German environmental survey; Gordon et al., Residential environmental measurements.

7. J. D. Mobley & S. Shaver, *Air Toxics Monitoring Concept Paper*. (Washingon, DC: Office of Air Quality Planning and Standards, USEPA, 1999).

8. I bid.

9. J. V. Bruckner & William B. Well, Biological factors which may influence an older child's or adolescent's response to toxic chemicals, *Regulatory Toxicology and Pharmacology*, 29 (1999): 158-164.

10. I bid.

11. L. Molhave, B. Bach & O. F. Pedersen, Human reaction to low concentrations of volatile organic compounds *Environmental International* 12 (1986): 167-175.

12. G. Hoek and B. Brunekreef, Effects of low-level winter air pollution concentrations on respiratory health of Dutch children, *Experimental Research* 64 (1994): 136-150.

13. B. Seifert, W. Mailahn, C. Schulz & D. Ullrich, Seasonal variation of concentrations of volatile organic compounds in selected German homes, *Environment International* 15 (1989): 397-408; R. Pristas. Benzene in air—organic vapor monitors versus charcoal tubes, *American Industrial Hygiene Association* 52. 7 (1991); 297-304.

14. M.T. Morandi, T.H. Stock, C.-W. Chung & M. Afshar, Personal exposures to toxic air pollutants; Contract Final Report, Mickey Leland National Urbran Air Toxics Research Center, Houston, TX. 1998.

15. C-W. Chung, M. T. Morandi, T. H. Stock & M. Afshar, Evaluation of a passive sampler for volatile organic compounds at ppb concentrations, varying temperatures, and humidities with24-h exposures. 1. description of exposure chamber system, *Environmental Science and Technology* 33 (1999); 3661-3665.

16. T. H. Stock, M. T. Morandi, C-W. Chung and M. Afshar, Feasibility study: laboratory evaluation and field method comparison. *NUATRC Study of Personal Exposure to Toxic Air Pollutants* (Jan. 19th, 1996) 1-54.

17. Joseph G. Montalvo Jr., Total elemental content of passive personal monitors, *American Industrial Hygiene Association Journal* 40 (1979): 1046-1054.

18. W. K. Fowler, Fundamentals of passive vapor sampling. *American Laboratory*, (December 1982): 80-87.

19. Montevalvo, Total element content.

20. C-W Chung, M. T. Morandi, T. H. Stock & M. Afshar, Evaluation of a passive sampler for volatile organic compounds at ppb concentrations, varying temperatures, and humidities with 24-h exposures. 2. sampler performance, *Environmental Science and Technology* 33 (1999): 3666-3671.

21. Montevalvo, Total element content.

22. I bid.

23. Fowler, Fundamentals of passive vapor sampling.

24. E. H. Daughtrey Jr., K. D. Oliver, J. R. Adams, W. A. Kronmiller and W. A. McClenny, A comparison of sampling and analysis methods for low-ppb levels of volatile organic compounds in ambient air, *Journal of Environmental Monitoring* 3 (2000): 166-174.

25. Morandi et al., Personal exposures.

26. Stock et al., Feasibility study.

27. Cohen et al., Indoor/outdoor measurements.

28. Stock et al., Feasibility study.

29. I bid.

30. *HP GC-MSD Chemstation and Instrument Operation Volume 2. Manual Part No. H4043-90000*. (Atlanta, GA: Hewlett-Packard Company, 1998) 91.

31. Minnesota Mining and Manufacturing, Inc. *3M Technical Data Bulletin # 1028, Organic vapor monitor sampling and analysis*. (1999).

32. Cohen et al., Indoor/outdoor measurements.

33. Pellizzari et al., Total exposure assessment methodology.

34 Pellizzari et al., An assessment of the data quality.

35. Lioy et al., Indoor/outdoor and personal monitoring.

36. Pellizzari et al., Total exposure assessment methodology.

37. Cohen et al., Indoor/outdoor measurements.

38. Gordan et al., Residential environmental measurements.

39. C.A. Clayton, E.D. Pellizzari, R.W. Whitmore, R.L. Perritt, & J.J. Quackenboss, National human exposure assessment survey (NHEXAS): distributions and associations of lead, arsenic and volatile organic compounds in EPA Region 5; *Journal of Exposure Analysis and Environmental Epidemiology* 9 (1999): 381-392.

40. Seifert et al., The German environmental survey.

41. Edwards et al., VOC concentrations measured.

42. L. Molhave, Z. Lui, A. H. Jorgensen, O. F. Pedersen, and S. K. Kjaergaard, Sensory and physiological effects on humans of combined exposures to air temperatures and volatile organic compounds, *Indoor Air* 3(1993): 155-169.

43. J. Ten Brinke, *Development of new VOC exposure metrics and their relationship to sick building syndrome symptoms* (Berkeley, CA: Lawrence Berkeley National Laboratory Report, LBL-37652: 1995).

44. Molhave et al., Sensory and physiological effects; K. Andersson, J. V. Bakke, O. Bjorseth, C. G. Bornehag, G. Clausen, J. K. Hongslo, M. Kjellman, S. Kjaergaard, F. Levy, L. Molhave, S. Skerfving & J. Sundell, J., TVOC and health in non-industrial indoor environments: report from a Nordic Scientific Consensus Meeting at Langholmen in Stockholm, *Indoor Air* 7(1997): 78-91.

45. G. W. Siple, EPA's focus on IAQ. *Environmental Protection* (December 1999): 28-31.

46. R. Kostiainen, Volatile organic compounds in the indoor air of normal and sick houses, *Atmospheric Environment* 29(1995): 693-702.

47. C. J. Weschler, H. C. Shields and D. Rainer, Concentrations of volatile organic compounds at a building with health and comfort complaints, *American Industrial Hygiene Association Journal* 51(1990): 261-268.

48. *29 Code of Federal Regulations. Subpart Z—Toxic and Hazardous Substances*. 1910.1000 Air Contaminants. Revised July, 2001.

49. American Conference of Governmental Industrial Hygienists. *2001 TLVs and BEIs. Threshold limit values for chemical substances and physical agents*. (Cincinnati, OH: ACGIH, 2001).

50. M. Hodgson, H. Levin & P. Wolkoff, Volatile organic compounds in indoor air, *Journal of Allergy and Clinical Immunology* 94 (1994): 296-303.

51 Stock et al., Feasibility study.

52. Claton et al., National human exposure assessment survey.

53. Mobley and Shaver, *Air Toxics Monitoring*.

54. P. A. Scheff, V. K. Paulius, S. W. Huang & L. M. Conroy, Indoor air quality in a middle school, part I: use of CO_2 as a tracer for effective ventilation, *Applied Occupational and Environmental Hygiene* 15(2000): 824-834.

55. Lioy et al., Indoor/outdoor and personal monitoring.

56. Seifert et al., Seasonal variation of concentrations.

57. C. Krause, W. Mailahn, R. Nagel, C. Schulz, B. Seifer & D. Ullrich, Occurrence of volatile organic compound in the air of 500 homes in the Federal Republic of Germany; In: Seifert, B. et al., eds., *Proceedings 4th International Conference on Indoor Air Quality and Climate (INDOOR AIR '87),* (West Berlin: August 17-21, 1987), Vol. 1, 102-106.

58. C. W. Lewis, Source of air pollutants indoors: VOC and fine particulate species, *Journal of Exposure Analysis and Environmental Epidemiology* 1(1991): 31-44.

59. M-L. Chen, M-S Uang and I-F Mao, Vaporizing characteristics of mixed solvents in indoor environment, *The Science of the Total Environment* 205 (1997): 129-135.

60. Pellizzari et al., Total exposure assessment methodology.
61. I bid.
62. Pellizzari et al. National human exposure assessment survey.
63. Cohen et al., Indoor/outdoor measurements.
64. Pellizarri et al., Total exposure assessment methodology.
65. I bid.
66. Lioy et al., Indoor/outdoor and personal monitoring.