Houston Exposure to Air Toxics Study (HEATS)

Final Report

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ABSTRACT

The main objective of the Houston Exposure to Air Toxics Study (HEATS) was to determine if personal exposures to a group of selected hazardous pollutants (HAPS) for adults residing in the Ship Channel area of Houston, Harris County, TX, that has a high density of point source emissions for these contaminants, are higher than those experienced by residents of the Aldine area, located in the same county, where few such sources are present. Indoor, outdoor, and personal concentrations for a group of volatile organic compounds (VOCs) of indoor and outdoor origin were monitored for a random sample of adults in each area, selected based on sociodemographic characteristics to be representative of the general population of non-smoking households. Seventy-eight adults were recruited from a corresponding number of houses, as well as 35 children ages 6 to 20 years, also one per household. Forty of the adults resided in the Ship Channel area, and 38 in Aldine. In addition, VOC concentrations were sampled at the closest ambient monitoring site to each residence during personal monitoring days. VOC concentrations and exposures were monitored using passive devices, the main one being the Perkin Elmer (PE) tube with Carbopack X together with organic vapor monitors (OVMs) for a fraction of the indoor samples. In addition, air exchange rates (AERs) were calculated and information on household and participant characteristics, indoor/outdoor time location budgets, and personal activities were also collected. The study also included administration of questionnaires related to health symptom patterns and environmental risk perception. The data collection effort was marred by difficulties in enrollment and retention of participants, and difficulties in the analysis of the PE-Tube sampler. However, hypotheses testing results using statistical weights to partially compensate for lower than expected recruitment and enrollment rates allow some conclusions to be derived. As with other studies of this type, personal exposures were higher than residential indoor or outdoor concentrations in both areas. Although there were no statistically significant differences in personal exposures between the two areas, ambient fixed site measurements were higher in the Ship Channel for several compounds with outdoor sources, consistent with the higher emission density in that area. Although personal exposures compared by some participant characteristics such as work status, or residential characteristics such as air exchange rates, were statistically different, inclusion of these variables did not alter the results of hypothesis testing. Likewise, the patterns of self-reported health symptoms were comparable in the two areas, with the exception of a higher prevalence of dermal conditions (eczema) in children, and skeletal-related symptoms (bone pain and bone joint problems) in adults in the Ship Channel. Differences in risk perception were also unremarkable, except for greater confidence in television as a source of information among Ship Channel residents, as well as higher trust that city/county health departments, and private industry are carrying out their missions of protecting people from health risks. The main conclusion of the study is that, based on the analysis of the data collected, personal exposures in these two areas are similar and do not appear to reflect the differences in the type and density of point source emissions or the ambient concentrations as measured at fixed sites in each of the areas.

GLOSSARY

AER	Air exchange rate, i.e., the rate of exchange between outdoor air and indoor air in a home (hr^{-1})
Alion	Alion Laboratories, Inc. EPA contractor for the DEARS.
ASPEN	Assessment System for Population Exposure Nationwide
Auto-GC	Automatic gas chromatograph that samples concentrations of volatile organic compounds on a quasi-continuous basis. The instruments are use at some TCEQ fixed sites.
CATs	capillary absorption tubes
DEARS	Detroit Exposure and Aerosol Research Study
DNSH	dansyl hydrazine
EER	Division of Exposure, Epidemiology, and Risk of Harvard School of Public Health
EHCMA	East Harris County Manufacturers' Association
EPA	Environmental Protection Agency
EPA-ORD	Office of Research and Development of US EPA
Fixed site (Central site)	Monitoring sites used for regulatory compliance
Fixed site concentration	Concentration monitored at any of the fixed sites (or Central sites)
GC/MS	gas chromatography / mass spectrometry
GED	General Educational Development
GIS	geographic information systems
GPS	global positioning systems
HAPs	Hazardous air pollutants according to EPA definition
HCAD	Harris County Appraisal District
He	helium
Indoor concentration	Concentration measured inside a residence
MDL	method detection limit
MTBE	methyl *tert*-butyl ether
NHANES	National Health and Nutritional Examination Survey
NHEXAS	National Human Exposure Assessment Survey
NIH	National Institute of Health
NUATRC	Mickey Leland National Urban Air Toxics Research Center

Outdoor concentration	Concentrations measured outdoors, close to a residence included in the study
OVM	3M organic vapor monitor
PCA	principal components analysis
PDCH	perfluoro1,3-dimethylcyclohexane
PE tube	Perking Elmer sampling tube
Personal concentration	Concentration measured in the breathing zone of individuals
PFT	perfluorocarbon tracer
PMCH	perfluorinated methylcyclohexane
QA/QC	quality assurance / quality control
RIOPA	Relationship of Indoor, Outdoor and Personal Air (study)
RTI	Research Triangle Institute International
SOP	Standard operating procedure
SPSS	Statistical Package for the Social Sciences
TCEQ	Texas Commission for Environmental Quality
TDS	thermal desorption system
TEAM	Total Exposure Assessment Methodology
TERC	Texas Environmental Research Consortium
TIGER	Topologically Integrated Geographic Encoding and Referencing (system)
TRI	Toxic Release Inventory
UTMB	University of Texas Medical Branch
UTSPH	University of Texas School of Public Health.
VOC	volatile organic compound

1. INTRODUCTION

1.1. Background

In recent years, there has been increasing concern among environmental health professionals, regulators and citizens in the Houston area, and nationally, regarding the possible health impact of urban ambient levels of hazardous air pollutants (HAPs). Special concern has been focused on the influence of emissions from refineries and petrochemical facilities in the highly industrialized Ship Channel area of Houston. Wide-spread community recognition of this concern occurred with the January 2005 publication of a Houston Chronicle series (Houston Chronicle, 2005) reporting outdoor concentrations of HAPs monitored in a neighborhood (Manchester) near the Ship Channel. The Houston Chronicle series was well publicized and raised the awareness level of citizens, as well as local, state, and federal officials regarding the potential health implications of these concentrations for the communities affected. This increased awareness and concern led to two expert-panel evaluations of Houston-area air toxics, one requested by the Mayor of Houston (Mayor's Task Force, 2006; Sexton et al., 2007) and the other sponsored by a local endowment (Rice University, 2006). Two subsequent studies have evaluated increased cancer risks in the Houston area associated with ambient levels of air toxics estimated from the U.S. EPA ASPEN model (Linder et al., 2008; Whitworth et al., 2008). None of these evaluations included estimates of personal exposures to HAPs, that is, measurements of concentration in the breathing zone of individuals that relate more closely to inhaled dose.

Until the present study, only one earlier project provided systematically collected residential indoor, outdoor and personal exposure data for any HAPs either in the Ship Channel communities or other areas in Houston or the rest of the state. The Houston component of the Relationship of Indoor, Outdoor and Personal Air (RIOPA) Study (RIOPA-Texas) (Weisel et al., 2005; Weisel et al., 2006) included 106 homes, with approximately 75% located within a half kilometer of major petrochemical facilities in the Ship Channel area and along the Hwy 225 (La Porte Freeway) industrial corridor. Consistent with findings from other comparable investigations, the results from RIOPA indicated that residential indoor air contributions to personal exposures to HAPs are higher than corresponding airborne concentrations measured in residential outdoor air or at regulatory network fixed monitoring sites. Unlike outdoor concentrations, residential indoor air concentrations correlate significantly with personal air concentration measurements. A recent comparative assessment of the cancer risk associated with personal exposures to HAPs measured in RIOPA-Texas (Hun et al., 2009) indicates that - despite the higher levels of personal exposure to HAPs such as benzene compared to ambient concentrations - the major contributors to cancer risk are formaldehyde and 1,4-dichlorobenzene, two HAPs of largely indoor origin. These results are consistent with those of other studies using a similar approach (Sax et al. 2006). However, the relative contribution of outdoor concentrations of HAPs to residential and personal air concentrations and the associated health risks in communities located in the vicinity of major sources as compared to those with few or no such sources is not well characterized.

Special concern has been focused on 1,3-butadiene, since levels monitored by the Texas Commission on Environmental Quality (TCEQ) at a monitoring site near Manchester during the first half of the current decade were consistently higher than at any other site in the Houston area,

suggesting the influence of nearby industrial sources. However, the sampler used in RIOPA and in the Houston Chronicle series investigations (i.e., the 3M Organic Vapor Monitor) is not suitable for detecting community-level concentrations of butadiene in a reliable manner. In addition, the RIOPA-Texas study design included a convenience sample of homes all located within an area potentially influenced by major outdoor sources of HAPs, so the findings cannot be extrapolated to the population residing in the area or comparisons used to derive conclusions about the impact from these sources in locations with few or no such sources. Thus, the aforementioned concern about ambient levels of HAPs, especially 1,3-butadiene, in areas of Houston located in very close proximity to major industrial point sources, the more fundamental concern about the impact on personal exposures, and the design limitations of the RIOPA-Texas study, were the stimuli for the Houston Exposure to Air Toxics Study (HEATS) described in this report. HEATS was financially supported by a consortium of agencies and other organizations, U.S. EPA, TCEQ, Mickey Leland National Urban Air Toxics Research Center (NUATRC) , Texas Environmental Research Consortium (TERC), and the East Harris County Manufacturers' Association (EHCMA). The City of Houston and Harris County provided non-financial support. The funds were awarded to NUATRC who administratively managed and coordinated the study. NUATRC contracted with the University of Texas, School of Public Health (UTSPH) for the design and implementation of the overall study. The UTSPH in turn subcontracted with three other organizations for design and implementation of three subcomponents of the study including:

1) RTI International (RTI) for population sample selection and recruitment (Drs. Roy Whitmore and Michael Phillips).
2) University of Texas Medical Branch (UTMB) for design and implementation of a Health Symptom Survey and Risk Perception Survey (Dr. Sharon Petronella and Ms. Michelle Cravey)
3) Harvard School of Public Health, EER Program, for providing sources and samplers and their analysis for estimating residential air exchange rates (Mr. Scott Forsberg).

HEATS thus represents a unique collaborative project that includes public (governmental and non-governmental), private and academic organizations.

1.2. Specific Aims and Hypotheses

1.2.1. Overview of Initial Study Design

The main objective of HEATS was to determine if the personal exposures to a select group of HAPs experienced by populations residing in the Ship Channel area of Houston, which has a high density of point source emissions of these air pollutants, are higher than personal exposures experienced by residents of the Aldine area of Houston that has few such sources. The two areas (Figures 1 and 2) were selected based on the density of Toxic Release Inventory (TRI) sources, and clear differences in air toxics ambient concentrations as measured at fixed monitoring sites. The overall approach included measurement of residential indoor, outdoor and personal adult (and child, if applicable) air concentrations of target VOCs during each of 2, 24-hour periods planned to be approximately six months apart, with a parallel measurement at the fixed monitoring site closest to the household. Other measurements included residential

indoor/outdoor temperatures and estimates of indoor-outdoor air exchange rates during sampling days. Additional exposure-relevant data (i.e., individual and household characteristics, relevant individual and household activities during the sampling period, and participant indoor/outdoor time location during sampling event) were collected using questionnaires. Information on health symptoms and risk perception for the participant and other residents of the household was also collected using questionnaires.

As described later, the participants in the study consisted of adults (21 years of age or older) recruited as part of a sociodemographically matched, evenly dispersed probability-based population sample in each area. The initial study design targeted a total of 100 adults, randomly selected from each of 100, non-smoking households in each respective area for recruitment into the study, together with 50 children, 6 to 20 years old, also randomly selected from each household. Unfortunately, serious difficulties with recruitment and enrollment of participants, combined with the impact from a major hurricane (Ike), as discussed later, reduced the number of participating households to approximately 40 in each area.

Initially, the study included a relatively large set of VOCs and airborne carbonyl compounds that had been included in the prior RIOPA study ((Weisel et al. 2005, 2006) between 1999 and 2001. In that study, VOCs and carbonyl compounds were monitored utilizing passive sampling devices, the 3M Organic Vapor Monitor (OVM; 3M Co., St Paul, MN) and the dansyl hydrazine (DNSH)-coated C18 passive sampler developed by Zhang et al. 2000, respectively. The RIOPA study results indicated that the pattern of concentrations for most of these air contaminants was consistent with that reported in other similar studies such as the U.S. EPA Total Exposure Assessment Methodology (TEAM) studies, i.e., personal concentrations > residential indoor concentrations > outdoor concentrations (Wallace et al., 1993).

Since the OVM is not adequate for ppb-level monitoring of 1,3-butadiene, a passive sampler filled with a graphitic carbon suitable for sampling this VOC (Martin et al., 2005), Carbopack X, was used instead. Use of a badge (UltraBadge II; SKC, Inc. Eighty-Four, PA) design filled with either Carbopack X for VOCs (Strandberg et al., 2005) or dansyl hydrazine (DNSH)-coated C18 for carbonyls was attempted initially, but discontinued due to insufficient time for development and validation. This resulted in excluding carbonyls from the study and adopting a tube-type passive sampling device (PE tube) with Carbopack X (McClenny et al., 2005). This sampler has been shown to be reliable in a comparison study with canister samples (McClenny et al., 2006). The McClenny et al. sampler was employed by EPA-ORD in the Detroit Exposure and Aerosol Research Study (DEARS) for 24-hour indoor/outdoor monitoring of a suite of VOCs (McClenny et al., 2006). These changes resulted in a reduced list of target VOCs that included key chemicals of interest such as 1,3-butadiene (Table 1).

Concentrations of target air toxics were monitored with passive samplers inside and outside each residence during two separate 24-hour periods, several months apart. Simultaneously, the randomly selected participants, both adult and child if applicable, underwent personal monitoring using the same passive samplers. Additional measurements conducted during each monitoring period included indoor/outdoor temperature and relative humidity and residential air exchange rates. Other data collected using questionnaires included time-location patterns, residential and neighborhood characteristics, and household and personal activities that could impact exposures

during monitoring. Air monitoring information was obtained from the TCEQ at their fixed monitoring sites in each of the two areas. HEATS passive samplers were placed at the closest monitoring site to each home concurrently with days of personal and home monitoring. VOC concentration information from the fixed sites that have automated continuous gas chromatographic sampling systems (auto-GC) was also collected. Finally, information on health symptoms and risk perception was obtained from each participant via questionnaires administered at least two days after the personal home monitoring.

1.2.2. Aims

The aims of HEATS were to:

1. assess residential indoor and outdoor concentrations and personal inhalation exposures to a subset of HAPs for a representative sample of the population living in an area heavily impacted by industrial sources of HAPs;

2. assess residential indoor and outdoor concentrations and personal inhalation exposures for a representative sample of a sociodemographically matched population living in an area minimally impacted by industrial sources of the same HAPs;

3. evaluate whether the respective fixed site measurements of target HAPs are good indicators of community, indoor and/or personal exposures;

4. apportion the contribution of outdoor air concentrations of the targeted HAPs to residential indoor concentrations and personal exposures;

5. collect and evaluate health symptom and risk perception data for both populations.

This report does not address one of the original study aims (original Aim 6), due to temporal constraints. This aim, the exploration of the association between self-reported indicators of health status/ risk perception and personal exposures to target HAPs, will be addressed in future analyses using the hypothesis-testing methodology indicated below.

Aim 4 was addressed by using the same modeling approach employed for the RIOPA analysis, as described by Weisel et al. (2006). See sections 6.5 and 7.3.6. This aim was also partially addressed in the testing of the corresponding secondary hypothesis stated below.

1.2.2.1. Hypotheses

Hypotheses are presented as primary, secondary and exploratory under the corresponding aims. The requirements for the primary hypothesis testing are the drivers for the population sample survey design and the data plan. Secondary hypotheses can be evaluated with the data collected and are complementary to the primary hypothesis. Results from testing exploratory hypotheses cannot be interpreted as indicative of causal relationships but suggestive of potential associations that may be used to generate hypotheses for future, appropriately designed studies. Each hypothesis is shown as the null followed by the alternative.

The primary hypothesis of HEATS (to be tested under Aims 1 and 2) is:

i) $H_{0:}$ personal exposures (personal air concentrations) to TRI-reported target HAPs will be similar for both communities;

$H_{1:}$ personal exposures (personal air concentrations) to TRI-reported target HAPs will be higher in the Ship Channel as compared to the Aldine area.

The secondary hypotheses of HEATS are:

To be tested under Aims 1 and 2:

ii) H_0: fixed site ambient air concentrations of TRI-reported target HAPs will be equal in the two communities;

$H_{1:}$ fixed site ambient air concentrations of TRI-reported target HAPs will be higher in the Ship Channel as compared to the Aldine area.

iii) H_0: community-level (residential outdoor) air concentrations of TRI-reported target HAPs will be equal in the two communities;

$H_{1:}$ community-level (residential outdoor) air concentrations of TRI-reported target HAPs will be higher in the Ship Channel as compared to the Aldine area.

iv) H_0: residential indoor air concentrations of TRI-reported target HAPs will be equal in the two communities;

H_1: residential indoor air concentrations of TRI-reported target HAPs will be higher in the Ship Channel as compared to the Aldine area.

To be tested under Aim 3:

v) $H_{0:}$ fixed site concentration measurements are good predictors of community (residential outdoor) concentrations of target HAPS for each of the respective areas.

$H_{1:}$ fixed site concentration measurements are not good predictors of community (residential outdoor) concentrations of target HAPS for each of the respective areas.

vi) $H_{0:}$ fixed site concentration measurements are good predictors of indoor concentrations of target HAPS for each of the respective areas;

$H_{1:}$ fixed site concentration measurements are not good predictors of indoor concentrations of target HAPS for each of the respective areas.

vii) $H_{0:}$ fixed site concentration measurements are good predictors of personal concentrations of target HAPS for each of the respective areas;

$H_{1:}$ fixed site concentration measurements are not good predictors of personal concentrations of target HAPS for each of the respective areas.

To be tested under Aim 4:

viii) H_0: the estimated relative contribution of outdoor concentrations of HAPs of primarily industrial origin (e.g., 1,3-butadiene) to indoor air concentrations, will be the same in both communities;

H_1: the estimated relative contribution of outdoor concentrations of HAPs of primarily industrial origin (e.g., 1,3-butadiene) to indoor air concentrations will be higher in the Ship Channel as compared to the Aldine area.

The exploratory hypotheses of HEATS are:

To be tested under Aim 5:

ix) H_0: the proportion of participants reporting at least one health symptom will be the same in both communities;

H_1: the proportion of participants reporting at least one health symptom will be higher in the Ship Channel as compared to the Aldine area.

x) H_0: perception of environmental health risks (as measured by risk perception indicators) will be the same in both populations;

H_1: perception of environmental health risk (as measured by risk perception indicators) will be higher in the Ship Channel population as compared to the Aldine area.

xi) H_0: the patterns of health symptoms (i.e., symptoms associated with specific organ system functions) reported by the participants will be the same in both communities;

H_1: at least one pattern of health symptoms will be more prevalent in the Ship Channel as compared to the Aldine area.

Given the few differences identified in responses between the two areas, based on t-test comparisons, the exploratory hypotheses will be explored using more robust statistics in later analyses.

2. STUDY DESIGN

2.1. Study Areas

Harris County is clearly a leader of TRI-reportable air toxics emissions nationally. For example, according to the 2003 Toxics Release Inventory (TRI), Harris County had the highest air emissions (combined point source and fugitive) of any U.S. county for both benzene and 1,3-butadiene. However, it is recognized that the density of major industrial sources is not uniform across the county, and that there are significant differences in the impact of such sources that depend on their specific location within the county. The two areas of Harris County selected for this study were the Ship Channel Area, centered approximately 7 mi. southeast of downtown Houston, and the Aldine Area, centered approximately 10 mi. north of downtown Houston. The sizes and relative proximity of these study areas are depicted in Figure 1.

2.1.1. Rationale for Selection of Study Areas

The two areas were selected based on the differences in the number and type of TRI-reportable emission sources, similarities in sociodemographic characteristics, and the presence of at least one fixed monitoring site. The specific census tracts included in each area (Figures 1-4) were initially selected, in part, based on an analysis by the Texas Department of State Health Services that showed good matching of sociodemographic characteristics for most of these census tracks with regard to total population and important demographic characteristics such as ethnicity, age structure and income.

2.2. TRI-Reportable Emissions

Since TRI emissions data are not easily available at the census-tract level, relevant zip codes that include the initially selected census tracts were utilized to estimate the potential influence of point and fugitive industrial air emission sources in each study area. TRI sources in the following zip codes were considered for each study area: Ship Channel - 77012, 77017, 77029, 77087, 77502, 77506, and 77547; Aldine - 77016, 77032, 77037, 77039, 77050, 77060, 77076, and 77093. For each of these zip code areas, both point source and fugitive air emissions were tabulated for compounds which are both HEATS target compounds and which had reportable emissions for 2003.

For the Ship Channel Study Area, there were reportable emissions of target compounds for only four zip codes: 77012, 77017, 77506 and 77547. Emissions for these four zip codes are shown in Table 2a. For the Aldine Study area, there were reportable emissions of target compounds for only two zip codes: 77037 and 77039 (see Table 1b). It is clear from an inspection of these data that there are considerable differences in both the number of TRI-reportable target compounds and the magnitudes of their emissions, when comparing the two study areas. There were no TRI reportable emissions of 1,3-butadiene in the Aldine area, while a total of 149,973 pounds of air

emissions of this compound were reported in the Ship Channel. The 2003 TRI emissions report indicated that Harris County was first in total point and fugitive emissions of 1,3-butadiene, followed by Jefferson and Brazoria counties, also located in the upper Gulf Coast of Texas. Of the top 100 facilities with reportable TRI air emissions of butadiene in 2003, the fourth, thirtieth, fifty-sixth, and seventy-third are located within the zip codes targeted by HEATS in the Ship Channel. Harris County was also the top county for fugitive and point source emissions to air of benzene, with most emitting facilities located in Houston's east side industrial corridor; the nation's sixteenth highest-emitting TRI facility is located in a Ship Channel zip code targeted by HEATS. Reportable TRI air emissions for benzene in the Aldine area represented approximately 0.2 % of the corresponding benzene emissions to air in the HEATS Ship Channel target areas. In 2003 there were only five TRI facilities in Aldine with reportable TRI target HAPs emissions. Of these, the highest emissions to air were for styrene which constituted approximately 47% of the emissions in HEATS Ship Channel target areas. The preponderance of 2003 styrene emissions to air in the Ship Channel was from the 22nd largest source in the U.S. MTBE TRI emissions to air in the target Aldine areas represented approximately 4% of the corresponding emissions in the Ship Channel target area. The total reportable air emissions of target compounds in the Aldine area are less than 16% of the corresponding total emissions in the Ship Channel area. Reportable air emissions of five target compounds in the Ship Channel area each exceed 1% of the total national air emissions (1,3-butadiene is 7.6%). Thus, on the basis of air emissions from TRI facilities, there is a much greater impact of industrial sources of air toxics on the Ship Channel area, relative to the Aldine area. This, combined with the good matching of these areas on socioeconomic factors, supported their selection as appropriate study areas for HEATS.

2.3. Sociodemographic Characteristics of Population

As indicated earlier, census tracks in each area (Figures 3-4) were initially selected based on similarity of important sociodemographic characteristics. Table A-1 (Appendix A) shows the demographic and socioeconomic summary statistics for the Ship Channel and Aldine study areas derived from Census 2000 data. The data show that for most of the census tracks, the sociodemographic characteristics of the populations in each of the areas are comparable with regard to total population and important demographic characteristics such as ethnicity, age structure and income.

2.4. Fixed Ambient Monitoring Sites

The Houston metropolitan area has the largest and longest operating ambient monitoring network for HAPs of any metropolitan area in the U.S. As of 2005, available sampling sites within the two selected areas, included:

1) Two sites (see Figures 5a-b): Milby Park, and Clinton Drive) collecting 24-hr canister samples of approximately 100 VOCs every 6th day. In addition to these three sites that have been historically monitored for VOCs in this manner, as of May 27, 2005 TCEQ has added an additional canister sampling system within the Manchester neighborhood (Figure 5d);

2) Automated Gas Chromatograph (auto-GC) sampling (40-minute sample collected every hour) at the Milby Park, Clinton Drive, and Cesar Chavez High School monitoring sites (see Figure 5d) for approximately 70 VOCs;

3) One site with every sixth day canister sampling for VOCs at Aldine (see Figure 5e).

The differences in reported TRI emissions to air are partially reflected in concentrations measured at ambient monitoring sites in each of the two areas. For example, Table 3 presents the 2004 summary statistics for selected HAP outdoor concentrations monitored by every sixth day, 24-hour canister sampling at the Aldine and Milby Park fixed sites. Results from a Wilcoxon sign rank test analysis of these data indicate that concentrations of 1,3-butadiene, chloroform, ethylbenzene, and styrene were considerably higher at Milby Park ($p \leq 0.000$), moderately higher for MTBE ($p \leq 0.019$) and elevated but borderline statistically significant for benzene ($p \leq 0.059$.) A preliminary principal components analysis (PCA) of these data using orthogonal (VARIMAX) rotation shows a factor that is uniquely and highly correlated with butadiene and styrene for Milby Park. This factor explains approximately 56% and 74% of the butadiene and styrene ambient concentration variance, respectively, at this fixed site. There is no clear identifiable pattern of common variance relationships in the data at the Aldine site, where styrene loadings are distributed over three different factors. Therefore, there is no evidence for a unique major point source of butadiene and styrene in Aldine, as there is in the Ship Channel area.

In summary, the TRI air emission data, the comparative differences in outdoor measurements at fixed sites in each area, and the preliminary PCA results show that there are differences in outdoor source emissions between the two areas, and that the concentrations and common variance patterns of some HAP concentrations reflect strong contributions from industrial sources in the Ship Channel areas targeted by HEATS.

3. POPULATION SAMPLE SELECTION

Achieving the main objective of the HEATS study required recruitment of a random sample of the adult population in each of the selected areas, so that findings derived from the population sample could be extrapolated to the population. Both the population sample selection design and implementation of recruitment were subcontracted to RTI International under the direction of Dr. Roy Whitmore and Dr. Mike Phillips in close collaboration with the UTSPH investigators via an initial meeting in Houston and subsequent telephone conferences. The criteria for eligibility included:

a. Non-smoking adult residing in a household with no other smokers.
b. Not planning to change residence within a year of recruitment to the study.
c. Willing to commit to the study protocols for two separate periods approximately six months apart (including placement of AER tracer sources in advance of actual monitoring, the 24-hour monitoring period, responding to all the exposure-related questionnaires, and responding to the health and risk perception questionnaires at least two days after the end of the monitoring period.)

d. If working outside the home, allowed by her/his employer to wear the passive monitors while at work. This criterion was modified to allow monitoring during non-working days due to difficulties in recruitment.

A detailed description of population sample size estimates at various levels of statistical power, expected percentages of non-eligible households or participants based on screening criteria, recruitment implementation modalities, and development of population sample weights is presented in Appendix A. Briefly, estimates of the sample sizes were derived from the 2000 Census information available for the two target areas, the differences in ambient benzene concentrations monitored in Aldine and the Ship Channel, the level and variance in personal exposure measurements of benzene made in the Houston component of the RIOPA Study, and various adjustments for eligibility, recruitment and retention. RTI also considered the limitation of resources available for the study. Based on the above considerations, and assuming a median adult benzene concentration of 3.25 $\mu g/m^3$ for the Ship Channel area and a detectable difference of 1.5 $\mu g/m^3$ between median benzene concentrations in the Ship Channel and Aldine, sample sizes between 17 (80% power) and 30 (95% power) households were estimated. Following RTI recommendations, the investigators decided to target an initial sample of 100 households per area, since assumed recruitment and retention rates were not based on local experience with randomly recruited populations, which was not available.

Recruitment was also subcontracted to RTI, under the direction of Dr. Mike Phillips. Local recruiters were hired by RTI through an employment agency that has provided this service for other RTI population survey projects. Dr. Phillips developed the recruitment guidelines, instructions, and eligibility screener forms that were provided to the recruiters and the UTSPH investigators (Appendix B). Face-to-face training on recruitment methods was implemented by Dr. Phillips on three separate occasions in Houston. These training sessions were also attended by the UTSPH investigators and staff.

4. DATA COLLECTION METHODS

4.1. General Approach.

A detailed description of field activities and methods is presented in the Standard Operating Procedures (SOPs) included in Appendix C. All methods and procedures were presented to and reviewed by the NUATRC Scientific Advisory Panel and the HEATS Advisory Committee. Briefly, each of the two residential sampling campaigns required four separate visits to each household, as follows:

a. Day 1 (approximately 2 hours). Field personnel described in detail the goals of the study, the type of information to be collected and how it would be used, and showed the type of samplers and other devices to be placed in the household. Once the selected adult participant indicated understanding of the objectives and procedures of the study and confirmed his/her interest in participating, (s)he was provided with a written informed consent form in the appropriate language (English or Spanish) which was signed by her/him and the authorized field team member. A separate informed consent form was provided to a child if eligible and selected to participate. Copies of these forms are

presented in Appendix F. After obtaining informed consent, the following activities were implemented:

- Administration of the Baseline Questionnaire (adult and child).
- Implementation of Walk-Through Survey.
- Placement of perfluorocarbon sources (living area and attached garage, if applicable).
- Recording of residential location coordinates using a GPS device.
- Scheduling of Day 2 visit, no earlier than 48-hours later.

b. Day 2 (approximately 1 hour). The field team placed VOC samplers and temperature/humidity recording devices indoors (main living area) and outdoors. Adult and child participants were fitted with VOC samplers for personal exposure measurements. One or more capillary absorption tubes (CATs) for perfluorocarbon tracer gas capture was placed next to the indoor VOC sampler. Participants were instructed on the appropriate handling of the personal sampling device, and they were provided with and instructed on how to use the Time-Location Activity Log. One or more VOC samplers were placed at the central fixed ambient sampling site closest to the home. Additional samplers were used at various times during the study, as described later. An appointment to visit the home 24 hours later was verified.

c. Day 3 (approximately 1.5 hours). The field team retrieved all the samplers and devices deployed inside and outside the home, and collected the personal sampling devices. The Time-Location Activity Log was reviewed with the adult (and child) participant. The Household Activity Questionnaire was administered to the adult (and child). The participant(s) was given the study incentive after signing a receipt form, and reminded that UTMB investigators would call to set up a fourth visit no sooner than 48 hours later.

a. Day 4 (approximately 2 hours). UTMB personnel administered the Health Symptom and Risk Perception Questionnaires.

4.2. Participant Recruitment

As indicated earlier, Dr. Mike Phillips supervised recruitment efforts for the study. Recruitment and enrollment protocols were as follows. RTI selected blocks of addresses to be visited sequentially by recruiters, each within a defined period of time (for example, one month). Subsets of addresses for each time period (typically 20 to 40 per area) were then sent to the UTSPH staff who proceeded to send letters describing the study, forewarning the residents to expect a visit by a recruiter, and providing phone contacts for recipients interested in obtaining more information. The letters also included a brochure. English and Spanish versions of letters and brochures were included (see Appendix E). Mailouts to blocks of addresses were sent every two weeks. Recruiters, working in bilingual teams in each area, were provided with recruitment/screener forms in both languages, and were asked to verify each address and check for any missing or no longer existing addresses. Each verified address was visited repeatedly until direct contact with a resident was made or up to six times (later increased to ten times), at which point the recruitment effort for the specific address was considered complete. Once a potential participant was contacted in person, the recruiter enquired about receipt of the letter by mail, provided additional copies of letters and brochures, and asked about the subject's interest in household participation in the study. If the answer was positive, the household eligibility and screening questionnaire was administered. If more than one adult was eligible to participate in a

household, the adult with the closest next birthday was solicited for participation. After again verifying eligibility and willingness of the adult selected to participate, the household and participant were considered recruited into the study. Recruiters submitted the name and phone numbers of recruits to RTI and to the UTSPH staff including the subjects' preferable days and times to be called for scheduling the first visit by HEATS field teams. Communication of this information was performed by secured e-mail. UTSPH staff proceeded to call and schedule first visits as soon as they received the contact information. Participants were considered enrolled in the study once the recruited participant read and signed the written informed consent form at the time of the first visit by the field team. Completed screener forms were periodically returned to the UTSPH by the lead recruiter.

Recruitment of participants proved to be far more difficult than originally thought, so a number of different approaches and strategies were used in an attempt to improve participation. These are described later in the results section.

4.3. Sampling and Analysis of VOCs

A detailed description of the VOC sampler cleanup and analysis is presented in the SOP included in Appendix C. Briefly, PE sampling tubes were purchased from Supelco, Inc. (Bellefonte, PA; part # 59701-U). Once received, the tubes were subjected to multiple sessions of cleaning to remove background contamination using a 6-tube conditioner (Model 9600, CDS Analytical, Inc., Oxford, PA) with ultrapure grade nitrogen (SG UHPNI230, Matheson Tri-Gas Inc., Houston, TX) purging at a flow rate of 70 - 85 mL/min at 350° C. After deployment, tubes were cleaned for at least 2 hours before re-use. Both ultrapure helium and nitrogen were tested and found to be equivalent in terms of reducing background levels, so nitrogen was used because of lower cost. As described later, relatively high and variable background levels of 1,3-butadiene, benzene, and toluene persisted in our analysis of the blank tubes, but analysis of some blanks by Alion, the EPA contractor that analyzed the DEARS PE samples, did not show elevated background levels. Cleaned, blank PE tubes and PE samples were stored in separate refrigerators located in two separate rooms. Sample identification and PE number were maintained using barcodes that were optically read for analysis and for entry into the database.

Analysis of blanks, standards and samples was performed by thermal desorption/GC-MS using a Gerstel TDS 3 Thermal Desorption System interfaced with a CIS-4 Cooled Injection System, controlled with a C505 Controller. Desorption was performed with 1.5 cc/min Ultra Pure He (SG UHPHE291; Matheson), initial temperature 25 °C, ramp at 60°C/min to 320°C, held 3 minutes. Transfer line temperature is 275 °C. The injector was maintained at an initial temperature of -100 °C, ramp 12 °C /sec to 300 °C, held for 3 minutes. The sample was analyzed with an Agilent 6890 Plus GC/5973 MS system, using a Restek RTX-624, 0.25 mm ID, 1.4 um film thickness, 60-meter length GC column, with an initial oven temperature at 0 °C, held 1.5 min, then ramped at 8 °C /min to 100 °C followed by a ramp of 15 °C /min to 230°C , held 5 minutes. The total analysis time per tube was 55 minutes.

Standards were prepared by flash injection (Supleco ATIS) of 1 µl solution of target VOCs prepared from a certified custom mix (Accustandard) in methanol containing 10 ug/ml each of 1,4-Difluorobenzene and Chlorobenzene-d5 as internal reference compounds. Dilutions included

methanol solvent blank and 0.2, 0.5, 2.0, 5.0, 10.0, and 20.0 μg/ml. Full calibrations were repeated when internal reference compound responses changed more than 10% during routine analysis and after replacement of transfer line/ trap or other instrument maintenance.

4.4. Residential Air Exchange Measurements

Air exchange measurements were performed with the well established procedure first described by Dietz et al., 1986 (Appendix C). Briefly, the method consists of deploying small sources of an inert perfluorocarbon tracer (PFT) indoors for a sufficient time to achieve steady-state concentration. Then, a small tube with a granular carbon sorbent (capillary absorption tube or CAT) is deployed to passively collect the tracer; the tube is analyzed by GC/MS. The estimate of the air exchange rate is derived from the concentration of tracer, the average temperature of the PFT source, and estimates of residential volume (derived from measurements of every room performed as part of the Residential Walkthrough Survey in HEATS). Because results from the RIOPA-Texas study suggested that homes with attached garages had increased levels of fuel-associated VOCs, such as benzene, two different tracers were used in homes with attached garages, one in the main living area (PMCH) and one in the attached garage (PDCH). Detection of PDCH in the CAT placed in the living area of the residence would confirm that emissions from sources in the garage can infiltrate the main residence. The Harvard School of Public Health supplied the PFT sources and CATs, and analyzed the latter. The AER estimates were calculated by UTSPH investigators using the standard procedure.

4.5. Survey Instruments and Questionnaires

As summarized earlier, several questionnaires and log forms were designed and used to collect data that could be useful to interpret results from sampling and inform conclusions. The exposure-related instruments were derived from previous studies such as RIOPA (Weisel et al., 2006) and DEARS (USEPA, 2009). The Health Symptom and Risk Perception questionnaires were adapted from existing and validated instruments. Some redundant questions were intentionally included in more than one questionnaire for future QA/QC checks.

4.5.1. Baseline (Adult and Child)

The purpose of this questionnaire was to collect sociodemographic data on the participant(s) as well as information on specific habitual activities that could potentially impact personal exposures to target VOCs. This questionnaire (Appendix F) was derived from the RIOPA study modified to include additional information derived from the experience of that study, such as more detailed information on transportation modalities, residential history, and type of employment of all residents in the household. The questionnaire was developed in both English and Spanish language.

4.5.2. Residential Walkthrough

The purpose of this instrument is to obtain data on the house itself (e.g., measurements that will be used to calculate AERs) and indoor emission sources that can impact indoor and personal concentrations. A field team member literally “walked through” the residence recording

information on potential sources of target chemicals or other characteristics that could affect exposures. As part of this survey, each room of the house was measured in order to calculate house volumes necessary for estimating AERs. This instrument (Appendix F) was also derived from the RIOPA study, with some questions removed (e.g., proximity to roadways that was derived from GIS-based software) but enhanced to include more detailed information on potential residential sources of VOCs, such as the number, type, place of storage, and frequency of use of household cleaning and maintenance products, and the age and condition of combustion appliances. In addition, photographs of the products were obtained. Compared to RIOPA, more detailed information on the number, type, and parking location for all household vehicles was also collected, and photographs of the outside of the residence showing parked vehicles were also obtained.

4.5.3. Household Activities

The purpose of this questionnaire was to obtain information on activities that the participants might have performed (for example, pumping gas) or that occurred near her/him that could potentially impact their exposure during the monitoring period. This questionnaire (Appendix F) enquires about specific activities undertaken by the participant during the monitoring period that could potentially have affected her/his exposure. This instrument was also derived from the RIOPA study, with some questions removed but other additional information elicited, such as the types of roads traveled during the monitoring period.

4.5.4. Time-Location Activity Log

This is a relatively simple, graphically-based log that is used by the participant to indicate which major environments and locations(s) were visited during the monitoring period (Appendix F). It was also derived from the one used in RIOPA, but with more details included, such as the approximate distance from the neighborhood when spending time outdoors.

4.5.5. Health Symptom Survey and Risk Perception Questionnaire.

This component of the study was undertaken under a subcontract with Dr. Sharon Petronella of UTMB. The purpose of this component was to obtain data that would permit exploration of patterns of health symptoms and the participants' perception of environmental exposures and risk in each of the study areas. The investigators performing the exposure measurements and health-related components were blind to the results of each other's efforts until the data were analyzed so as to avoid any potential for contamination or introduction of information bias as each team contacted participants. Likewise, the personal health symptom and risk perception questionnaires were administered at least 48 hours after each home/personal exposure monitoring was completed, to limit the effect that monitoring-induced increased awareness or concerns may have on participants' responses. Each family was interviewed by a bilingual medical resident trained to collect data on health status and symptoms. The health-related questionnaire was administered after both sampling periods at each house, while the risk perception questionnaire was administered only during the first set of visits.

The Health Symptom Survey was derived from questions abstracted from the National Health Information and the American Thoracic Society Respiratory Symptoms surveys (National Health and Nutritional Examination Surveys, 2003) augmented by environment-relevant questions (Legator et al., 1993). The Risk Perception Questionnaire was submitted to and kindly revised by Dr. Paul Slovik, president of Decision Research, Eugene, OR, who deemed it suitable for its intended use. The instruments were piloted prior to implementation in the study with two small groups, representative of the target populations for the purpose of identifying deficiencies or problems.

4.6. GIS Mapping of Roads and Outdoor Sources

Addresses of potential local emission sources (e.g., gas stations, scrap metal and auto parts, and dry cleaners) within the study areas and neighboring zip codes were identified from Harris County Appraisal District (HCAD) registries. Data collectors visited the addresses, determined whether the listed potential emission sources were active or inactive and, if active, obtained the location coordinates with a GPS positioning unit (eTrex Legend, Garmin Co., Olathe, Kansas). The coordinates of the point emission sources of target VOCs were identified from the 2006 Toxic Release Inventory (TRI) for Harris County, Texas. Location coordinates for fixed ambient sampling sites were obtained from the TCEQ website. Census TIGER maps were used to represent the roadway networks. Source, ambient monitoring sites, and residential location coordinates sources were mapped using ArcView GIS 9.2 (ESRI Inc., Redlands, California) using Geographic Information System (GIS) software. These maps are included in Appendix G.

5. DATA MANAGEMENT AND QA/QC

5.1. Data Management

An overall summary of the study components is presented as a flow chart in Figure 6. Data for each set of visits was recorded in hard copy forms included in a binder labeled with a code that uniquely identified the home and the visit number (first set or second set of visits). The binder included information on the participant (name, address, phone number), a map showing the location of the home and driving directions, the HCAD description of the home if available at the HCAD website, informed consent forms, receipt forms for participant incentive, sampling collection forms, and all exposure-related questionnaires. Each data collection instrument was assigned a barcode that uniquely identified the home, participant and instrument. All sampling devices used in each sampling event were also assigned a unique barcode that was also used as the identifier in the chemical analysis. This approach allowed entry via optical reading of the identifying barcodes for both scanning of survey instruments and analysis of samples, so misidentification errors incurred by manual entry were avoided. Surveys were first checked by double scanning and all data entry anomalies were corrected by direct comparison with the field forms. This approach was also used for the analytical results. All data were entered in an Access© database. Access tables are directly fed into statistical software packages such as SPSS and Stata. Photographs were downloaded into individual electronic folders for each home/visit.

Hard copy health and risk perception questionnaires were converted for processing with SNAP

Survey© software (SNAP Surveys, Boston, MA), used in conjunction with an Fi-5650C image scanner (ScanTron, Tustin, CA). The Fi-5650C, which handles up to 55 single-sided documents per minute, scanned the data into an Access© database. The software and scanner are configured for character-recognition, enabling data collection from open-ended questions. The system was pre-tested with 25 "dummy" surveys to assess ease and accuracy of survey processing. Each of the 25 surveys was then manually checked; data entry was error free. The questionnaires were developed in scannable format and entered twice for QC checks.

5.2. Quality Assurance/Quality Control.

A QA/QC document (Quality Assurance Project Plan) was submitted to the NUATRC and TCEQ. The document included a summary description of the study, a project organization chart and specific responsibilities for each component of the study, overall QA objectives, standard operating procedures (SOPs) for sampler preparation, storage, transportation, deployment, and post-collection sample transport, storage and analysis, field sampling quality control procedures including number and placement locations of field blanks and spikes for the total study and per sampling event. The overall target included at least 10% of the total samples as field blanks, at least 10% collocated samples distributed across all sampling locations (personal, indoor, outdoor, and fixed site) for air pollutants and to collocate an equivalent of 10% of the CATs for AER measurement. Other components included in the document were: field standard operating procedures for placement and handling of monitors, AER sources and collection tubes, and temperature-humidity sensors, copies of field sampling forms, analytical procedures for VOCs, calibration frequency and concentration range for each type of analysis, number and frequency of laboratory blank analyses (at least 10% of all analyzed samples), and analytical spikes. Post analysis data entry and quality evaluation procedures were also included.

The Health Symptoms and Risk Perception surveys were pilot-tested for clarity, comprehensibility, word choice and potential deficiencies using focus groups representative of the target populations. The original source of the questionnaires (validated instruments developed by experts) attest to content validity. Criterion validity was tested by correlating representative sample of 100 responses or scales to the Medical Conditions component of the National Health and Nutritional Examination Survey (NHANES, 2006). Convergent and discriminant construct validity was tested by correlation analysis. Reliability was tested using Cronbach's alpha criterion (Windsor et al., 1994) using a test - retest reliability assessment approach.

6. DATA ANALYSIS METHODS

All data were entered into a Microsoft Access database. Data analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 17, and Stata version 10.1. Descriptive and summary statistics tables were prepared in Microsoft Excel. Comparison of participants or residential characteristics was done using nonparametric methods.

6.1. Statistical Methods

Regression models expressing the concentration of each HAP of interest as a function of sample location, sample source and other conditions were fitted to the data. Hypotheses were tested by examining the regression coefficients in the fitted models. Weights (supplied by RTI) were incorporated in the models to reflect the characteristics of the underlying population and a robust estimation method was used to take into account correlations resulting from repeated measurement of outcomes on each household.

6.2. Data Transformations

Field measurements of the various HAP concentrations were corrected by subtracting appropriate blank values from the measured concentrations. Since this resulted in a negative number in some instances, the usual logarithmic transformation could not be used directly to achieve approximate normal distribution of the data. To overcome this difficulty, the data were transformed by first adding 1 to the blank-corrected measurement, then taking the base 10 logarithm. After fitting the regression models, examination of the residuals still showed non-normal distributions in some instances. However, the properties of the statistical tests tend to be robust to violations of normality assumptions for large samples (140 in this study), so the hypotheses tests were judged to be fairly reliable. As a separate confirmation of results, the observations were replaced by ranks and the regression analyses were repeated, yielding similar results (Conover and Iman, 1981).

6.3. Tests of Hypotheses

The primary hypothesis that personal exposures to target HAPs are equal in the Ship Channel and the Aldine area was tested by a regression model for HAPs of the form

$$y_{ij} = \beta_0 + \beta_1(L)$$

where

y_{ij} = log transformation of personal HAP exposure on i^{th} occasion of measurement for j^{th} subject

L = indicator variable for location (0 = Aldine, 1 = Ship Channel)

β's = unknown regression coefficients to be determined

Weights were used as appropriate for personal or household observations.

The mean HAP exposure for Aldine is estimated by β_0, the mean for the Ship Channel is the sum $\beta_0 + \beta_1$ and the difference in the mean exposure in the two locations is β_1. The standardized coefficient $\beta_1 / se(\beta_1)$ was compared to the appropriate t- distribution to determine the p-value.

The secondary hypothesis under Aims 1 and 2 is that residential outdoor, indoor, and fixed site concentrations of the target HAPs are equal in the two communities. The regression models are of the form described above with the response y_{ij} being defined as residential outdoor concentrations, residential indoor concentrations, or central site concentrations, respectively.

Aim 3 evaluated whether the fixed site measurements of target HAPs are statistically significant indicators of residential outdoor, residential indoor, or personal exposures, for each community. Regression models were of the form

$$y_{ij} = \beta_0 + \beta_1(L) + \beta_2(M) + \beta_3(LM)$$

where

y_{ij} = log transformation of concentration of selected HAP (outdoor, indoor or personal) on i^{th} occasion of measurement for j^{th} subject
L = indicator variable for location (0 = Aldine, 1 = Ship Channel)
M = measured fixed site concentration of selected HAP
LM = interaction of location and measured fixed site concentration

In this model, β_0 denotes the average outdoor, indoor, or personal concentration for Aldine when the fixed site concentration is zero, and $\beta_0 + \beta_1$ is the average outdoor, indoor, or personal concentration for the Ship Channel area when the fixed site concentration is zero. The coefficient β_2 represents the linear effect of the measured fixed site concentration M for Aldine; the sum of the coefficients $\beta_2 + \beta_3$ represents the linear effect of the measured fixed site concentration M for the Ship Channel; and the interactive effect β_3 represents the differential effect of M for the Ship Channel as compared to Aldine.

To test the hypothesis associated with Aim 4 that the relative contribution of outdoor concentrations of HAPs to indoor air concentrations is the same in both the Aldine and the Ship Channel communities, the regression model was of the same form as above, with the response y_{ij} defined as residential indoor concentrations and M defined as residential outdoor concentrations. The differential impact of location (study area) was evaluated by determining the statistical significance of β_3.

The final model was a further evaluation of the primary hypothesis, taking into account possible differences between study areas based on personal and household characteristics determined to have significant effects on one or more VOCs in preliminary bivariate analyses. The multivariate regression model was of the form

$$y_{ij} = \beta_0 + \beta_1(L) + \beta_2(x_2) + \beta_3(x_3) + \ldots$$

where

y_{ij} = log transformation of personal HAP exposure on i^{th} occasion of measurement for j^{th} subject
L = indicator variable for location (0 = Aldine, 1 = Ship Channel)
β's = unknown regression coefficients to be determined
$x_2, x_3, \ldots$ = sociodemographic or other covariates

This is the same as the first model above with addition of the covariates to correct for imbalance between locations. These covariates include *Gender, Income, Building Type, Stove Fuel, Work Status, Air Exchange Rate, Time Spent In Home* and *Time Spent In Vehicle* in various combinations for different HAPs. The hypothesis of interest can be expressed as

Is the mean exposure, when corrected for covariates, the same in the two locations?

H_0: the difference in means is zero, i.e., $\beta_1 = 0$.

The *p*-value is determined by a *t*-test.

(Note: In the analysis for this model, it was not technically feasible to simultaneously include several categorical predictor variables (e.g., *Gender, Income, Building Type*), weights and also correction for repeated measurements. This may have resulted in a slight underestimation of the standard errors and a corresponding increase in apparent sensitivity of the tests.)

6.4. Adjustment for Multiple Tests

No formal statistical techniques were used to compensate for the possibility of inflated Type-I error probabilities due to multiple testing. However, in all instances, the test results were interpreted in view of both the practical context and the possibility of Type-I errors.

6.5. Contributions of Indoor and Outdoor Sources to Indoor Concentrations

A one-compartment mass balance model was used to estimate the contribution of indoor and outdoor sources to indoor concentrations measured in HEATS homes following the approach previously used for the RIOPA study (Weisel et al., 2005, Liu et al., 2006). Each sampled home was assumed to be a well-mixed compartment in which the compound of concern present in outdoor air penetrates through windows, doors, and house exterior cracks and crevices into the indoor air and is removed from the indoor air by air exchange, surface deposition, and/or chemical reactions. It was also assumed that indoor sources and sinks remain constant during the 24-hour period of measurement. The steady-state indoor concentration can be described by the following equation:

$$C_{in} = C_{out}\,[aP / (a+k)] + (S/V)\,[1 / (a+k)] \qquad (1)$$

Where C_{in} is the residential indoor concentration ($\mu g/m^3$) of a compound; C_{out} is the residential outdoor concentration ($\mu g/m^3$) of the compound; a is the air exchange rate (hr^{-1}); S is indoor source strength ($\mu g/hr$); V is the volume of the house (m^3); k is the decay rate constant (hr^{-1}); P is the penetration factor. As shown in equation 1, C_{in} is expressed as the sum of the outdoor-to-indoor infiltration ($[aP/(a+k)]C_{out}$) and the contribution of indoor sources ($(S/V)\,[1/(a+k)]$).

To estimate indoor source contribution, measured indoor and outdoor concentrations, air exchange rate, and home volume were used for each home. A penetration factor of unity for non-reactive gases (P=1) was assumed for the analysis, consistent with many previous studies that have either found or assumed this value for the outdoor-to-indoor penetration process (Lewis, 1991, Lewis and Zweidinger, 1992, Sax et al., 2004, Weisel et al., 2005, Liu et al., 2006, Dodson et al., 2007). Except for highly reactive compounds (e.g., ozone, $P \sim 0.8$), most gases should have P values equal or close to unity. Previous studies of indoor/outdoor (I/O) pollution concentration relationships have suggested that P can be assumed to be unity for most VOCs. This assumption simplifies equation 1 as:

$C_{in} = C_{out} [a / (a+k)] + (S/V) [1 / (a+k)]$ (2)

Little information exists on the decay process of individual VOCs in residential indoor air because there are large uncertainties such as the concentration of reactive radicals in indoor air and variable conditions in each case. For the estimation of the decay constant from observation, indoor and outdoor concentrations and air exchange rates of the homes that had I/O ratios less than 1 were selected, assuming that S =0 for these homes. The calculated median decay rate constants ranged from 0.07 to 0.28 hr^{-1} for optimal compounds, and from 0.14 to 0.30 hr^{-1} for non-optimal compounds. Because the percent of homes that had indoor/outdoor (I/O) ratios less than 1 was very small (1% to 8%) among the optimal compounds except tetrachloroethylene (19%) in order to be able to estimate decay rates, these rate constants for all the VOCs were assumed to be 0, as was assumed for the RIOPA study (Weisel et al., 2005), which simplifies equation 2 as follows:

$C_{in} = C_{out} + [S / (aV)]$ (3)

Therefore, the indoor source strength (S) of an individual compound was calculated from the measured indoor and outdoor concentrations, air exchange rate, and home volume for each case, using the following equation:

$S = aV (C_{in} - C_{out})$ (4)

Likewise, the simplifying assumptions discussed above result in the estimate of the fractional outdoor contribution to the indoor concentrations as simply:

$F = C_{out} / C_{in}$ (5)

7. RESULTS AND DISCUSSION

7.1. Subject Recruitment and Retention

Recruitment and retention of participants proved to be far more difficult than originally foreseen, and presented a major barrier to the timely implementation and progress of the study. In addition, completion of second visits and participant retention were unexpectedly compromised by Hurricane Ike and its aftermath that resulted in large sectors of the Houston metropolitan area remaining without power and other basic services for several weeks from September 13 through at least the end of October, 2008. Significant damage to residential structures resulted not only in loss of participants who moved away permanently from the study areas, but also in delayed implementation of the second set of visits for remaining participants whose residences were damaged by the hurricane. The investigators waited for repairs to be essentially completed before conducting a second set of visits.

Initially, female recruiters working in bilingual teams indicated good success in raising interest in participation and in recruiting participants. Some difficulties were reported, such as an inability to reach a resident because the residence was surrounded by fences with no means of communication with the home, but these were not frequent occurrences. However, enrollment proved to be significantly more difficult, despite efforts and assurances that the home visits would accommodate the participants' schedules. Follow-up phone contact by staff to verify interest in participation and to schedule first visits with recruits was labor intensive and required repeated phone calls on different days and at varying times on weekday evenings and on weekends. Unexpectedly, a sizable number of recruits lacked home phone answering machines. Voice messages were rarely responded to by participants who had voice-recording devices but were not at home or did not answer calls when contacted by staff. An unexpectedly high number of recruits declined enrollment once reached by phone, frequently alleging lack of suitable times for home visits due to work or family obligations.

To reestablish personal contact, the field team members revisited homes of non-respondent but recruited participants residing in the same area as a home being visited. However, it was not infrequent to notice evidence of a resident being at home but not answering the door. In part, this response could be due to concern about door-to-door sales pitches, or even the potential for a home robbery. In order to more clearly identify the HEATS team members, both recruiters and field personnel wore specially designed, red color t-shirts with the study logo and personal identification tags when visiting the target areas.

We believe that, because of cultural sensitivities (both areas have large proportions of Hispanic residents) individuals may have responded positively to the recruiters out of politeness in face-to-face meetings, but did not feel so compelled when contacted by the less personal phone calls. Another barrier to enrollment and also retention related to gender-driven familial relationships that appear specific to some sectors of these populations. There were several instances of married female recruits who declined enrollment (or declined participation in the second set of visits) claiming they had consulted with their male spouse who did not agree to their participation in the study. In these cases, the investigators requested permission from the female recruit to speak directly to their spouse. In some cases the request was denied, but even when agreed the investigators failed to convert the reluctant male spouse. As a means to minimize conflict and impact from gender-related cultural sensitivities, Dr. Morandi or other Spanish-speaking female members of the staff engaged in converting eligible Spanish-speaking participants. In addition, field teams always included female members who took the lead in approaching subjects of either gender. On the other hand, and generally related to work status, potential male participants were more likely to be reluctant to enroll, generally citing work-related reasons, and would inquire about the possibility of their spouse participating instead, which was not allowable under the recruitment protocol.

Few of the potential participants, recruits and/or those initially enrolled remembered receiving the letter and brochure describing the study which also provided contact phone numbers to obtain additional information. Letters may have been discarded unopened as "junk mail", so envelopes were clearly marked to the effect that the contents were about participating in a study for which an incentive would be paid, and not an advertisement, and to please open the envelope and read its contents. In some cases, mail could have been stolen once delivered to mail boxes. In order to

partially address this problem, and in addition to the mailouts, the recruiters and field teams placed letters and brochures directly in mailboxes whenever someone was not found at home or did not answer the door. Despite these efforts, it was rare to receive a call from potential participants in response to direct placement of information in their mailboxes.

With assistance from the sponsors, a series of enhanced communication activities through local media and meetings attended by community and local government leaders were undertaken. There were repeated announcements of the ongoing study by local radio stations and even at local cinemas during intermissions. Meetings with local representatives and community organizers to inform them about the study were also held. These efforts did not appear to improve recruitment and enrollment to an appreciable extent in part because these forms of communication may not have reached the potential participants in these populations.

RTI attempted but was not successful at identifying an available "super recruiter", i.e., a recruiter who specializes in difficult recruitment situations such as we encountered, who could be hired temporarily to work with HEATS recruiters to improve recruitment rates and enrollment. Unfortunately, individuals with the experience and necessary skills could not be hired because they were engaged in other studies elsewhere in Texas or in other states.

Study participation fees were originally provided in the form of gift cards selected by the participant from two large retailers with multiple locations in the Houston area. We found that these retailers were not necessarily customary for Hispanic residents in the two study areas. The initial stipend ($50 for adult for each of the two sets of visits) and form of payment were changed to a cash payment of $100. This change increased the level of satisfaction of the subjects enrolled but did not seem to impact conversion among the reluctant. It was also apparent that that a significant fraction of the potential participants had relatively little concern or knowledge about air pollutants and potential impacts on health and that, combined with day to day family obligations and job pressures, this probably resulted in lower than expected recruitment and enrollment rates. Unforeseen events also impacted recruitment and retention. For example, in some cases, potential participants had to travel outside the city or outside the country unexpectedly because of family reasons. One participant died and was lost to follow-up, and another divorced and was lost to follow-up because she moved to live with her parents.

Hurricane Ike made landfall in Galveston at midnight on September 13, 2008, moving directly over the Houston metropolitan area, impacting more seriously the southern sector of the city. There was significant damage to residences, especially in the Ship Channel area. Beyond the delay in implementing already scheduled first and repeat visits due to the lack of electricity for 6 or more weeks, both recruitment and retention were affected as prospective and former participants moved outside the area because severe damage to their home or apartment made them unfit for occupancy. In addition, repeat visits were postponed for participants whose homes were damaged pending completion of home repairs. The investigators started surveying the two areas and visiting the homes of participants during the week following Ike's landfall. The purpose of these visits was to inquire about the participants' situation and that of their families. This approach was appreciated by participants and we believe that it had a positive impact on retention of those that could be contacted. Throughout the end of the field component of the study, the field teams called, and visited repeatedly, each of the enrolled households that were

still occupied until the resident could be contacted, leaving cards and handwritten notes in mailboxes when residents were not at home or did not answer the door. Of the 16 participants lost to follow-up, eight left the area after the hurricane. Two of the 16 declined second visits because their spouses did not permit them to continue in the study, two refused because of lack of time or were no longer interested in participation, and another two did not respond to repeated calls or personal visits by the investigators after multiple attempts.

Studies using a representative population sample design approach are notorious for having low response rates as compared to recruitment of convenience samples. As with the DEARS experience (Phillips et al., 2007), low recruitment rates were associated with factors such as a larger fraction of households with smokers; difficulty in contacting participants by phone; potential participants, recruits, and enrollees rarely returning phone calls; and recruits and enrollees declining to participate or dropping out because of pressures from family members. Population mobility was not as major an issue in HEATS as it was in DEARS. Among those residences randomly selected and contacted by recruiters, approximately 5.8% in Aldine and 4.4 % of the Ship Chanel residents were not eligible because they were planning to move within the year. Three homes that were enrolled initially in the study cancelled first visits because they were moving. However, other factors specific to the populations targeted by HEATS may have impacted enrollment rates. The target populations in HEATS may have been less well established compared to others elsewhere in the country, and have a larger proportion of recent immigrants. Based on the information derived from the questionnaires, the sample enrolled had a relatively large proportion of individuals who were relatively new residents. Twenty-two percent of those enrolled (21% in Aldine and 35% in the Ship Channel) had resided at their present address for 2 or fewer years, and 50% (47% in Aldine and 62% in the Ship Channel) for 5 years or less. This, in combination with the large proportion of Spanish-speaking residents, suggests that potential participants may have been less attuned to some issues of concern to the broader and more established sectors of the population in the Houston area, such as air pollution, and also would be less likely to be involved in community activities than long-term residents. In order to improve recruitment and enrollment rates in future studies of this type, it appears that an intensive dissemination effort should be undertaken prior to the study, including adoption of community-based participatory research methods involving residents of the areas in planning and implementation of the study.

7.1.1. Revised Sample Size

Dr. Whitmore explored the impact of the reduction in the number of homes on the statistical representativeness of a reduced sample size of participants per area. He indicated that the minimum requirements for a statistically representative sample for the HEATS would be:

1. Select a probability sample of addresses for each area.
2. Achieve at least a 50% response rate in each area.
3. Achieve at least 30 participants in each area.

The random cluster sampling method used for the HEATS study satisfies the first requirement. The third requirement is the minimum sample size recommended to protect against selection bias simply due to the random variation between the characteristics of small randomly selected

samples. Power calculations (see Appendix A) have shown that this sample size is sufficient to support 95% power to detect the difference between the median benzene concentrations for the Ship Channel and Aldine study areas if the median is 3.25 $\mu g/m^3$ for the Ship Channel area and is 1.75 $\mu g/m^3$ for the Aldine area, a difference of 1.5 $\mu g/m^3$. The second requirement was the most problematic and could not be met in spite of very intensive efforts in recruitment and conversion of participants.

7.1.2. Response Rates

Information on response rates is presented in Tables 4 and 5 for Aldine and the Ship Channel, respectively. A total of 311 and 270 households in the Aldine and Ship Channel areas were contacted, with 40.6% and 48.2 %, respectively, eligible at the household level. Recruitment of eligible responders exceeded 50% in each of the areas but, enrollment response rates were 34.7% and 36.4% respectively, which is somewhat below those of studies such as TEAM and NHEXAS (approximately 40%).

A comparison of key sociodemographic variables (see Appendix A), indicated that for both visits and in both areas, there was a gender bias towards females, and no suggestion of bias except for gender in the first round of visits.

RTI developed statistical weights to account for household level and person level response rates and bias in sociodemographic characteristics. A description of the methods and the actual weights are presented in Appendix A.

7.2. Data Completeness

Aside from recruitment and retention limitations, only three samples were lost to analysis from among 612 collected (one personal child, one indoor and one fixed site sample). As Table 6 indicates, the planned percentage of field, laboratory, and trip blanks was exceeded, in part due to additional experiments and blank sample analyses in an attempt to resolve PE tube elevated background levels. The number of positive controls was 4%, relative to the number of samples, less than the originally planned 5%. Recovery of questionnaires and logs was 100% for all homes and visits completed. Only 45% of the homes had children willing to enroll (as compared to the 50% target). Children were more resistant than adults to wearing the PE tube, so they were also more likely to decline to participate or to withdraw from participation in the second visit.

7.3. Descriptive Analysis and Summary Statistics

7.3.1. VOC Monitoring QA/QC

Initially, UTSPH investigators used PE tubes loaned by the EPA on a temporary basis in order to expedite the start of the field study in a timely manner, while a set of new tubes were received and conditioned. EPA-supplied tubes had been used in the DEARS study and, consequently, had undergone multiple cycles of sampling, cleaning, and analysis. Alion Laboratories (Alion) cleaned and analyzed the tubes used in DEARS under contract with EPA. UTSPH investigators consulted with DEARS researchers and Alion scientists on cleaning, handling and storage of PE

tubes. Main differences between the laboratories were: 1) the spiking protocols for preparation of standards and positive controls, i.e., Alion exposed blank tubes in controlled test atmospheres in a dynamic chamber and the UTSPH used flash injection of mixed standards in methanol, and 2) the GC/MS systems available in each of the laboratories.

7.3.1.1. Blank Concentrations

From the start of the field study, UTSPH laboratory analysis of field, laboratory and trip blanks collected with EPA-supplied PE tubes showed elevated and more variable background concentrations of key compounds such as benzene and 1,3-butadiene compared to the analysis of these tubes by Alion for the DEARS study. Blank concentrations and, especially, their variability for some target chemicals seriously affected the method detection limits, to the extent that large portions of the data would be below detection. Given the time constraints for implementation of the study and participant enrollment difficulties, the field efforts could not be put on hold pending resolution of this issue. Results from analysis of blanks tubes purchased and conditioned by UTSPH were initially higher - as expected and also experienced by EPA during the initial period of sampling in DEARS - and declined after intensive re-conditioning and repeated use but remained elevated and variable compared to DEARS PE blanks. Intensive efforts at identifying sources of contamination (i.e., storage procedures after cleaning and during transport to the field, o-rings and gaskets in tube adapters and GC/MS, gases used in the conditioning procedures) failed to identify the problem.

Several small substudies were undertaken to identify the causes for the results that were at variance with the DEARS experience. In addition, the number of field blanks deployed was increased, and collocation of PE samples and organic vapor monitors (OVMs) indoors was done for approximately one half of the home visits. These substudies included a limited number of experiments performed in collaboration with Alion Laboratories. Detailed information and results of the substudies are presented in Appendix H. The dates and summary of findings are presented below with reference to the data presented in Appendix H.

7.3.1.2. Substudy 1:UTSPH-Alion Intercomparison of Blank PE Tubes (May1-June 5, 2009, Appendix H)

Twelve blank tubes randomly selected from an older and recently purchased set of PE tubes were preconditioned at the UTSPH laboratory, sent to Alion for analysis, cleaned by Alion after analysis, and returned to the SPH for re-analysis, Only 1,3-butadiene, benzene, and toluene results are shown because these were the problematic compounds. The results (Tables H-1 through H-6 in Appendix H) consistently indicated that elevated and variable background levels of key target compounds were found in the UT analyses but not in Alion's. The Alion analytical results indicated background levels typical of DEARS' tubes. However, re-analysis of the tubes upon return to the UTSPH showed backgrounds similar to or higher than in their prior analysis. The backgrounds decreased after additional cleaning but not consistently. Newer tubes had higher concentrations initially but also not consistently across all compounds. There was significant variability between tubes in the UTSPH analysis. The results of the analysis by Alion suggest that background contamination could not be explained by the conditioning procedure at the UTSPH since Alion did not clean the tubes after they analyzed them but the UTSPH found

elevated concentrations comparable to their pre-shipment levels. However, this comparison did not assist in identifying the reason for the elevated background. Analysis of the two tubes stored over a period of almost 3 weeks at the UTSPH showed increased concentrations of background levels compared to pre-storage analytical results, but within the range of the results for the ten tubes analyzed after Alion returned them to the SPH.

7.3.1.3. Substudy 2: Comparison of UTSPH PE Tubes with OVMs Placed Indoors (July 28, 2008 - February 24, 2009; Appendix H)

Given the persistent problem of high and variable background concentration in PE blanks, the investigators decided to collocate another sampler with HEATS tubes. Since the UTSPH research group has had considerable experience with another passive air sample for VOCs, the 3M model 3500 Organic Vapor Monitor (OVM), and has successfully validated and utilized this sampler in community settings (Chung et al., 1999; Morandi and Stock, 1998; Weisel et al., 2005, Stock et al., 2008), it was decided that a side-by-side comparison with the PE tube sampler would be useful in the evaluation of the latter. Butadiene was excluded sin the OVM is not a suitable sampler for it. Because the OVMs are solvent-extracted, acceptable performance depends on concentration level and sampling duration. For typical outdoor concentrations it has been shown that 72-hour sampling is required for good performance (Stock et al., 2008). Since HEATS employed 24-hour samples, comparison sampling was performed only in residential indoor environments (main living area and attached garage if present) in order to achieve higher concentrations. OVMs were clipped under the same shelter as the PE samplers. Comparison indoor collocation sampling was performed over 24 hours in a total of 60 homes; OVM sampling occurred in 5 of the homes during both first and second sampling rounds, but only during the second round for the rest. Thus, the total number of comparison samples was 65. Regression analysis (Tables H-10 and H-11) and scatterplots of the data (Figures H-1 and H-2) indicate reasonably good agreement for the xylenes, tetrachloroethylene, 1,4-dichlorobenzene excluding sample pairs over 50 $\mu g/m^3$ ethylbenzene, and toluene. There was a positive bias for the PE tube for all these VOCs with the exception of toluene. There was no agreement between the two methods for benzene and most of the PE measurements for benzene were below the corresponding OVM concentrations.

7.3.1.4. Substudy 3: UTSPH Analysis of Alion PE Standards and PE Samples with/without Helium Purge (November 21 – December 10, 2008)

In order to further evaluate the performance of the PE tubes at the UTSPH, NUATRC, Alion, and EPA personnel met with HEATS investigators, Drs. Maria Morandi (in person) and Tom Stock (by phone conference), at EPA's ORD headquarters in Research Triangle Park, NC, on November 20, 2008. The objectives were to discuss and evaluate potential explanations for the PE tube high blanks experienced by the HEATS investigators as these results might be explained by analytical methods and/or systems used by the Alion and UTSPH laboratory. In addition, partial data for the OVM-PE comparison described above in 7.3.1.4. were presented. The comparison data indicated poor agreement and high negative bias between PE and OVM measurements for the early eluting compounds through toluene, and better agreement for the rest of the VOCs. Detailed discussion of the methods and the field comparison data lead to the conclusion that results for 1,3 butadiene, benzene, and toluene observed by the UTSPH could be

related to water management of the samples prior to thermal desorption. Although the tubes use a graphitic carbon sorbent, there is some water absorption of water vapor during sampling. During the analysis, water adsorbed onto the PE tube sorbent and released during thermal desorption would tend to dampen the detector response to the analytes in the sample, thus resulting in lower analytical responses especially for the lower molecular weight compounds eluting earlier such as butadiene and benzene. Alion's TDS system allows for an automatic purge of samples prior to thermal desorption while the UTSPH system does not. Alion's PE tube standards are prepared in a controlled test atmosphere at a 70% relative humidity, and both standards and samples are purged with helium prior to thermal desorption in order to reduce/remove excess water. The UTSPH standards are prepared by flash vaporization of certified standard dilutions in methanol onto blank tubes, so that the tubes containing the standards (as well as the laboratory and field blanks) would not be affected by water but the samples will since the sorbent would be expected to have adsorbed moisture during the sampling period. Thus, while the response to standards and blanks would likely not be affected by water effects, the response to analytes in actual samples could be attenuated, especially for the earlier eluting compounds, resulting in lower estimated concentrations and lower variability in field samples. Alternatively, or in addition to the water management issue, differences could also be due to the way standards are prepared, i.e., chamber exposures with controlled test atmospheres used by Alion and flash evaporation of standards in methanol solution onto tubes performed by the UTSPH. However, while this effect could explain poor agreement between PE and OVM samples, it could not explain the high background in PE tube blanks.

In order to evaluate the interference of water in the UTSPH PE samples, two sets of experiments were planned and implemented immediately after the meeting. The first involved analysis of PE tubes spiked by Alion in their chamber at a concentration of 2ppbv and 75% RH. The second experiment involved sampling with 6 PE tubes and OVMs inside an attached garage during approximately two days; three of the tubes were manually purged with helium prior to analysis at the UTSPH laboratory (see Appendix H). Analysis of the 2 ppb (at 75% RH) spiked tubes prepared by Alion and of a small set of samples deployed inside the attached garage and analyzed with and without manual water purge with helium, indicated that water suppression occurred and that it impacted especially the earlier eluting compounds (earlier eluting than ethylbenzene). There was also some evidence of small VOC loses due to external purge. There is some consistency with the results from OVM-PE sample pairs collocated indoors, PE tubes had a positive bias for multiple VOCs with respect to OVM measurements, but not for toluene. Based on the results of this substudy, compounds eluting earlier than ethylbenzene were considered non-optimal (1,3-butadiene, carbon tetrachloride, benzene, trichloroethylene, and toluene) and those eluting later were classified as optimal (tetrachloroethylene, ethylbenzene, m&p xylenes, o-xylene, styrene, 1,3,5-trimethylbenzene, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene and p-dichlorobenzene).

7.3.1.5. Substudy 4: Collocation of Alion-supplied and UTSPH PE Tubes at HEATS Field Sites (February 8 - February 24, 2009, Appendix H)

The UTSPH and Alion performed a collocation study at HEATS sampling locations in order to further investigate the reasons for UTSPH high blanks and the negative bias in estimated concentrations when compared to collocated OVM samples. Protocols and results are presented

in detail in Appendix H. In summary, Alion supplied a set of their pre-conditioned tubes which were collocated with HEATS samples indoors, outdoors at four residences and at three fixed sites which have operating auto-GCs. The Alion-supplied tubes were split, so one half was returned to Alion for analysis, and the other half was analyzed at the UTSPH. In addition, a set of 12 blank PE tubes (Alion tubes conditioned by Alion, Alion tubes conditioned by UTSPH, and UTSPH tubes conditioned by UTSPH) were also analyzed by Alion.

The results of these comparisons at the fixed sites indicated that: 1) there was a negative bias in concentrations derived from Alion-supplied and UTSPH tubes analyzed by UTSPH compared to results from Alion-supplied PE tubes analyzed by Alion; 2) there was a relative positive bias for the PE samples analyzed by Alion compared to concentrations measured by auto-GC; 3) blank subtraction seriously impacted the concentrations estimated from UTSPH analyzed samples; and 4) precision of collocated pairs of PE samples analyzed by UTSPH was poor compared to that of PE samples analyzed by Alion. Results for collocated pairs deployed indoors and outdoors at residential sites are consistent with the patterns observed at the fixed sites described above, showing also that the Alion-analyzed PE samples had a positive bias compared to the OVMs. Notably, this bias is surprising for carbon tetrachloride that is generally reported to be at concentrations below 1 $\mu g/m^3$, as shown by the OVM measurements in this experiment. In general, the PE tube measurements (Alion or UTSPH) did not compare well with either the auto-GC or OVM measurements.

The results for the comparison of PE blank tubes of different origin (Alion or UTSPH) and conditioning (Alion or UTSPH) indicated that the conditioning method at the UTSPH was essentially similar to Alion's in efficacy, so the reason for the high blanks in HEATS must reside in the analysis system. In this case, lack of water management problems cannot explain this effect because blanks are not exposed to ambient air.

7.3.1.6. Precision

Consistent with the results for UTSPH-analyzed collocated pairs, estimated precision median values for HEATS collocated pairs (Table 7) during the study, calculated for pairs in which at least one of the samples had a detectable concentration of analyte, are variable and above 20% except for tetrachloroethylene, ethylbenzene, m&p xylene, and o-xylene for the optimal compounds, and only for toluene among the non-optimal VOCs.

7.3.1.7. Accuracy

Regression analysis for optimal compounds for collocation of HEATS PE samples at sites with auto-GC are summarized in Table7a. R^2 values above 0.8 were only found for butadiene and styrene. The slopes were above two for all compounds except benzene, and the slopes of the regression had a $p \leq 0.05$ for all compounds except benzene and o-xylene. Intercepts were not significantly different from 0 for all compounds except butadiene. These data indicate poor agreement between the HEATS PE samples and the auto-GC results, so it was not possible to adjust the PE-derived concentrations using these measurements. Accuracy with respect to OVMs collocated indoors is described in section 7.3.1.3.

7.3.1.8. Strategy for Background Subtraction in HEATS Samples

Since suitable correction factors could not be derived from the comparison of HEATS results with other methods as a means of implicit correction for high and variable background levels, as an alternative approach, box plots of field and laboratory blank loads and temporal trends in blank concentrations were explored to determine if there were patterns of clear extreme values (using box plots) and/or periods of elevated and more variable blanks. Eight laboratory and five field blanks were removed from the analysis since they were well above the whiskers of the box plots. The rationale for this approach is that these extreme outliers would not be representative of the typical range of background contamination in the sample tubes. It was also apparent that blank load and variability had increased after the end of August 2008. The field and lab blanks were divided into two sets (prior to and after August 28, 2008), and then compared for equality of means and variance for each compound within each of the time periods. Field and laboratory blanks were pooled if these tests showed they were similar and the mean of the pooled blanks was used for blank correction for samples collected during the corresponding time period. For compounds showing statistical differences between field and laboratory blanks, the field blank average (the higher of the two) was used for blank correction. As a result of this approach, varying proportions of the concentrations (depending on specific VOC) were negative (mean blanks for each period and corresponding MDLs are shown in Tables 8 and 9). After several discussions with Dr. Whitmore and Dr. Harrist, it was decided that all statistical analysis would be done without censoring negative values by replacement with 0 or a positive concentration (e.g., ½ the detection limit) as it was felt that this approach would introduce additional bias and that the extent of error and/or bias in the measurement would be expected to be similar in two comparison areas. Therefore, all concentration data presented in the report are derived from blank-corrected concentrations without censoring

7.3.2. Population Characteristics

A summary of selected demographic characteristics for HEATS participants enrolled in the study (i.e., the home received at least one set of visits) is presented in Table 10. A total of 113 participants were enrolled, including 78 adults and 35 children. Overall, of the 113, 45% were born in the US (38% of the adults and 57 % of the children). Mean adult and child ages were similar in both areas. Note that a child was defined as “an individual under the age of 21 years” to be consistent with NIH guidelines (NIH, 1998). There was a larger proportion of females (67%) compared to males among the adults, but a lower proportion (34%) among the children. The preponderance of the adults were Hispanic, as were all the children except 2. Two adults reported no or minimal schooling, 25 % had completed high school or had a GED, and almost 25% had some post-high school education. Five percent had a college degree. Approximately 45 % reported family income under $ 50,000, and 19% did not know their family income or declined to answer the question. Approximately 38% of the adults worked full time outside the home. Overall, the two areas were comparable in most categories, except that the proportion of foreign-born adults was higher in Aldine, while education attained and family income were higher in the Ship Channel. Differences in demographics between the sample of enrolled participants and the population residing in the selected zip codes were used to derive weights for statistical analysis.

7.3.3. Residential Characteristics

A summary of selected residential characteristics is presented in Table 11. Approximately 69% of the homes were single family, detached dwellings, 13% were mobile homes, and almost 12% of the participants resided in apartments. Four times as many participants residing in Aldine lived in mobile homes compared to the Ship Channel. Approximately 20% of the residences had an attached garage, and 75% of these had a doorway between the garage and the main living areas. Almost 80% of the homes had a gas cook stove, with approximately 50% of them having exhaust ventilation to the outside. Twenty eight percent of the home had no means for space heating. Approximately 25% of the homes had no form of air conditioning. Approximately 60% of the homes were built before 1970, and there were more houses built before 1955 in the Ship Channel, consistent with the history of development of both areas. Total house volumes (and indication of size) range from 64 m^3 to 495 m^3, with the mean house volume being slightly higher in the Ship Channel.

7.3.4. Air Exchange Rates

A statistical summary of the air exchange rates measured in HEATS is presented in Table 12. The measurements are stratified by both season and study area, since it is likely that the use of natural ventilation and the impact of indoor-outdoor temperature differences would have a seasonal dependence. This may be seen more clearly in Figure 7. These results indicate that air exchange rates are highest in the winter and lowest in the summer, for both study areas. Rates during the spring and fall appear to be intermediate between summer and winter. The relatively low air exchange rates in the summer are undoubtedly due to maximum use of air conditioning with closed windows. The relatively higher rates observed during the winter may be due to a mix of natural ventilation employed on mild days, combined with the effect of a large outdoor-indoor temperature gradient on air exchange in older, leakier houses. The seasonal pattern in air exchange rates is similar to that observed in Houston homes monitored for the RIOPA study. Median values were slightly lower in HEATS (0.41hr^{-1}) as compared to RIOPA Houston homes (0.47 hr^{-1}), but the difference in medians is small.

Differences in air exchange rates for different housing types are depicted in Figure 8. Overall, mobile homes had the highest rates, consistent with observations during field sampling that these homes were frequently found to be less than structurally sound. Apartments and attached homes tended to have lower air exchange rates, most likely due to fewer walls available for direct exchange with outdoor air. This pattern is also similar to that observed in the RIOPA Houston homes. Figure 9 indicates the effect of age of the home on the measured air exchange rates. As expected, there is a trend of increasing air exchange rates with increasing age of the structure, which is consistent with increased energy efficiency and better insulation in newer homes. The final figure, Figure 10, illustrates the relationship of air exchange with household income level. It is clear that lower family income is associated with higher air exchange rates, most likely due to higher prevalence of substandard and leakier housing.

7.3.5. Optimal VOC Concentrations and Exposures

Tables 13 – 17 present statistical summaries for residential indoor, residential outdoor and TCEQ fixed site concentration and adult and child personal exposure measurements for the HEATS optimal compounds. The distributions of these measurements are also graphically depicted by box plots in Figure 11. The tabulated summaries are presented both by study area, and overall. Mean concentrations are consistently higher than median values, reflecting the expected positive skewness of the concentration and exposure distributions. Also as expected, personal and indoor concentrations are consistently higher than outdoor or fixed site concentrations. Interestingly, while median concentrations of residential outdoor measurements were higher than fixed site measurements in Aldine, the reverse was true in the Ship Channel area. Generally, m&p-xylene had the highest median concentration for all types of measurements, and 1,3,5-trimethylbenzene had the lowest. An exception was the child personal exposures, where the highest median exposure overall, and in Aldine, was for 1,4-dichlorobenzene. Exposures of children to this compound were consistently higher than for adults, at all distributional percentiles, perhaps reflecting a greater percentage of time spent inside homes using air deodorizers containing this compound.

In order to test for differences in concentrations and exposures between study areas, the nonparametric Mann-Whitney U test was utilized. There were no significant differences between residential outdoor concentrations in the two areas. Residential indoor concentrations of o-xylene, styrene, and 1,2,3-trimethylbenzene were significantly higher in Aldine. Adult personal exposures to 1,2,3-trimethylbenzene and 1,2,4-trimethylbenzene were significantly higher in Aldine. Child personal exposures to m&p-xylene, o-xylene, styrene, and 1,2,3-trimethylbenzene were significantly higher in Aldine. Fixed site concentrations of ethylbenzene, styrene, and all three trimethylbenzenes were significantly higher in the Ship Channel. These results suggest that differences in measurements between fixed monitoring sites may not be good predictors of differences in relevant microenvironmental concentrations or personal exposures. The relationships of each type of measurement to the others are shown in the scatter plots in Figure 12. In these plots, the two study areas are differentiated with different symbols. The general trend of personal exposure > indoor concentration > outdoor/fixed site concentration observed for most compounds is consistent with the results from RIOPA and many other community exposure studies. In addition, the relatively poor relationship between personal or indoor concentrations and outdoor or fixed site concentrations, and the relatively good relationship between indoor concentrations and personal exposures are entirely consistent with previous studies. With the exception of styrene and 1,4-dichlorobenzene, these plots indicate that elevated indoor concentrations occur more frequently in Ship Channel homes. This disparity, however, does not seem to be reflected in the personal exposures.

7.3.5.1. Residential Indoor OVM Measurements

Because of the increasing awareness of the investigators that there were technical issues with the performance of the PE tubes, 3M 3500 Organic Vapor Monitors (OVMs) began to be utilized for home indoor sampling, parallel with the PE tube measurements, in late July 2008. OVM measurements were performed in 60 homes (31 in Aldine and 29 in the Ship Channel). Five of the homes were monitored with OVMs during both sampling rounds; the rest were monitored only during the second round of sampling. Thus, an independent evaluation of indoor levels of

the target compounds could be obtained with these measurements. Table 18 presents the summary statistics for the OVM measurements, separately by study area. The data summarized in this table excludes the first round measurements in the five homes, in order to not bias the results by double weighting a few homes. A nonparametric procedure for two independent samples (Mann-Whitney U) was employed to test for statistically significant differences between the indoor concentrations measured in the two areas. The only significant difference was for tetrachloroethylene ($p = 0.047$); indoor concentrations were higher in the Ship Channel area. These results are not directly comparable with those from the indoor PE tube measurements, since the latter include approximately twice as many measurements.

7.3.6. Contributions of Indoor and Outdoor Sources to Indoor Concentrations

The results estimated from the one compartment model show large home-to-home variations in both source strength (*S*) values and the fractional outdoor contributions to indoor concentrations for all the VOCs. Across-home estimates of indoor source strengths for optimal VOCs are presented in Table19. Estimated outdoor source contributions to residential indoor concentrations of optimal VOCs are summarized in Table 20. Corresponding graphical representations showing all compounds are presented as Figures 13 and 14. Corresponding tables for non-optimal VOCs and comparison results from the RIOPA study are presented in Appendix J. Overall, the calculated source strengths are consistent with the interpretation of the scatter plots presented in Figure 12 and Figure I-2. 1,4-Dichlorobenzene, styrene, and toluene had relatively high indoor source strengths, low fractional outdoor contributions, and high I/O ratios. 1,4-Dichlorobenzene had strong indoor sources such as mothballs and solid deodorizers in a fraction of the homes. The estimated indoor source strengths observed in HEATS homes were consistently significantly lower than that of RIOPA Texas homes (one third to one fifth).

More than 80 % of indoor concentration of 1,3-butadiene, and almost 100% of carbon tetrachloride, 1,3,5-trimethylbenzene, and trichloroethylene were contributed from outdoor concentrations. For carbon tetrachloride which has no known sources, the contribution from outdoor air was 100% in all homes. It is interesting that less than 40% of indoor concentrations of o-xylene, m&p-xylene, ethylbenzene, 1,2,4-trimethylbenzene, benzene, and 1,2,3-trimethylbenzene were attributed to outdoor sources. Infiltration from attached garages, carports, and within-home storage of gasoline, paints and solvents might account for elevated levels of these petrochemical-based compounds in a fraction of the homes. These compounds' outdoor contributable fractions observed in HEATS homes were 10 to 30 % lower than the results observed in Texas homes of the RIOPA study (Figure 14). As listed in Table 20, the median fractions of outdoor contributions for RIOPA Texas homes were lower than the overall median fractions for RIOPA homes. This suggests that larger fractions were due to indoor sources of these compounds and this is supported by the observation that the indoor source strengths of these compounds were almost twice that for RIOPA overall (Table 19).

7.3.7. Patterns of Health Symptoms

A total of 73 initial household interviews were completed, 37 in the Ship Channel area, and 36 in the Aldine area. Follow-up health surveys were completed for 50 households, 26 in the Ship

Channel and 24 in Aldine. A preponderance of surveys were completed by females (49 out of 73 in the initial interview, and 33 out of 17 in the follow up interview).

7.3.7.1. Data Reduction

The Health Symptoms Questionnaire yielded a large dataset with over 1000 variables which included self-report by the person completing the questionnaire as well as data regarding the health status of other adult members of the household, and resident children. To reduce the dataset to a manageable number of variables, data were aggregated by counting number of individuals in each household with the same symptom and/or diagnosis and creating a summary variable. For example, one area of the questionnaire elicited a present/not present response for a constellation of symptoms or diagnoses for each person in the household (male head of household, female head of household, grandparents, any other resident adult, and up to five children). This yielded nine separate variables in the data set (4 adults and 5 children). To reduce data and to produce a better comparison variable, the nine variables were reduced to two (one for adults and one for children) by counting number of cases of adults in the household with the symptom and number of children with the same symptom. These summary variables were then used in comparing symptoms per household for the two geographic study areas. It is important to note that the same symptoms were compared. Thus, in no instance was a symptom of cough compared to a diagnosis of cancer. The reduced data set consists of 214 variables. The list of variables, their labels and the results of statistical comparisons are included in Appendix L.

The analysis comparing symptoms revealed few instances of statistically significant findings as observed in a comparison of means by geographic area. Few cases/symptoms were reported in both areas so this could affect our power to detect an effect if one was present in the data. Because we were concerned about lack of statistical power due to low number of cases, some symptoms were aggregated into scales of symptoms similar in nature. The results from comparisons of specific variables and scaled symptoms is presented in Table L-1 (Appendix L). Cases and comparisons for specific symptoms included in a scale are listed directly under the results for the comparison for that scale.

Comparison of the vast majority of individual symptoms and diagnoses by Chi-square analysis did not reveal statistically significant findings, with the exception of self-reported bone pain ($p=0.03$) and a report of any adult with bone or joint problems ($p=0.03$). Prevalence of lifetime (ever reported) asthma was 5.7% in the Ship Channel area and 8.3% in Aldine, both based upon a small number of cases, with no statistical differences between neighborhoods. Prevalence of current (symptomatic) asthma was 3% in the Ship Channel area and 8% in Aldine, again, both based upon only a handful of cases, with no statistical differences between neighborhoods. Comparison of reported scaled conditions by location was unremarkable with two exceptions. Reports of skin disorders in children were more prevalent in the Ship Channel area ($p = 0.05$), driven largely by reports of eczema and other skin disorders. Depression and anxiety are more prevalent in the Ship Channel area residents, although this finding did not reach statistical significance. Comparison of reproductive outcomes also failed to identify any statistically significant differences.

7.3.8. Patterns of Risk Perception

The Perception of Risk Questionnaire consisted three separate sections regarding perceived risk to self and/or family as well as risk to the Houston community overall for:

1) Perceived Risk: high voltage power lines, waste incinerators, nuclear waste, AIDS, safe drinking water, lack of sewerage, chemical pollution, pesticides in the food supply, cigarette smoking, bacteria in the food supply, motor vehicle accidents, asbestos, ozone and outdoor air quality, crime and violence, terrorist attacks, alcohol or drug abuse, world climate change, sun exposure, indoor air quality, hazardous wastes, bird flu, and mad cow disease,

2) Sources of Information and Public Trust: sources of information and the subject's level of confidence in each source including: television, newspaper, radio, internet, private industry, city/county health departments, Texas Department of State Health Services, the Environmental Protection Agency, university scientists, friends and relatives, and the level of responsibility the subject perceives each of these entities exercises in protecting the environmental health of the public, and

3) Personal Beliefs: conditions and issues related to health risk, including opinions about risk posed by chemicals, degree of community pollution, personal and governmental responsibility for health and environmental conditions, and self efficacy

The summary data and results from comparison between areas are presented in Table L-2, Appendix L. Each section of the survey elicited a response on a 5 point Likert-style scale. The Perceived Risk section, for example, evaluates risk perception on a scale of 0 to 4, with each numeric increase reflecting a unit increase in perceived risk (0=No opinion of risk; 1=Almost no health risk, 2=Slight health risk, 3=Moderate health risk, 4=High health risk).

To compare results from our two target neighborhoods, we used an independent t-test to compare the mean scores of the Ship Channel area and Aldine neighborhoods for each question. For each variable, the sample size, mean, standard deviation, and standard error of the mean are shown as are the difference in means: mean, standard error, and confidence. Also included are results of the Levene's test for equality of variances, and both pooled- and separate-variances t tests for equality of means. While few comparisons between the groups were actually statistically significant at a $p=0.05$, several were, and some variables approached statistical significance.

Several distinctions were found related to the subjects beliefs' that public and/or public health entities were carrying out their missions of protecting people from health risks, including the internet ($p=0.029$), private industry ($p=0.03$), and city/county health departments ($p=0.039$). Individuals from the Ship Channel area were more likely to report using the television as a source of information ($p=0.057$) and, unsurprisingly, to report in greater confidence in the accuracy of television reporting ($p=0.034$). While not statistically significant, individuals from the Ship Channel area were more likely to report that the internet is a responsible source of information (57%), compared with only 40% of those from Aldine ($p = 0.276$). Those from

Aldine were also less likely to voice a sense of responsibility on the part of private industry in protecting public health (33% vs. 57%; p = 0.077). The Ship Channel area residents were also more likely to respond that the city/county health department demonstrated major responsibility for public health at 64.9% vs. 38.9% (p = 0.02).

Only one question elicited a statistically significant finding for beliefs regarding conditions or issues related to health risks, i.e., "I feel that I have very little control over risks to my health" (p=0.03), although several questions were close to reaching statistical significance, including the adequacy of laws to regulate chemical risk (p=0.109), the need to reduce restrictions on chemicals (p=0.083), and a reflection that society tends to overemphasize the importance of small health risks (p=0.062). Seventy percent of residents of the Ship Channel area disagreed with the statement presented above in quotes, related to control over risks to their health, compared with only 30% of Aldine residents, echoed by responses related to the adequacy of laws to regulate chemical risks, with 59% of the Ship Channel area residents indicating that they did not find laws adequate to protect against risk, compared with only 44% from Aldine. This same pattern of response was elicited by a question suggesting that fewer laws should exist to regulate chemicals, with 56.7% of the Ship Channel area strongly disagreeing with this statement, and only 40.6% of Aldine residents disagreeing. This may be reflective of the trend that residents of the Ship Channel report had a greater number of reports of depression and anxiety than the residents of Aldine, although the comparison did not yield a statistically significant finding.

Given the lack of statistical significant differences for the large majority of the variables in the risk and health symptom surveys, and those differences in exposures between the two areas were also found not to be statistically significant, no analysis of relationships between exposures and risk or health outcomes for each area was performed. Future analysis of potential relationships will be done combining the information for both areas.

7.4. Tests of Hypotheses for Optimal VOCs

7.4.1. Primary Hypothesis Test (Aims 1 and 2)

H_0: Personal exposures to TRI-reported target HAPs are similar for both communities.

A) Parametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L)$$

where:

y_{ij} = log transformation (log [1 + concentration]) of personal HAP exposure on i^{th} occasion of measurement for j^{th} subject

L = indicator variable for location (0 = Aldine, 1 = Ship Channel)

β's = unknown regression coefficients to be determined

The results of the tests of the primary hypothesis using this model indicated that there were no statistically significant ($p < 0.05$) differences in personal exposures between study areas for all nine target compounds (see Table 21).

B) Nonparametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L)$$

where:

y_{ij} = rank transformation of personal HAP exposure on i^{th} occasion of measurement for j^{th} subject

L = indicator variable for location (0 = Aldine, 1 = Ship Channel)

β's = unknown regression coefficients to be determined

The results of the tests of the primary hypothesis using this model indicated that personal exposures to 1,2,4-trimethylbenzene were significantly higher in Aldine compared to the Ship Channel. For all the remaining eight target compounds, there were no statistically significant ($p < 0.05$) differences in personal exposures between study areas (see Table 22).

7.4.2. Secondary Hypotheses Tests (Aims 1 and 2)

1) H_0: Residential indoor concentrations of TRI-reported target HAPs are similar for both communities.

A) Parametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L)$$

where:

y_{ij} = log transformation (log [1 + concentration]) of indoor HAP concentration on i^{th} occasion of measurement for j^{th} house

L = indicator variable for location (0 = Aldine, 1 = Ship Channel)

β's = unknown regression coefficients to be determined

The results of the tests of this secondary hypothesis using this model indicated that indoor concentrations of styrene were significantly higher in Aldine compared to the Ship Channel. For all the remaining eight target compounds, there were no statistically significant ($p < 0.05$) differences in indoor concentrations between study areas (see Table 21).

B) Nonparametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L)$$

where:

y_{ij} = concentration of indoor HAP concentration on i^{th} occasion of measurement for j^{th} house

L = indicator variable for location (0 = Aldine, 1 = Ship Channel)

β's = unknown regression coefficients to be determined

The results of the tests of this secondary hypothesis using this model indicated that there were no statistically significant ($p < 0.05$) differences in indoor concentrations between study areas for all nine target compounds (see Table 22).

2) H_0: Residential outdoor concentrations of TRI-reported target HAPs are similar for both communities.

A) Parametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L)$$

where:

y_{ij} = log transformation (log [1 + concentration]) of outdoor HAP concentration on i^{th} occasion of measurement for j^{th} house
L = indicator variable for location (0 = Aldine, 1 = Ship Channel)
β's = unknown regression coefficients to be determined

The results of the tests of this secondary hypothesis using this model indicated that for all nine target compounds, there were no statistically significant ($p < 0.05$) differences in outdoor concentrations between study areas (see Table 21).

B) Nonparametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L)$$

where:

y_{ij} = rank transformation of outdoor HAP concentration on i^{th} occasion of measurement for j^{th} subject
L = indicator variable for location (0 = Aldine, 1 = Ship Channel)
β's = unknown regression coefficients to be determined

The results of the tests of this secondary hypothesis using this model indicated that for all nine target compounds, there were no statistically significant ($p < 0.05$) differences in outdoor concentrations between study areas (see Table 22).

3) H_0: Fixed site ambient air concentrations of TRI-reported target HAPs are similar for both communities.

A) Parametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L)$$

where:

y_{ij} = log transformation (log [1 + concentration]) of fixed site HAP concentration on i^{th} occasion of measurement for j^{th} subject

L = indicator variable for location (0 = Aldine, 1 = Ship Channel)

β's = unknown regression coefficients to be determined

The results of the tests of this secondary hypothesis using this model indicated that fixed site concentrations of three target compounds (styrene, ethylbenzene and 1,2,4-trimethylbenzene) were significantly higher in the Ship Channel compared to Aldine. For all the remaining six target compounds, there were no statistically significant ($p < 0.05$) differences in fixed site concentrations between study areas (see Table 21).

B) Nonparametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L)$$

where:

y_{ij} = rank transformation of fixed site HAP concentration on i^{th} occasion of measurement for j^{th} subject

L = indicator variable for location (0 = Aldine, 1 = Ship Channel)

β's = unknown regression coefficients to be determined

The results of the tests of this secondary hypothesis using this model indicated that fixed site concentrations of five target compounds (styrene, ethylbenzene, 1,2,4-trimethylbenzene, 1,2,3-trimethylbenzene and 1,3,5-trimethylbenzene) were significantly higher in the Ship Channel compared to Aldine. For all the remaining four target compounds, there were no statistically significant ($p < 0.05$) differences in fixed site concentrations between study areas (see Table 22).

7.4.3. Secondary Hypotheses Tests (Aim 3)

1) H_0: Fixed site ambient air concentrations are significant predictors of residential outdoor concentrations of TRI-reported target HAPs in each of the communities.

Parametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L) + \beta_2(M) + \beta_3(LM)$$

where

y_{ij} = log transformation (log [1 + concentration]) of outdoor concentration of selected HAP on i^{th} occasion of measurement for j^{th} house
L = indicator variable for location (0 = Aldine, 1 = Ship Channel)
M = measured fixed site concentration of selected HAP
LM = interaction of location and measured fixed site concentration

The results of the tests of this secondary hypothesis indicated that fixed site concentrations of ethylbenzene, m&p-xylene, o-xylene and 1,2,4-trimethylbenzene were significant predictors of residential outdoor concentrations in both areas; styrene and 1,4-dichlorobenzene were significant predictors only in Aldine; tetrachloroethylene was a significant predictor only in the Ship Channel; and 1,2,3-trimethylbenzene and 1,3,5-trimethylbenzene were not significant predictors in either area (see Table 23).

2) H_0: Fixed site ambient air concentrations are significant predictors of residential indoor concentrations of TRI-reported target HAPs in each of the communities.

Parametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L) + \beta_2(M) + \beta_3(LM)$$

where

y_{ij} = log transformation (log [1 + concentration]) of indoor concentration of selected HAP on i^{th} occasion of measurement for j^{th} house
L = indicator variable for location (0 = Aldine, 1 = Ship Channel)
M = measured fixed site concentration of selected HAP
LM = interaction of location and measured fixed site concentration

The results of the tests of this secondary hypothesis indicated that fixed site concentrations of ethylbenzene, m&p-xylene, o-xylene and 1,4-dichlorobenzene were significant predictors of residential indoor concentrations in both areas; tetrachloroethylene and styrene were significant predictors only in Aldine; 1,2,4-trimethylbenzene was a significant predictor only in the Ship Channel; and 1,2,3-trimethylbenzene and 1,3,5-trimethylbenzene were not significant predictors in either area (see Table 24).

3) H_0: Fixed site ambient air concentrations are significant predictors of personal exposures to TRI-reported target HAPs in each of the communities.

Parametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L) + \beta_2(M) + \beta_3(LM)$$

where

y_{ij} = log transformation (log [1 + concentration]) of personal exposure to selected HAP on i^{th} occasion of measurement for j^{th} subject
L = indicator variable for location (0 = Aldine, 1 = Ship Channel)

M = measured fixed site concentration of selected HAP
LM = interaction of location and measured fixed site concentration

The results of the tests of this secondary hypothesis indicated that fixed site concentrations of ethylbenzene, m&p-xylene, and o-xylene were significant predictors of personal exposures only in Aldine; tetrachloroethylene, styrene, 1,4-dichlorobenzene and 1,2,4-trimethylbenzene were significant predictors only in the Ship Channel; and 1,2,3-trimethylbenzene and 1,3,5-trimethylbenzene were not significant predictors in either area (see Table 25).

7.4.4. Secondary Hypothesis Test (Aim 4)

H_0: The relative contribution of residential outdoor concentrations of TRI-reported target HAPs to residential indoor concentrations is similar for both communities.

Parametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L) + \beta_2(M) + \beta_3(LM)$$

where

y_{ij} = log transformation (log [1 + concentration]) of indoor concentration of selected HAP on i^{th} occasion of measurement for j^{th} house
L = indicator variable for location (0 = Aldine, 1 = Ship Channel)
M = measured outdoor concentration of selected HAP
LM = interaction of location and measured outdoor concentration

The results of the tests of this secondary hypothesis indicated that the relative contribution of residential outdoor air concentrations to indoor concentrations was similar in both study areas, except for 1,4-dichlorobenzene (see Table 26).

7.4.5. Primary Hypothesis Test Using Multivariate Model

H_0: Personal exposures to TRI-reported target HAPs are similar for both communities, after accounting for differences in influential covariates.

Parametric regression model:

$$y_{ij} = \beta_0 + \beta_1(L) + \beta_2(x_2) + \beta_3(x_3) + \ldots$$

where

y_{ij} = log transformation (log [1 + concentration]) of personal HAP exposure on i^{th} occasion of measurement for j^{th} subject
L = indicator variable for location (0 = Aldine, 1 = Ship Channel)
β's = unknown regression coefficients to be determined

$x_2, x_3, \ldots$ = sociodemographic or other covariates

The results of the test of the primary hypothesis using a multivariate model confirmed the results from the initial test of this hypothesis, i.e., that there were no statistically significant ($p < 0.05$) differences in personal exposures between study areas for all nine target compounds.

7.4.6. Detailed Description of Regression Analyses for Aims 1 and 2 Hypotheses

A detailed summary of the weighted parametric regression analyses utilized for the testing of the primary and secondary hypotheses for Aims 1 and 2 for all optimal VOCs is presented in Appendix K. The regression parameters and confidence intervals are expressed as the transformed variable used in the calculations, i.e., $\log_{10}(x+1)$, where x is the concentration in $\mu g/m^3$. Plots of residuals for each regression are also included.

The assumption that the residuals are independently normally distributed implies through a mathematical theorem that the least squares estimates of the model parameters are normally distributed and that the ratios of the parameter estimates to their standard errors (SE's) follow a t-distribution, thus permitting statistical tests with controlled error probabilities. However, for "large" samples, the estimates of the model parameters may be at least approximately normally distributed even though the assumption that the residuals are normally distributed is not met. This is a result of the Central Limit Theorem which states that parameter estimates based on "large" samples from any (non-degenerate) distribution whatever are approximately normally distributed.

Usually, samples of size 30 or more are recommended to invoke the Central Limit Theorem and thus justify statistical tests with controlled error probabilities. In this study, for each measured VOC, there are from 73 to 78 households approximately evenly divided between the two study areas. This results in enough independent observations to produce approximately normally distributed parameter estimates even when the distribution of the residuals deviates from normality. Estimates of the standard errors carry in excess of 70 degrees of freedom as do the resulting t-tests.

7.4.7. Effect of Sample Size on Results of Hypothesis Testing for Aims 1 and 2

The ability to detect a small difference in concentration between the study areas is dependent on sample size, as well as magnitude and variability of the concentrations. Although the initial sample size estimates for HEATS were determined (at a power of 80% and $\alpha = 0.05$) using a difference in measured benzene concentrations at fixed monitoring sites in each area during 2004, it is likely that this difference has decreased since then, and other target VOCs may show larger or smaller differences. Therefore, it was decided to perform a post-hoc assessment of the minimum detectable difference for each of the optimal compounds. This analysis utilized the individual regression model derived for each tested relationship (see Appendix K) in order to

determine the minimum difference in concentrations between the study areas that could be detected ($\alpha = 0.05$), with the number of samples measured in this study. A summary of the results of this analysis is presented in Table 27. The first three rows for each VOC show the average concentrations observed from the four types of regression models for the Aldine area, the Ship Channel area, and the signed difference between the two (Ship Channel – Aldine), all expressed as $\mu g/m^3$. From the regression models presented in sections 7.4.1 and 7.4.2, it can be seen that the average concentration in Aldine can be calculated from β_0 (constant) by taking the antilog and then subtracting 1. Likewise, the average concentration in the Ship Channel can be calculated from the sum of β_0 and β_1 (slope) by taking the antilog and then subtracting 1. The last row for each VOC in Table 27 shows the calculated minimum detectable difference in concentrations between study areas (unsigned) for each type of regression model. The concentrations are calculated in a similar way as the actual concentrations, except that the value of β_1 is replaced by a value equal to twice the standard error, taking into account the sign of β_1. This is derived from the fact that the null hypothesis is rejected when $\left| \beta_1 / (\text{se } \beta_1) \right| > 2$, therefore, $\beta_1 = 2$ (se β_1) is the minimum detectable difference.

Significant differences between concentrations are highlighted in Table 27, i.e., where the absolute value of the observed difference exceeds the minimum detectable difference. These results suggest that the HEATS study design, i.e., the number of samples in each study area, was adequate to detect meaningful differences in concentrations for fixed site and residential outdoor measurements. The minimum detectable differences for the target optimal compounds for these two types of measurements ranged from 0.1 to 0.6 $\mu g/m^3$. The minimum detectable differences were generally similar for fixed site and residential outdoor measurements, thus supporting the observed difference in results between these two types of measurements, i.e., significantly higher fixed site concentrations for three VOCs in the Ship Channel area, while there were no significant differences between the areas for any VOC measured in residential outdoor samples. Furthermore, a trend could be observed for six of the nine compounds, whereby fixed site concentrations were higher in the Ship Channel area, while the corresponding residential outdoor concentrations were higher in the Aldine area.

The minimum detectable differences in optimal VOC concentrations for personal exposures and residential indoor measurements were generally considerably higher, especially for 1,4-dichlorobenzene and m&p-xylene. Thus, the number of samples may have been insufficient to detect meaningful differences between study areas for these two types of measurements. However, residential indoor concentrations of styrene in Aldine were found to be significantly higher than those in the Ship Channel, and for six of the remaining eight VOCs, a trend of higher concentrations in Aldine for both personal exposures and residential indoor measurements was observed.

8. STUDY CONCLUSIONS

1. Recruitment and enrollment of participants was an extraordinary challenge with this population. More resources in time and personnel need to be devoted to this type effort in

advance of field sampling implementation. There is a need for research on the social and cultural drivers for participation in research studies among populations that include large proportions of foreign-born individuals who reside in areas with relatively small proportions of US-born or otherwise acculturated persons.

2. Sampling methods should be fully evaluated at specific locations where monitoring is to be conducted in advance of the implementation of a study, in particular when the method is not yet widely use by multiple investigator groups.

3. In spite of the limitations, the HEATS results are consistent with findings from other major exposure studies (e.g., TEAM, NHEXAS, RIOPA, DEARS) in that personal exposures are higher than ambient levels of VOCs, and that they are more strongly associated with residential indoor concentrations than with outdoor or fixed site measurements.

4. The HEATS design was adequate to detect meaningful (i.e., health-relevant) differences between areas for residential outdoor and fixed site concentrations. However, the number of samples may have been insufficient to detect meaningful differences between study areas for residential indoor and personal measurements.

5. Estimated minimum detectable differences (α=0.05) in concentrations between study areas for outdoor and fixed site concentrations were comparable, suggesting that, since some significant differences between areas were found for fixed site measurements, if the determinants of outdoor concentrations were the same as those for the respective fixed sites, then we would expect to find multiple significant differences for the outdoor concentrations also. Since differences were not found and the relationships between mean outdoor concentrations in the two areas were frequently reversed compared to the respective fixed site means, it can be concluded that there have to be differences between determinants of outdoor concentrations and determinants of fixed site concentrations, and that the determinants of outdoor concentrations are comparable in the two areas.

6. While the results showed that there are differences in fixed site concentrations between the two areas, fixed site concentrations may not be good predictors of differences in relevant microenvironmental concentrations or personal exposures between the participants enrolled in the Ship Channel and in Aldine.

7. While personal characteristics such as time spent in the home or employment status, as well as residential characteristics such as type of dwelling and air exchange rate were associated with differences in personal exposure, the similarity in personal measurements between the two areas persisted even after accounting for these covariates.

8. Patterns of health symptoms and risk perception were remarkably similar in the two areas. However, this finding, combined with the comparable exposure levels between the participants residing in the two areas, cannot be interpreted as evidence that there are no exposure-associated health risks. Further analysis of the combined exposure and health data is planned to evaluate potential exposure-response associations and identify subgroups that may be at increased health risk.

This report is based on a limited analysis of a very rich database. Therefore additional insights may be derived in future analyses of the data by exposure researchers.

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* Indicates reference does not come from the peer-reviewed literature.

10. LIST OF TABLES

Table 1. HEATS target VOCs. VOCs in bolded font are those for which there are empirical sampling rates for PE Tubes.

VOC	CAS No.
1,2,3-Trimethylbenzene	**526-73-8**
1,2,4-trimethylbenzene	95-63-6
1,3,5-Trimethylbenzene	**108-67-8**
1,3-Butadiene	**106-99-0**
1,4-Dichlorobenzene	**106-46-7**
2,3-Dimethylpentane	565-59-3
a-Pinene	80-56-8
β-Pinene	127-91-3
Benzene	**17-43-2**
Carbon Tetrachloride	**56-23-5**
Chloroform	67-66-3
Chloroprene	126-99-8
d-Limonene	5989-27-5
Ethylbenzene	**1004-14-41**
Isoprene	78-79-5
m,p-Xylene	**108-38-3**
Methyl Ethyl Ketone	78-93-3
Methyl tert-Butyl Ether	1634-04-4
Methylcyclopentane	96-37-7
Methylene Chloride	75-09-2
Naphthalene	91-20-3
n-Decane	124-18-5
n-Hexane	110-54-3
n-Pentane	109-66-0
o-Xylene	**95-47-6**
Styrene	**100-42-5**
Toluene	**108-88-3**
Tetrachloroethylene	**79-01-6**
Trichloroethylene	**1271-81-4**

Table 2a. Fugitive and Point Source Emissions to Air of Selected HAPs in the Ship Channel Area Zip-Codes* (2003; in pounds/year)

HAPs	77012 Fugitive	77012 Point Source	77017 Fugitive	77017 Point Source	77547 Fugitive	77547 Point Source	77506 Fugitive	77506 Point Source	Ship Channel Total	US Fugitive	US Point Source	US Total	Ship Channel % of US Total
1,3-BUTADIENE	95	70	61745	62852	54	5757	10900	8500	149973	740699	1241592	1982290	7.57
ACETALDEHYDE	52	94					580	833	1559	2244725	10725714	12970439	0.01
BENZENE	1322	9929	64251	28276	435	1520	3774	3619	113126	2140987	4120804	6261791	1.81
DICHLOROMETHANE	30	55							85	3092299	5478927	8571226	0
ETHYLBENZENE	1469	3547	12708	19787	65	153	647	556	38932	1463262	4465496	5928758	0.66
m-XYLENE			0	28271					28271	141862	417715	559578	5.05
METHYL ETHYL KETONE	9	16							25	10131521	14422389	24553911	0
METHYL TERT-BUTYL ETHER	7256	11768	10624	13996	6200	8300	5522	12796	76462	738062	1694212	2432275	3.14
n-HEXANE	2620	19460	55742	1112	954	2606	10956	80750	174200	15822673	25771429	41594102	0.42
NAPHTHALENE	3119	841	290	5					4255	560713	1480894	2041608	0.21
p-XYLENE			21543	30500					52043	363561	943435	1306996	3.98
STYRENE	0	1	71072	231150			4367	1038	307628	10144344	38139993	48284338	0.64
TOLUENE	4959	16263	52113	41573	641	1323	6570	10484	133926	20068074	35176405	55244480	0.24
XYLENES (MIXED ISOMERS)	5509	16187	103478	24637	271	563	4434	9764	164843	8919597	28573532	37493129	0.44
Total	26440	78231	453566	482159	8620	20222	47750	128340	1245328				

* Includes only zip codes with reported TRI emissions

Table 2b. Fugitive and Point Source Emissions to Air of Selected HAPs in the Aldine Area Zip-Codes* (2003; in pounds/year)

HAPs	77037 Fugitive	77037 Point Source	77039 Fugitive	77039 Point Source	Aldine Total
Benzene	108	119			227
Ethylbenzene	36	43			79
Methyl tert-butyl ether	3053	3367			6420
n- Hexane	368	396			764
o-Xylene			2647	41473	44120
Styrene	0	14120	0	129280	143400
Toluene	331	345			676
Xylene (Mixed isomers)	141	165			306
Total	4037	18555	2647	170753	195992

* Includes only zip codes with reported TRI emissions

Table 3. Descriptive Statistics for 24-Hour Concentrations at Fixed Sites in the Two Study Areas (ppb)

HAPs	ALDINE							MILBY PARK (Ship Channel)						
	Mean	Median	Minimum	Maximum	Std. Deviation	Geometric Mean	N	Mean	Median	Minimum	Maximum	Std. Deviation	Geometric Mean	N
1, 3-Butadiene	0.12	0.06	0.01	0.95	0.19	0.03	52	4.03	1.81	0.01	37.42	6.39	0.81	60
Benzene	0.47	0.43	0.12	1.72	0.28	0.41	52	0.74	0.53	0.13	6.84	0.92	0.52	60
Carbon Tetrachloride	0.10	0.10	0.06	0.15	0.02	0.10	52	0.10	0.10	0.05	0.20	0.02	0.10	60
Chloroform	0.02	0.01	0.01	0.13	0.02	0.01	52	0.05	0.04	0.01	0.42	0.06	0.03	60
Ethyl Benzene	0.06	0.04	0.01	0.27	0.06	0.03	52	0.12	0.10	0.01	0.69	0.10	0.08	60
Methylene Chloride	0.05	0.01	0.01	0.44	0.07	0.02	52	0.06	0.05	0.01	0.24	0.07	0.03	60
Styrene	0.03	0.01	0.01	0.21	0.04	0.01	52	0.43	0.14	0.01	2.54	0.59	0.09	60
Tetrachloroethylene	0.01	0.01	0.01	0.07	0.02	0.01	52	0.01	0.01	0.01	0.14	0.03	0.01	59
Toluene	0.44	0.37	0.09	1.46	0.30	0.35	52	0.36	0.29	0.06	1.27	0.27	0.28	60
Trichloroethylene	0.01	0.01	0.01	0.07	0.01	0.01	52	0.01	0.01	0.01	0.03	0.00	0.01	60
o-Xylene	0.05	0.03	0.01	0.20	0.05	0.03	52	0.05	0.05	0.01	0.22	0.05	0.03	60
m/p-Xylene	0.17	0.12	0.03	0.63	0.12	0.13	52	0.17	0.14	0.01	0.63	0.13	0.12	60
Methyl-t-Butyl ether	0.40	0.29	0.01	1.79	0.35	0.28	52	0.62	0.46	0.01	2.64	0.57	0.40	60

Data represent 24-hour integrated samples collected with canisters every six days during 2004

Table 4 Aldine Response Rates

Result	**Number**	**Percentage**
Not a residential address	11	3.54%
Unable to locate address	3	0.96%
Vacant	27	8.68%
No one at address/repeated attempts	65	20.90%
Access denied	15	4.82%
Refusal - before completing screener	52	16.72%
Moving within the next 12 months	17	5.47%
Smoker in household	64	20.58%
Language barrier - other	0	0.00%
Physically/mentally incapable	1	0.32%
Refusal - after completing screener	12	3.86%
Recruited adult	19	6.11%
Recruited adult and child	25	8.04%
Total	**311**	100.00%
Eligible Households	270	
Screened Households	138	
Screened Households Rate	51.1%	
Recruited Households	44	
Recruited Households Rate	31.9%	
Smokers/Screened Households	46.4%	
Overall Recruitment Rate	16.3%	
Nonresponding households	132	
Ineligible households	82	
Nonresponding persons	12	
Respondents	44	
Enrolled	38	
Total	311	
Aldine Eligibility Rates		**Assumed**
Address-level	86.8%	93.0%
Household-level	40.6%	85.0%
Overall	35.2%	79.1%
Aldine Recruitment Rates		**Assumed**
Household-level	51.1%	80.0%
Person-level	78.6%	75.0%
Overall Recruitment Rate	40.2%	60.0%
Enrolled/Eligible Respondents	67.9%	
Overall Enrollment Response Rate	34.7%	

Table 5 Ship Channel Response Rates

Result	**Number**	**Percentage**
Not a residential address	5	1.85%
Unable to locate address	3	1.11%
Vacant	34	12.59%
No one at address/repeated attempts	34	12.59%
Access denied	5	1.85%
Refusal - before completing screener	48	17.78%
Moving within the next 12 months	12	4.44%
Smoker in household	60	22.22%
Language barrier - other	2	0.74%
Physically/mentally incapable	0	0.00%
Refusal - after completing screener	4	1.48%
Recruited adult	25	9.26%
Recruited adult and child	38	14.07%
Total	**270**	100.00%
Eligible Households	228	
Screened Households	139	
Screened Households Rate	61.0%	
Recruited Households	61	
Recruited Households Rate	43.9%	
Smokers/Screened Households	43.2%	
Overall Recruitment Rate	26.8%	
Ineligible addresses	42	
Nonresponding households	89	
Ineligible households	72	
Nonresponding persons	4	
Respondents	63	
Enrolled	40	
Total	270	
Ship Channel Eligibility Rates		**Assumed**
Address-level	84.4%	93.0%
Household-level	48.2%	85.0%
Overall	40.7%	79.1%
Ship Channel Recruitment Rates		**Assumed**
Household-level	61.0%	80.0%
Person-level	94.0%	75.0%
Overall Recruitment Rate	57.3%	60.0%
Enrolled/Eligible Respondents	59.7%	
Enrollment Response Rate	36.4%	

Table 6. The percent of the quality assurance and quality control samples summarized by collected area (calculation based on total number of samples including, outdoor, indoor, personal adult, personal child, and fixed site main samples, N=612)

	Total	Aldine	Ship Channel
Collocated samples	12%	6%	7%
Field Blanks	13%	6%	6%
Lab Blanks	23%	na	na
Trip Blanks	12%	6%	5%
Positive controls	4%	3%	1%

Table 7. Analytical Precision (%) (N=74 pairs total)

	Median	Percent of usable pairs
Optimal VOCs		
Tetrachloroethylene	19%	93%
Ethylbenzene	18%	100%
m&p-Xylene	19%	100%
o-Xylene	18%	96%
Styrene	37%	100%
1,3,5-Trimethylbenzene	62%	55%
1,2,4-Trimethylbenzene	47%	88%
1,2,3-Trimethylbenzene	40%	78%
p-Dichlorobenzene	24%	97%
Non-optimal VOCs		
1,3-Butadiene	30%	99%
Carbon tetrachloride	181%	35%
Trichloroethylene	58%	12%
Benzene	31%	100%
Toluene	15%	100%

Usable pair was defined as any pair where at least one of the samples was detectable for each compound.

Table 7a. Regression of collocated UTSPH - PE samples and Auto-GC at fixed sites (samples blank-subtracted)

VOC ($\mu g/m^3$)	n	slope	intercept	Adj R^2
1,3 Butadiene	35	2.204	-0.404	0.837
Benzene	35	0.341	0.230	-0.021
Toluene	34	2.695	0.090	0.243
Ethylbenzene	35	4.589	0.054	0.682
m,p-Xylene	36	2.504	0.143	0.279
o-Xylene	35	2.132	0.205	0.069
Styrene	35	4.940	0.415	0.870
1,3,5-Trimethylbenzene	35	4.140	-0.007	0.199
1,2,4-Trimethylbenzene	35	6.055	0.009	0.250
1,2,3-Trimethylbenzene	34	4.500	0.014	0.097

$p < 0.05$ for all slopes except Benzene and o-Xylene

$p > 0.05$ for all intercepts except 1,3 Butadiene

Table 8. Descriptive Summary of Blank Concentrations (ng/tube) Analyzed before August 21 2008 (Block1).

Block 1	t test decision	Lab Blank			Field Blank			Pooled (Lab + Field)			MDL (µg/m³)
		Mean	SD	N	Mean	SD	N	Mean	SD	N	
Optimal VOCs											
Tetrachloroethylene	P	.023	.073	79	.028	.063	48	.025	.069	127	0.25
Ethylbenzene	FB	.033	.030	79	.071	.057	48	.047	.046	127	0.20
m,p-Xylene	FB	.062	.050	79	.122	.101	48	.085	.079	127	0.35
o-Xylene	FB	.009	.017	79	.026	.052	48	.015	.035	127	0.18
Styrene	FB	.113	.165	79	.242	.264	48	.161	.216	127	0.88
1,3,5-Trimethylbenzene	P	.000	.000	79	.002	.011	48	.001	.007	127	0.02
1,2,4-Trimethylbenzene	FB	.005	.016	79	.020	.053	48	.011	.036	127	0.19
1,2,3-Trimethylbenzene	P	.002	.011	79	.012	.042	48	.006	.027	127	0.10
p-Dichlorobenzene	P	.029	.072	79	.533	2.442	48	.220	1.513	127	4.67
Non-optimal VOCs											
1,3-Butadiene	FB	.234	.099	79	.323	.128	48	.268	.119	127	0.38
Carbon tetrachloride	P	.000	.000	79	.007	.046	48	.003	.028	127	0.10
Benzene	P	.391	.157	79	.527	.517	48	.442	.346	127	0.96
Trichloroethylene	P	.005	.023	79	.001	.006	48	.003	.019	127	0.07
Toluene	FB	.333	.234	79	.475	.391	48	.387	.309	127	1.21

FB: field and laboratory blanks are statistically different ($p \leq 0.05$) so the higher of the two (FB: field blank) was used for blank subtraction and MDL calculation

P: field and laboratory blanks are statistically similar ($p \geq 0.05$) so they were pooled for mean blank subtraction and MDL calculation

Table 9. Descriptive Summary of Blank Concentrations (ng/tube) Analyzed after August 21 2008 (Block2).

Block 2	t test decision	Lab Blank			Field Blank			Pooled (Lab + Field)			MDL (µg/m³)
		Mean	SD	N	Mean	SD	N	Mean	SD	N	
Optimal VOCs											
Tetrachloroethylene	P	.027	.051	61	.014	.040	30	.023	.048	91	0.17
Ethylbenzene	FB	.091	.067	61	.129	.090	30	.103	.077	91	0.32
m,p-Xylene	Pool	.216	.288	61	.286	.350	30	.239	.309	91	1.04
o-Xylene	FB	.041	.057	61	.072	.079	30	.051	.066	91	0.28
Styrene	P	.299	.464	61	.401	.468	30	.332	.466	91	1.53
1,3,5-Trimethylbenzene	P	.000	.004	61	.007	.040	30	.003	.023	91	0.08
1,2,4-Trimethylbenzene	P	.003	.014	61	.013	.042	30	.006	.027	91	0.09
1,2,3-Trimethylbenzene	P	.024	.078	61	.033	.075	30	.027	.077	91	0.27
p-Dichlorobenzene	P	.130	.799	61	.074	.140	30	.112	.658	91	2.04
Non-optimal VOCs											
1,3-Butadiene	P	.358	.107	61	.402	.234	30	.373	.161	91	0.47
Carbon tetrachloride	P	.000	.000	61	.008	.045	30	.003	.026	91	0.09
Benzene	P	.651	.286	61	.745	.412	30	.682	.334	91	0.93
Trichloroethylene	NA	.000	.000	61	.000	.000	30	.000	.000	91	0.07
Toluene	FB	.446	.187	61	.596	.336	30	.495	.254	91	1.06

FB: field and laboratory blanks are statistically different ($p \leq 0.05$) so the higher of the two (FB: field blank) was used for blank subtraction and MDL calculation

P: field and laboratory blanks are statistically similar ($p \geq 0.05$) so they were pooled for mean blank subtraction and MDL calculation

Table 10. Number of Participants by Area and Demographic Group

	Aldine		Ship Channel		Total	
	Adult	Child	Adult	Child	Adult	Child
Number	38	21	40	14	78	35
Country of Birth						
USA	12	10	19	10	31	20
Mexico	26	11	17	3	43	14
Peru	—	—	1	1	1	1
El Salvador	—	—	2	—	2	—
Guatemala	—	—	1	—	1	—
Age						
Mean	47	13	45	12	46	13
Minimum	21	7	22	6	21	6
Maximum	87	20	86	17	87	20
Gender						
Female	25	7	27	5	52	12
Male	13	14	13	9	26	23
Race/Ethnicity						
White	4	—	1	—	5	—
Black/African/African American	5	2	4	—	9	2
Hispanic	20	8	14	9	34	17
Hispanic Mexican American	9	11	18	5	27	16
Hispanic White	—	—	2	—	2	—
Other	—	—	1	—	1	—
Highest level of education completed						
No schooling or Kindergarten only	2		—		2	
Primary/Middle School	14		13		27	
Some high school	5		6		11	
High school graduate/GED	11		8		19	
Some College/Technical School	5		10		15	
College graduate	1		3		4	
Household Income						
Less than $24,999	17		10		27	
$25,000 - $49,000	11		17		28	
$50,000 - $74,999	1		4		5	
$75,000 - $99,999	1		2		3	
Don't know	2		5		7	
Wish not to answer	6		2		8	

Table 10. Number of Participants by Area and Demographic Group (continued)

	Aldine		Ship Channel		Total	
	Adult	Child	Adult	Child	Adult	Child
Work Status						
Working full time	17		13		30	
Working part time	4		2		6	
Self-employed/working at home/homemaker	9		12		21	
Out of work but usually employed	2		3		5	
Retired	5		7		12	
Disabled/Unable to work	1		1		2	
Missing	—		2		2	

Table 11. Number of Homes by Area and Classified by Home Characteristics

	Aldine	Ship Channel	Total
Number	38	40	78
Volume, m^3			
Mean	212	227	220
Minimum	64	115	64
Maximum	382	495	495
Home Type			
Mobile Home	8	2	10
One family house detached	22	32	54
One family house attached	3	2	5
1-4 apartments	4	—	4
5-20 apartments	1	4	5
Year the home was built			
1900 to 1954	1	24	25
1955 to 1969	13	8	21
1970 to 1984	11	5	16
1985 to 1994	2	—	2
1995 to 2004	4	—	4
2005 to present	—	1	1
Don't know	7	2	9
Attached Garage			
Yes	10	6	16
No	28	34	62
Attached Garage Location			
Same level as main living area	10	5	15
Underneath the main living quarters	—	1	1
Doorway between Attached Garage and Living Quarters			
Yes	8	4	12
No	2	2	4
Kitchen Stove Type			
Gas	29	33	62
Electric	8	7	15
Propane	1	—	1

Table 11. Number of Homes by Area and Classified by Home Characteristics (continued)

	Aldine	Ship Channel	Total
Type of Exhaust of Kitchen Stove			
Horizontal	—	1	1
Exhaust above stove	25	21	46
No exhaust	8	9	17
Missing	5	9	14
Type of Ventilation of Kitchen Stove			
Vented outside	15	17	32
Not vented outside	6	4	10
Recirculation vent	4	2	6
Missing	13	17	30
Heating Unit			
Electric	11	10	21
Gas	15	20	35
Not Available	12	10	22
Air Conditioning Unit			
Electric	24	27	51
Gas	4	3	7
Not Available	10	10	20

Table 12. Summary of air exchange rates (hr^{-1}) by study area and season.

AREA	Seasonality	Maximum	Mean	Median	Minimum	Std. Deviation	N
ALDINE	Spring	1.66	.53	.37	0.16	.42	19
	Summer	3.63	.49	.26	0.09	.83	17
	Fall	2.65	.57	.38	0.13	.56	29
	Winter	1.63	.80	.68	0.23	.64	4
	Total	3.63	.55	.36	0.09	.60	69
SHIP CHANNEL	Spring	4.21	.71	.44	0.03	.97	17
	Summer	0.68	.34	.36	0.09	.17	9
	Fall	3.25	.72	.56	0.06	.66	33
	Winter	2.39	1.18	1.07	0.41	.73	11
	Total	4.21	.74	.50	0.03	.74	70
Total	Spring	4.21	.62	.39	0.03	.73	36
	Summer	3.63	.44	.31	0.09	.67	26
	Fall	3.25	.65	.42	0.06	.62	62
	Winter	2.39	1.08	.97	0.23	.71	15
	Total	4.21	.65	.41	0.03	.68	139

Table 13. Descriptive Summary of Residential Outdoor Air Concentrations (µg/m³)

VOCs	N	Mean	SD	Percentiles				
				5	25	50	75	95
Overall								
Tetrachloroethylene	140	.19	.38	-.04	.01	.11	.25	.63
Ethylbenzene	140	.56	.67	-.02	.13	.31	.81	1.79
m&p-Xylene	140	1.84	2.63	-.02	.30	.88	2.54	6.05
o-Xylene	140	.67	.92	.00	.15	.34	.86	2.15
Styrene	140	.55	1.11	-.30	-.10	.09	.69	2.87
1,3,5-Trimethylbenzene	140	.12	.20	.00	.00	.00	.17	.61
1,2,4-Trimethylbenzene	140	.33	.48	-.03	.08	.16	.38	1.42
1,2,3-Trimethylbenzene	140	.18	.26	-.04	-.01	.10	.22	.76
p-Dichlorobenzene	140	3.68	29.56	-.25	-.08	.17	.54	8.85
Aldine								
Tetrachloroethylene	70	.19	.22	-.04	.05	.14	.26	.61
Ethylbenzene	70	.59	.71	.03	.13	.32	.82	1.77
m&p-Xylene	70	1.91	2.37	.00	.38	1.03	2.73	6.04
o-Xylene	70	.70	.84	.08	.19	.36	.93	2.17
Styrene	70	.58	1.23	-.33	-.15	.06	.72	2.90
1,3,5-Trimethylbenzene	70	.13	.22	.00	.00	.00	.17	.64
1,2,4-Trimethylbenzene	70	.34	.46	-.03	.09	.16	.42	1.41
1,2,3-Trimethylbenzene	70	.21	.30	-.01	.04	.10	.26	.89
p-Dichlorobenzene	70	6.49	41.70	-.22	-.04	.15	.47	17.46
Ship Channel								
Tetrachloroethylene	70	.19	.49	-.04	-.02	.06	.24	.65
Ethylbenzene	70	.53	.63	-.02	.11	.30	.81	1.81
m&p-Xylene	70	1.76	2.89	-.05	.21	.68	2.32	6.05
o-Xylene	70	.64	1.00	-.04	.13	.30	.77	2.06
Styrene	70	.52	.98	-.27	-.07	.12	.67	2.53
1,3,5-Trimethylbenzene	70	.11	.18	.00	.00	.00	.20	.54
1,2,4-Trimethylbenzene	70	.32	.51	-.03	.07	.15	.36	1.43
1,2,3-Trimethylbenzene	70	.15	.21	-.04	-.01	.11	.20	.63
p-Dichlorobenzene	70	.86	2.17	-.26	-.10	.20	.55	5.05

Table 14. Descriptive Summary of Residential Indoor Air Concentrations (µg/m³)

VOCs	N	Mean	SD	Percentiles				
				5	25	50	75	95
Overall								
Tetrachloroethylene	139	.70	2.12	-.04	.10	.23	.47	3.00
Ethylbenzene	139	1.93	3.59	.21	.66	1.11	1.75	4.88
m&p-Xylene	139	6.04	11.89	.43	1.67	3.15	5.75	19.38
o-Xylene	139	2.33	5.61	.24	.66	1.15	2.00	6.90
Styrene	139	1.53	1.77	.00	.48	.94	1.84	4.74
1,3,5-Trimethylbenzene	139	.61	2.02	.00	.00	.00	.53	2.22
1,2,4-Trimethylbenzene	139	1.58	3.04	-.01	.31	.64	1.46	8.26
1,2,3-Trimethylbenzene	139	.94	1.71	-.01	.21	.46	.96	3.74
p-Dichlorobenzene	139	37.80	91.49	-.01	.46	1.66	11.43	226.86
Aldine								
Tetrachloroethylene	70	.50	1.27	-.04	.15	.28	.49	1.04
Ethylbenzene	70	1.67	1.44	.32	.79	1.27	1.92	4.84
m&p-Xylene	70	5.27	5.04	.35	2.09	3.51	5.80	18.68
o-Xylene	70	1.84	1.61	.37	.81	1.27	2.05	6.28
Styrene	70	1.97	2.20	.04	.60	1.17	2.74	6.44
1,3,5-Trimethylbenzene	70	.41	.75	.00	.00	.00	.63	1.85
1,2,4-Trimethylbenzene	70	1.30	1.72	-.01	.36	.75	1.62	3.23
1,2,3-Trimethylbenzene	70	.84	.97	-.01	.28	.54	1.09	2.26
p-Dichlorobenzene	70	37.80	102.15	.09	.68	2.20	12.38	213.47
Ship Channel								
Tetrachloroethylene	69	.89	2.73	-.04	.09	.20	.46	3.70
Ethylbenzene	69	2.20	4.89	.19	.58	1.07	1.55	12.53
m&p-Xylene	69	6.82	16.13	.49	1.48	2.76	4.96	35.97
o-Xylene	69	2.82	7.79	.11	.59	1.04	1.77	13.10
Styrene	69	1.08	1.02	-.23	.47	.85	1.39	3.46
1,3,5-Trimethylbenzene	69	.81	2.77	.00	.00	.10	.45	2.97
1,2,4-Trimethylbenzene	69	1.86	3.95	-.01	.29	.51	1.13	11.08
1,2,3-Trimethylbenzene	69	1.03	2.23	-.04	.11	.40	.64	5.77
p-Dichlorobenzene	69	37.81	79.99	-.01	.34	.98	10.90	226.86

Table 15. Descriptive Summary of Personal Adult Air Concentrations (µg/m³)

VOCs	N	Mean	SD	Percentiles				
				5	25	50	75	95
Overall								
Tetrachloroethylene	140	.98	4.01	-.04	.14	.25	.49	2.47
Ethylbenzene	140	2.65	5.15	.24	.67	1.22	2.25	11.41
m&p-Xylene	140	8.15	14.78	.43	1.88	3.67	7.33	36.97
o-Xylene	140	3.20	5.84	.20	.75	1.37	2.74	14.79
Styrene	140	1.43	1.53	-.05	.46	.98	1.90	4.87
1,3,5-Trimethylbenzene	140	.78	2.09	.00	.00	.00	.64	3.59
1,2,4-Trimethylbenzene	140	2.40	6.05	.07	.35	.81	1.85	9.20
1,2,3-Trimethylbenzene	140	1.10	1.85	-.01	.27	.53	1.13	4.70
p-Dichlorobenzene	140	34.75	81.36	-.04	.63	2.00	11.45	204.96
Aldine								
Tetrachloroethylene	70	.38	.40	-.04	.18	.28	.46	1.07
Ethylbenzene	70	2.87	6.14	.33	.78	1.31	2.43	7.00
m&p-Xylene	70	8.43	15.55	.46	2.33	3.97	9.05	23.59
o-Xylene	70	3.18	5.58	.40	.88	1.46	3.09	9.24
Styrene	70	1.69	1.84	-.07	.47	1.10	2.30	5.25
1,3,5-Trimethylbenzene	70	.72	1.89	.00	.00	.00	.88	3.19
1,2,4-Trimethylbenzene	70	2.42	6.12	.10	.50	.86	2.17	7.27
1,2,3-Trimethylbenzene	70	1.09	1.50	-.01	.37	.68	1.30	2.73
p-Dichlorobenzene	70	35.17	90.56	.02	.94	3.02	11.31	212.32
Ship Channel								
Tetrachloroethylene	70	1.59	5.62	-.04	.10	.25	.64	7.12
Ethylbenzene	70	2.42	3.96	.14	.61	1.18	2.04	12.40
m&p-Xylene	70	7.86	14.09	.41	1.56	3.53	6.04	50.34
o-Xylene	70	3.22	6.12	.10	.62	1.28	2.16	20.80
Styrene	70	1.17	1.10	-.03	.41	.92	1.79	3.30
1,3,5-Trimethylbenzene	70	.84	2.29	.00	.00	.15	.54	4.77
1,2,4-Trimethylbenzene	70	2.39	6.03	.04	.28	.54	1.59	9.65
1,2,3-Trimethylbenzene	70	1.11	2.16	-.01	.14	.46	.84	6.25
p-Dichlorobenzene	70	34.32	71.65	-.09	.44	1.29	11.68	197.59

Table 16. Descriptive Summary of Personal Child Air Concentrations (µg/m³)

VOCs	N	Mean	SD	Percentiles				
				5	25	50	75	95
Overall								
Tetrachloroethylene	53	.86	2.48	-.04	.12	.27	.55	3.36
Ethylbenzene	53	2.99	5.79	.24	.82	1.45	2.89	9.05
m&p-Xylene	53	9.00	16.31	.71	2.48	3.98	7.37	37.26
o-Xylene	53	3.29	5.78	.24	.97	1.37	3.13	12.60
Styrene	53	1.40	1.47	.05	.56	.92	1.60	4.58
1,3,5-Trimethylbenzene	53	.75	1.73	.00	.00	.30	.84	2.34
1,2,4-Trimethylbenzene	53	2.46	5.89	.21	.63	1.27	1.77	7.46
1,2,3-Trimethylbenzene	53	1.04	1.65	-.01	.32	.56	1.11	3.55
p-Dichlorobenzene	53	62.83	120.45	.25	1.93	5.71	42.65	307.18
Aldine								
Tetrachloroethylene	34	.84	2.98	-.04	.15	.28	.47	1.34
Ethylbenzene	34	3.65	7.04	.37	1.03	1.62	3.32	9.24
m&p-Xylene	34	11.13	19.46	.71	3.21	5.29	9.46	39.79
o-Xylene	34	4.00	6.91	.43	1.15	1.95	3.28	14.01
Styrene	34	1.73	1.70	.05	.66	1.24	1.93	5.55
1,3,5-Trimethylbenzene	34	.93	2.09	.00	.00	.39	1.17	2.34
1,2,4-Trimethylbenzene	34	3.06	7.23	.22	.74	1.15	2.23	8.62
1,2,3-Trimethylbenzene	34	1.27	1.97	-.01	.36	.68	1.38	3.87
p-Dichlorobenzene	34	68.07	134.04	.48	2.65	7.03	42.65	378.18
Ship Channel								
Tetrachloroethylene	19	.90	1.26	-.04	.07	.26	1.67	4.16
Ethylbenzene	19	1.80	1.96	.04	.63	1.20	2.89	8.41
m&p-Xylene	19	5.20	7.14	.24	1.63	3.67	4.38	29.24
o-Xylene	19	2.02	2.49	.08	.71	1.21	1.66	9.93
Styrene	19	.82	.62	.00	.33	.78	1.14	2.76
1,3,5-Trimethylbenzene	19	.43	.69	.00	.00	.27	.45	2.65
1,2,4-Trimethylbenzene	19	1.38	1.53	-.01	.40	1.28	1.64	6.92
1,2,3-Trimethylbenzene	19	.61	.70	-.04	.15	.52	.77	2.75
p-Dichlorobenzene	19	53.46	93.97	-.12	.95	2.63	107.98	295.01

Table 17. Descriptive Summary of Fixed Site Air Concentrations (µg/m³)

VOCs	N	Mean	SD	Percentiles				
				5	25	50	75	95
Overall								
Tetrachloroethylene	140	.25	1.12	-.04	.03	.11	.20	.79
Ethylbenzene	140	.52	.61	-.01	.12	.27	.75	1.90
m&p-Xylene	140	1.44	2.10	-.07	.18	.73	1.78	5.40
o-Xylene	140	.52	.68	-.02	.12	.28	.70	1.47
Styrene	140	1.23	3.48	-.33	-.12	.15	.80	5.34
1,3,5-Trimethylbenzene	140	.08	.17	.00	.00	.00	.12	.36
1,2,4-Trimethylbenzene	140	.23	.32	-.03	.04	.13	.29	.84
1,2,3-Trimethylbenzene	140	.23	.55	-.04	-.01	.08	.23	.82
p-Dichlorobenzene	140	.45	2.15	-.27	-.12	.01	.25	1.95
Aldine								
Tetrachloroethylene	68	.37	1.59	-.04	.05	.11	.20	.84
Ethylbenzene	68	.40	.58	-.07	.09	.21	.39	1.57
m&p-Xylene	68	1.50	2.55	-.07	.13	.61	1.20	9.90
o-Xylene	68	.53	.81	.00	.10	.22	.49	1.47
Styrene	68	.31	.96	-.34	-.20	-.05	.33	2.71
1,3,5-Trimethylbenzene	68	.07	.17	.00	.00	.00	.05	.31
1,2,4-Trimethylbenzene	68	.17	.26	-.03	-.01	.11	.20	.75
1,2,3-Trimethylbenzene	68	.22	.71	-.04	-.01	.06	.13	.82
p-Dichlorobenzene	68	.68	2.93	-.25	-.19	-.03	.28	2.82
Ship Channel								
Tetrachloroethylene	72	.14	.18	-.04	.03	.11	.20	.48
Ethylbenzene	72	.63	.62	.03	.19	.43	.89	2.05
m&p-Xylene	72	1.39	1.58	-.01	.30	.90	2.00	4.08
o-Xylene	72	.50	.54	-.04	.14	.34	.72	1.47
Styrene	72	2.10	4.62	-.18	-.03	.45	2.00	14.26
1,3,5-Trimethylbenzene	72	.10	.16	.00	.00	.00	.15	.36
1,2,4-Trimethylbenzene	72	.29	.37	-.03	.07	.15	.39	1.24
1,2,3-Trimethylbenzene	72	.23	.36	-.04	.00	.12	.33	.92
p-Dichlorobenzene	72	.24	.90	-.28	-.11	.05	.22	1.95

Table 18. Statistical Summary of Second Round Indoor OVM Measurements by Study Area (ug/m3)

VOC	AREA							
	Aldine				Ship Channel			
	N	Mean	SD	Median	N	Mean	SD	Median
Carbon tetrachloride	31	0.03	0.18	0.00	29	0.03	0.15	0.00
Benzene	31	2.40	2.10	1.77	29	3.09	3.85	2.13
Trichloroethylene	31	0.69	0.62	1.05	29	0.68	0.64	0.92
Toluene	31	8.97	6.89	7.71	29	16.41	40.95	6.24
Tetrachloroethylene*	31	0.03	0.15	0.00	29	0.63	1.70	0.00
Ethylbenzene	31	1.77	1.33	1.64	29	3.27	7.72	2.07
m&p-Xylene	31	3.35	2.39	3.15	29	8.37	25.13	2.78
o-Xylene	31	1.36	0.90	1.19	29	3.59	11.27	1.20
Styrene	31	1.02	1.48	0.85	29	0.52	0.50	0.57
1,4-Dichlorobenzene	31	28.28	82.46	1.77	29	78.27	234.37	1.04
1,3,5-Trimethylbenzene	31	0.43	0.34	0.43	29	1.55	6.48	0.00
1,2,4-Trimethylbenzene	31	1.46	1.01	1.17	29	4.54	15.77	1.21
1,2,3-Trimethylbenzene	31	0.49	0.32	0.53	29	1.03	3.18	0.49

* Significantly higher indoor concentrations in Ship Channel area ($p = 0.047$).

Table 19. Estimated indoor source strengths (µg/hour) of optimal compounds.

VOCs	AREA	N	Minimum	Median	Mean	Std. Dev.	Maximum
Tetrachloroethylene	HEATS OA**	137	0	6	46	176	1668
	Aldine	67	0	6	30	125	1011
	Ship Channel	70	0	5	62	213	1668
	RIOPA TX	164	0	22	162	401	2456
	RIOPA OA**	486	0	32	168	523	7823
Ethylbenzene	HEATS OA**	137	0	59	141	434	4311
	Aldine	67	0	62	86	78	332
	Ship Channel	70	0	56	194	600	4311
	RIOPA TX	164	0	221	596	2888	36525
	RIOPA OA**	486	0	123	473	2727	45485
m,p-Xylene	HEATS OA**	137	0	160	415	1326	13867
	Aldine	67	0	175	253	256	1116
	Ship Channel	70	0	152	571	1830	13867
	RIOPA TX	164	0	501	1836	10314	131201
	RIOPA OA**	486	0	265	1352	9079	144684
o-Xylene	HEATS OA**	137	0	57	167	651	7214
	Aldine	67	0	57	88	83	402
	Ship Channel	70	0	57	243	904	7214
	RIOPA TX	164	0	182	620	3543	45004
	RIOPA OA**	486	0	109	424	2572	45004
Styrene	HEATS OA**	137	0	57	108	166	911
	Aldine	67	0	68	121	169	911
	Ship Channel	70	0	43	96	163	865
	RIOPA TX	164	0	119	264	1010	9623
	RIOPA OA**	486	0	73	258	1011	14573
1,3,5-Trimethylbenzene*	HEATS OA**	137	0	0	55	252	2550
	Aldine	67	0	0	21	39	238
	Ship Channel	70	0	6	88	349	2550
1,2,4-Trimethylbenzene*	HEATS OA**	137	0	43	128	449	4907
	Aldine	67	0	43	66	74	337
	Ship Channel	70	0	40	187	620	4907
1,2,3-Trimethylbenzene*	HEATS OA**	137	0	27	77	242	2449
	Aldine	67	0	27	43	49	230
	Ship Channel	70	0	28	108	333	2449
1,4-Dichlorobenzene	HEATS OA**	137	0	133	3968	11418	73345
	Aldine	67	0	185	3750	12866	73345
	Ship Channel	70	0	124	4177	9928	47268
	RIOPA TX	164	0	482	32129	101747	687017
	RIOPA OA**	486	0	239	18289	91467	1428074

* Not available for RIOPA ; ** OA: Overall area combined

Table 20. Fractional outdoor contributions to measured indoor concentrations of optimal compounds.

VOCs	Area	N	Median	Mean	Std. Dev.
Tetrachloroethylene	HEATS OA**	137	.58	.54	.39
	Aldine	67	.60	.58	.38
	Ship Channel	70	.49	.50	.41
	RIOPA TX	160	.51	.52	.41
	RIOPA OA**	480	.81	.68	.36
Ethylbenzene	HEATS OA**	137	.33	.38	.31
	Aldine	67	.30	.36	.29
	Ship Channel	70	.34	.39	.32
	RIOPA TX	164	.45	.50	.29
	RIOPA OA**	484	.69	.64	.34
m,p-Xylene	HEATS OA**	137	.33	.38	.33
	Aldine	67	.31	.37	.31
	Ship Channel	70	.35	.40	.34
	RIOPA TX	164	.48	.51	.29
	RIOPA OA**	484	.71	.67	.31
o-Xylene	HEATS OA**	137	.37	.40	.31
	Aldine	67	.33	.39	.29
	Ship Channel	70	.40	.41	.33
	RIOPA TX	163	.48	.54	.30
	RIOPA OA**	485	.74	.68	.31
Styrene	HEATS OA**	137	.12	.32	.39
	Aldine	67	.05	.28	.38
	Ship Channel	70	.16	.36	.40
	RIOPA TX	157	.17	.30	.35
	RIOPA OA**	416	.18	.34	.38
1,3,5-Trimethylbenzene*	HEATS OA**	137	1.00	.63	.43
	Aldine	67	1.00	.67	.42
	Ship Channel	70	.79	.60	.44
1,2,4-Trimethylbenzene*	HEATS OA**	137	.31	.38	.34
	Aldine	67	.31	.37	.34
	Ship Channel	70	.34	.39	.34
1,2,3-Trimethylbenzene*	HEATS OA**	137	.23	.37	.37
	Aldine	67	.20	.34	.34
	Ship Channel	70	.28	.39	.39
1,4-Dichlorobenzene	HEATS OA**	137	.03	.24	.37
	Aldine	67	.03	.21	.35
	Ship Channel	70	.03	.27	.39
	RIOPA TX	163	.03	.20	.30
	RIOPA OA**	472	.15	.34	.39

* Not available for RIOPA ; ** OA: Overall area combined

Table 21. Summary of parametric (log transformation) weighted regression results for significance of differences between study areas for primary and secondary hypotheses related to Aims 1 and 2. Direction and probabilities for significant differences are indicated.

VOC	Personal	Indoor	Outdoor	Fixed Site
Tetrachloroethylene	NS	NS	NS	NS
Ethylbenzene	NS	NS	NS	SC > A (p = 0.006)
m&p-Xylene	NS	NS	NS	NS
o-Xylene	NS	NS	NS	NS
Styrene	NS	A > SC (p = 0.036)	NS	SC > A (p = 0.000)
1,4-Dichlorobenzene	NS	NS	NS	NS
1,2,3-Trimethylbenzene	NS	NS	NS	NS
1,2,4-Trimethylbenzene	NS	NS	NS	SC > A (p = 0.020)
1,3,5-Trimethylbenzene	NS	NS	NS	NS

NS = nonsignificant; A = Aldine; SC = Ship Channel

Table 22. Summary of nonparametric (rank transformation) weighted regression results for significance of differences between study areas for primary and secondary hypotheses related to Aims 1 and 2. Direction and probabilities for significant differences are indicated.

VOC	Personal	Indoor	Outdoor	Fixed Site
Tetrachloroethylene	NS	NS	NS	NS
Ethylbenzene	NS	NS	NS	SC > A (p = 0.002)
m&p-Xylene	NS	NS	NS	NS
o-Xylene	NS	NS	NS	NS
Styrene	NS	NS	NS	SC > A (p = 0.000)
1,4-Dichlorobenzene	NS	NS	NS	NS
1,2,3-Trimethylbenzene	NS	NS	NS	SC > A (p = 0.007)
1,2,4-Trimethylbenzene	A > SC (p =0.034)	NS	NS	SC > A (p = 0.021)
1,3,5-Trimethylbenzene	NS	NS	NS	SC > A (p = 0.015)

NS = nonsignificant; A = Aldine; SC = Ship Channel

Table 23. Summary of weighted regression results for significance of fixed site measurements as a predictor of residential outdoor concentrations in each area. Probabilities for tests of the difference from zero for the regression slopes are presented. NS is nonsignificant.

VOC	Aldine	Ship Channel
Tetrachloroethylene	NS	0.000
Ethylbenzene	0.000	0.000
m&p-Xylene	0.000	0.000
o-Xylene	0.000	0.000
Styrene	0.006	NS
1,4-Dichlorobenzene	0.005	NS
1,2,3-Trimethylbenzene	NS	NS
1,2,4-Trimethylbenzene	0.000	0.000
1,3,5-Trimethylbenzene	NS	NS

Table 24. Summary of weighted regression results for significance of fixed site measurements as a predictor of residential indoor concentrations in each area. Probabilities for tests of the difference from zero for the regression slopes are presented.

VOC	Aldine	Ship Channel
Tetrachloroethylene	0.000	NS
Ethylbenzene	0.000	0.048
m&p-Xylene	0.000	0.004
o-Xylene	0.000	0.005
Styrene	0.003	NS
1,4-Dichlorobenzene	0.000	0.000
1,2,3-Trimethylbenzene	NS	NS
1,2,4-Trimethylbenzene	NS	0.031
1,3,5-Trimethylbenzene	NS	NS

Table 25. Summary of weighted regression results for significance of fixed site measurements as a predictor of personal exposures in each area. Probabilities for tests of the difference from zero for the regression slopes are presented.

VOC	Aldine	Ship Channel
Tetrachloroethylene	NS	0.042
Ethylbenzene	0.002	NS
m&p-Xylene	0.000	NS
o-Xylene	0.001	NS
Styrene	NS	0.042
1,4-Dichlorobenzene	NS	0.000
1,2,3-Trimethylbenzene	NS	NS
1,2,4-Trimethylbenzene	NS	0.001
1,3,5-Trimethylbenzene	NS	NS

Table 26. Summary of weighted regression results for significance of the interaction between outdoor concentrations and area in the prediction of indoor concentrations. Probabilities for tests of the difference from zero for the β_3 coefficient are presented.

VOC	Area x Concentration
Tetrachloroethylene	NS
Ethylbenzene	NS
m&p-Xylene	NS
o-Xylene	NS
Styrene	NS
1,4-Dichlorobenzene	0.033*
1,2,3-Trimethylbenzene	NS
1,2,4-Trimethylbenzene	NS
1,3,5-Trimethylbenzene	NS

* Result not consistent with highly significant regression slopes in both areas.

Table 27. Summary of average concentration measurements (μg/m^3) for optimal VOCs obtained from parametric regression models utilized in hypothesis testing for study aims 1 and 2. Observed concentration differences are (Ship Channel – Aldine).

VOC	VOC Measurement	Concentration			
		Outdoor	Indoor	Personal	Fixed
Tetrachloroethylene	Aldine	0.174	0.352	0.335	0.200
	Ship Channel	0.157	0.505	0.511	0.124
	Observed difference	-0.017	0.154	0.176	-0.076
	Minimum detectable difference	0.076	0.407	0.266	0.111
Ethylbenzene	Aldine	0.477	1.363	1.808	0.323
	Ship Channel	0.449	1.251	1.647	0.527
	Observed difference	-0.028	-0.113	-0.161	0.204
	Minimum detectable difference	0.184	0.571	1.054	0.141
m,p-Xylene	Aldine	1.314	3.776	4.884	0.875
	Ship Channel	1.100	3.148	4.353	1.005
	Observed difference	-0.214	-0.628	-0.532	0.130
	Minimum detectable difference	0.588	1.758	3.056	0.430
o-Xylene	Aldine	0.555	1.478	2.030	0.407
	Ship Channel	0.489	1.345	1.870	0.424
	Observed difference	-0.067	-0.133	-0.160	0.017
	Minimum detectable difference	0.223	0.662	0.926	0.165
Styrene	Aldine	0.304	1.440	1.256	0.122
	Ship Channel	0.357	0.936	0.941	0.863
	Observed difference	0.053	-0.504	-0.315	0.741
	Minimum detectable difference	0.302	0.476	0.493	0.277
1,3,5-Trimethylbenzene	Aldine	0.109	0.294	0.436	0.059
	Ship Channel	0.103	0.348	0.491	0.091
	Observed difference	-0.006	0.055	0.055	0.032
	Minimum detectable difference	0.067	0.261	0.441	0.046
1,2,4-Trimethylbenzene	Aldine	0.275	0.917	1.310	0.149
	Ship Channel	0.275	0.885	1.147	0.250
	Observed difference	-0.000	-0.032	-0.163	0.101
	Minimum detectable difference	0.163	0.480	0.876	0.085
1,2,3-Trimethylbenzene	Aldine	0.174	0.689	0.860	0.144
	Ship Channel	0.145	0.582	0.706	0.192
	Observed difference	-0.029	-0.106	-0.154	0.048
	Minimum detectable difference	0.089	0.349	0.496	0.100
p-Dichlorobenzene	Aldine	0.546	4.627	5.254	0.166
	Ship Channel	0.369	3.796	4.502	0.113
	Observed difference	-0.177	-0.831	-0.753	-0.052
	Minimum detectable difference	0.517	5.321	5.786	0.229

11. LIST OF FIGURES

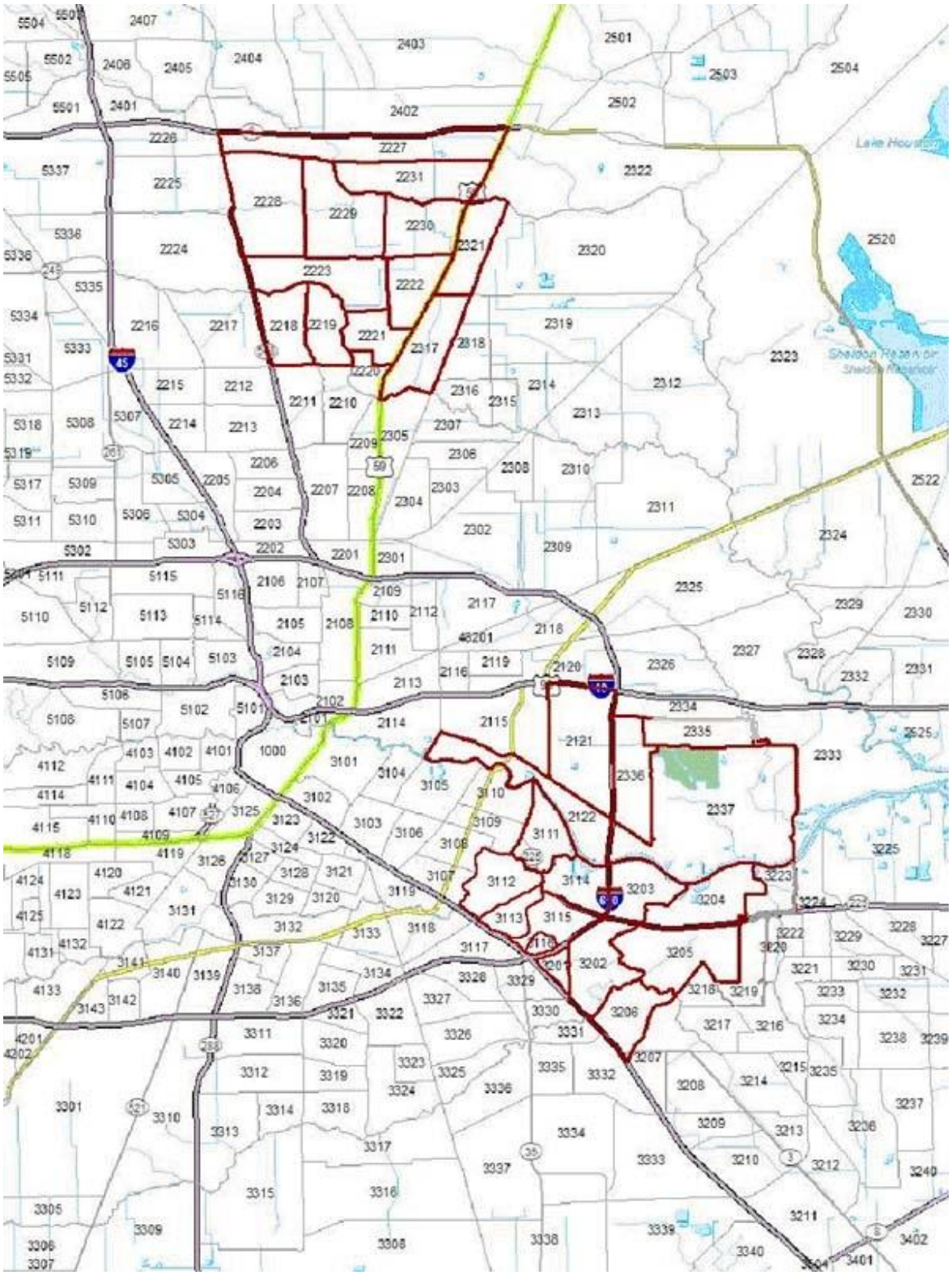


Figure 1: Map of Houston showing the HEATS areas.

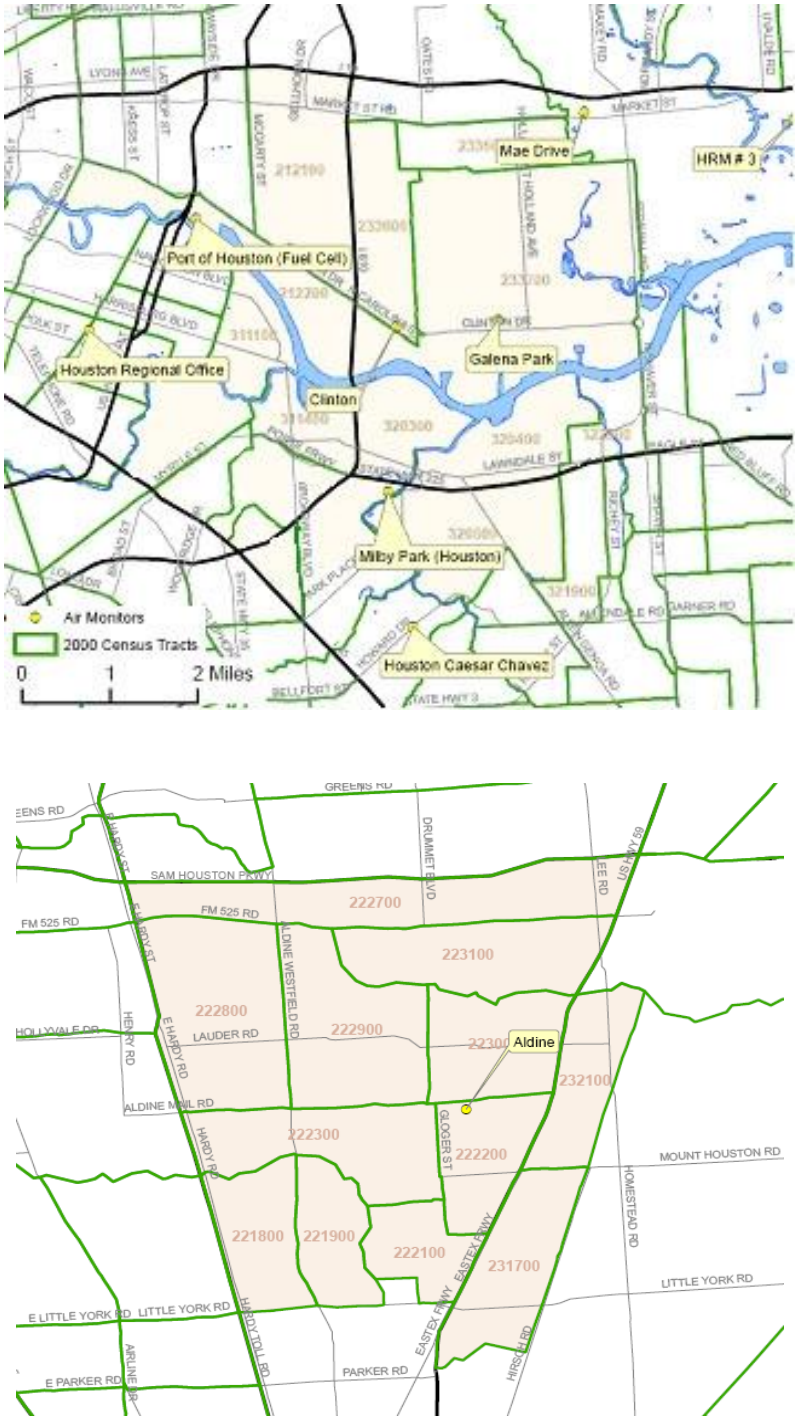


Figure 2. Maps of Study Areas: Ship Channel (top) and Aldine (bottom). Census tracts included in each study area are shaded. Maps courtesy of the Texas Dept. of State Health Services, Austin, TX.

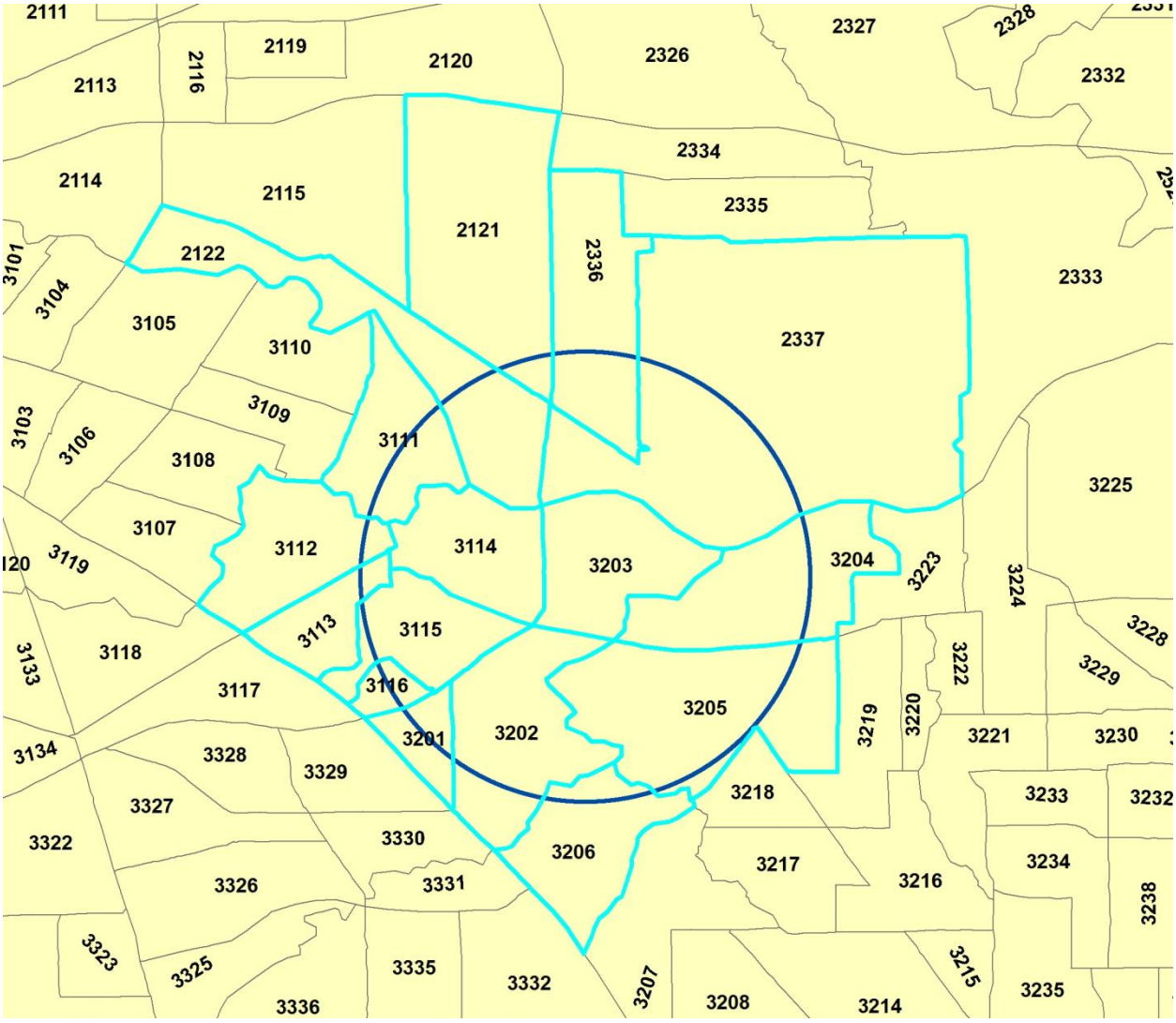


Figure 3. Census Tracts for Ship Channel Study Area. Circle indicates a 2-mile radius from the center of the Manchester neighborhood. All census tracts wholly or partially contained within this circle were selected for this study area.

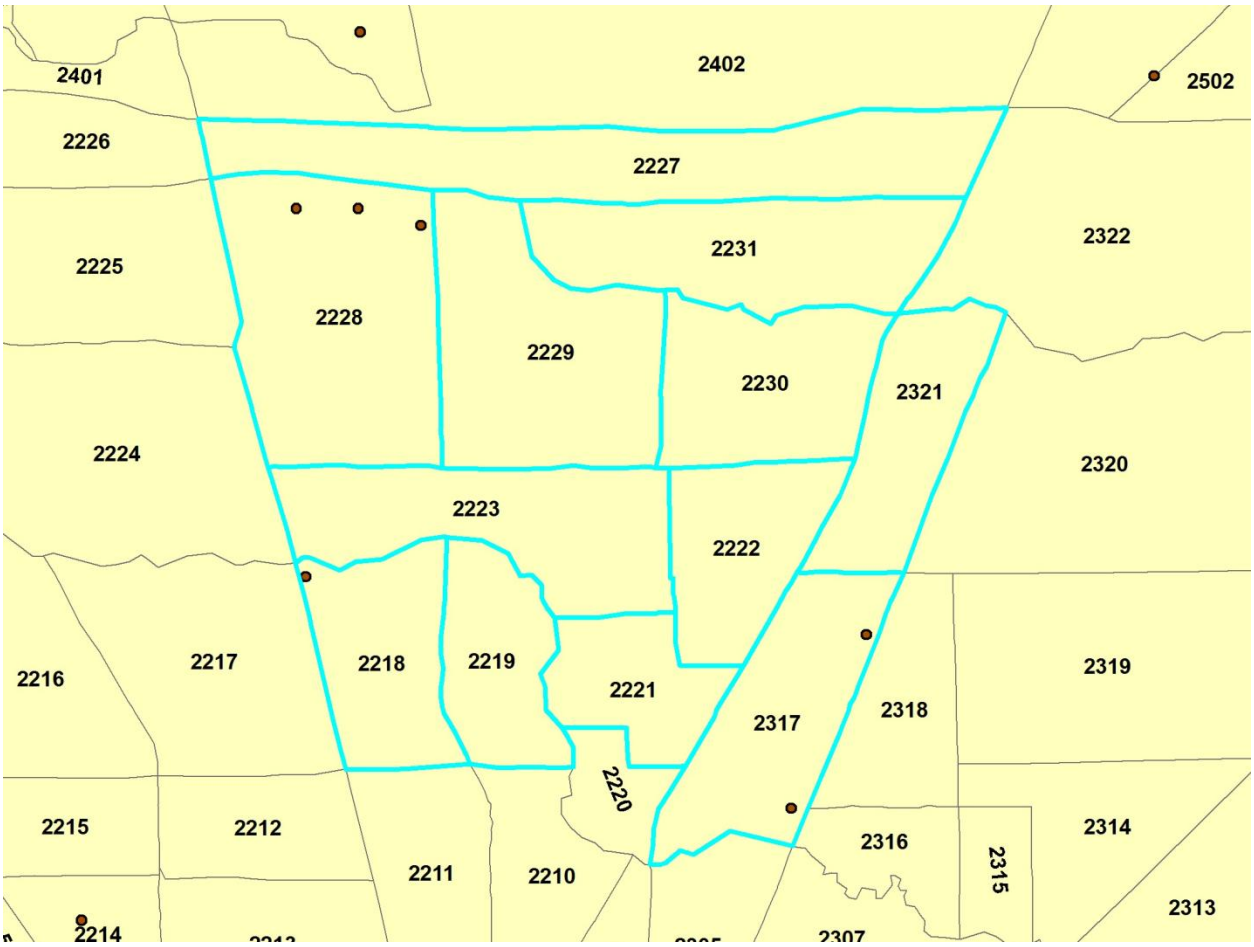


Figure 4. Census Tracts for Aldine Study Area

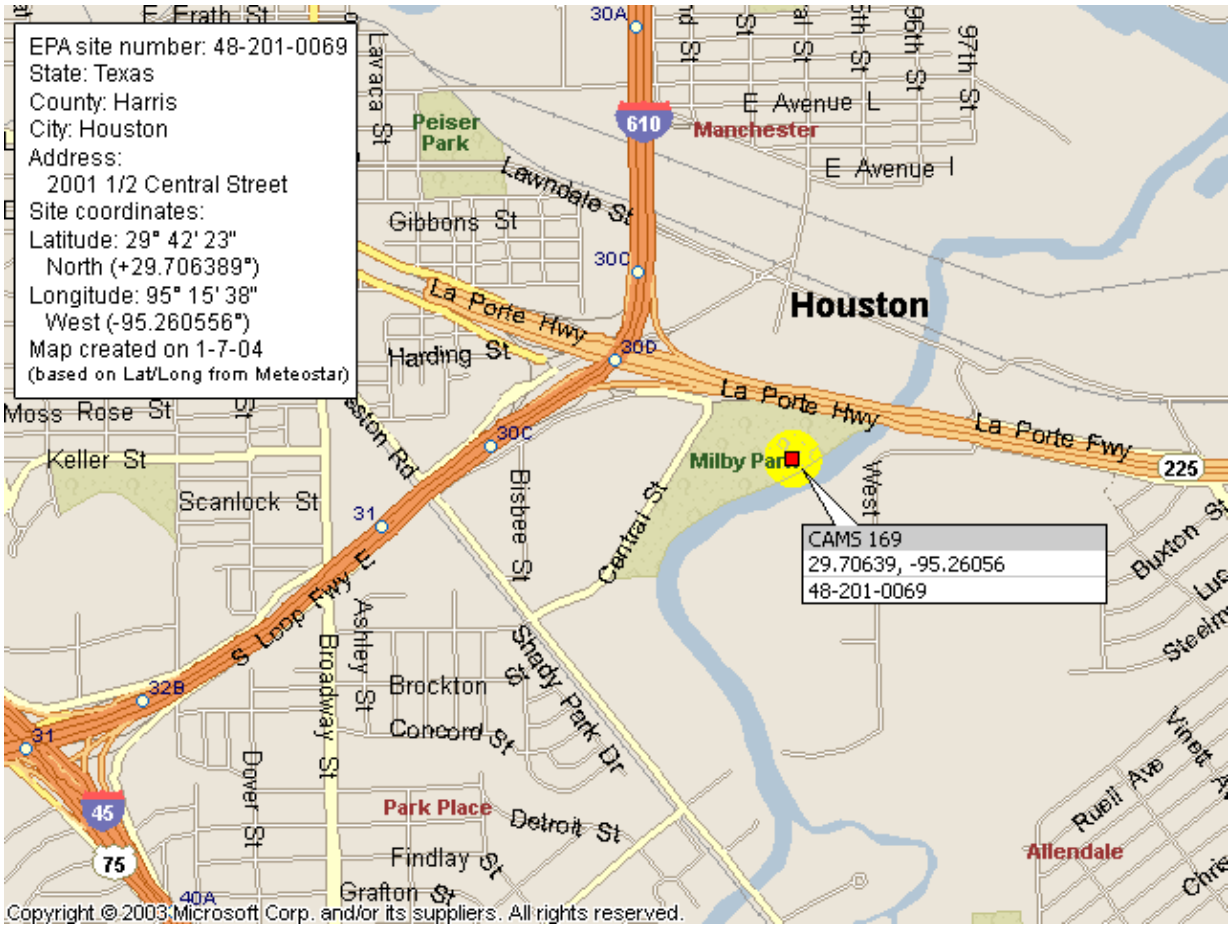


Figure 5a. Milby Park monitoring site.

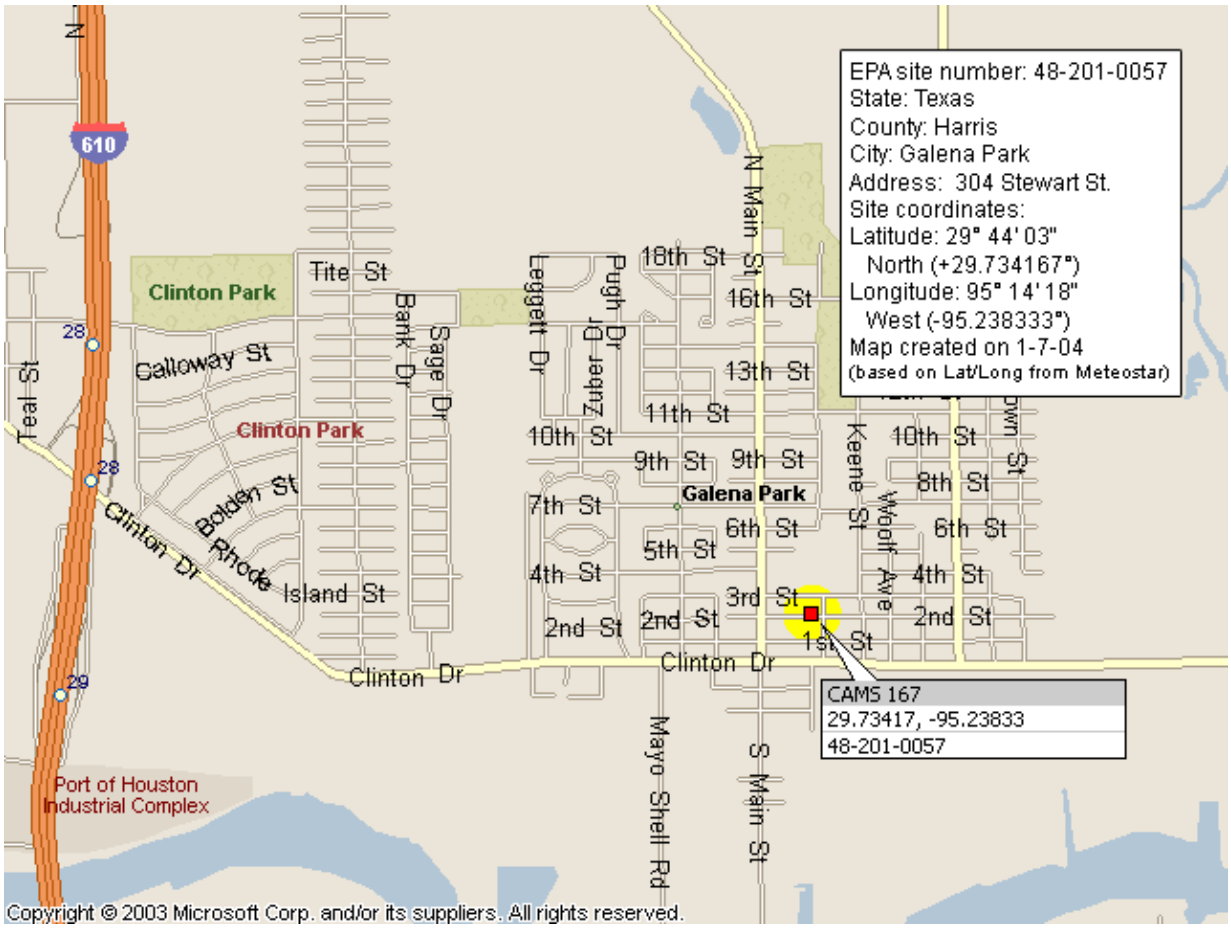


Figure 5b. Clinton Dr. monitoring site.

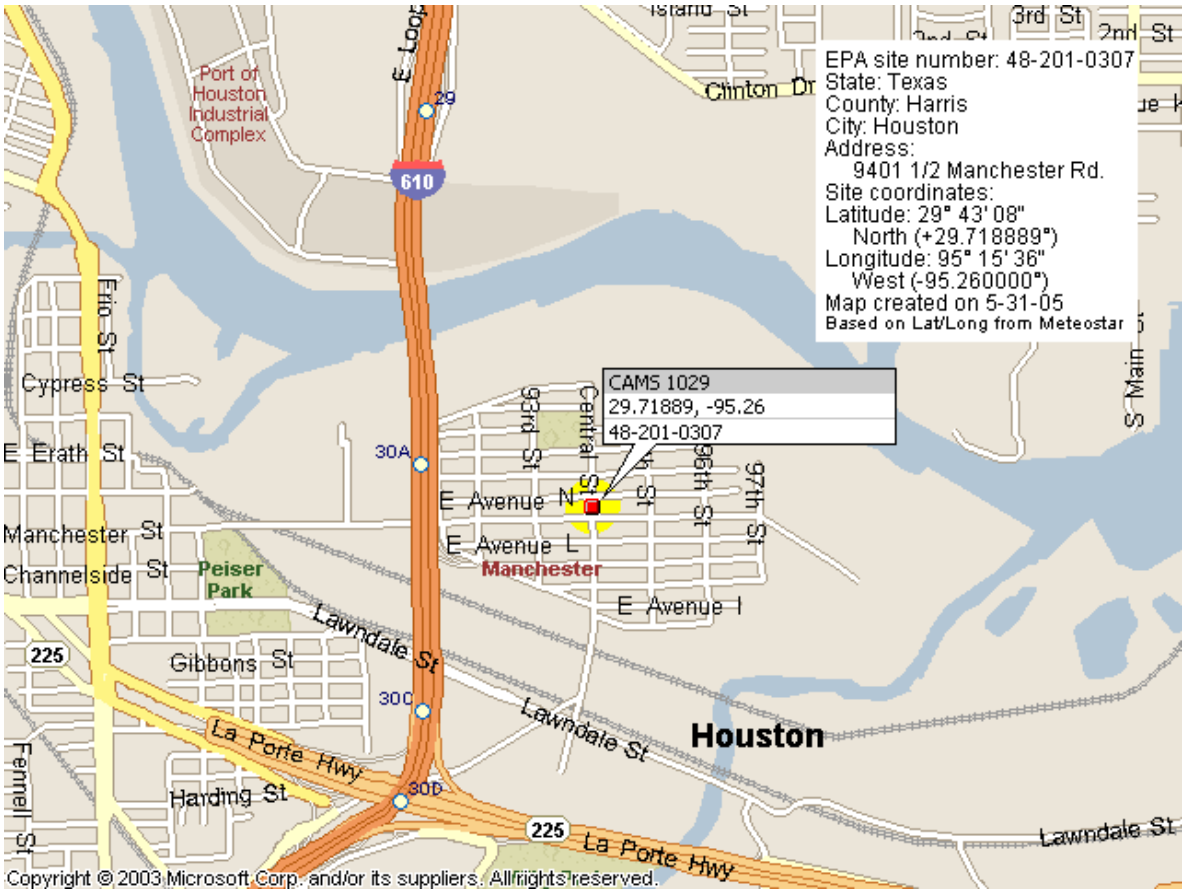


Figure 5c. Manchester monitoring site

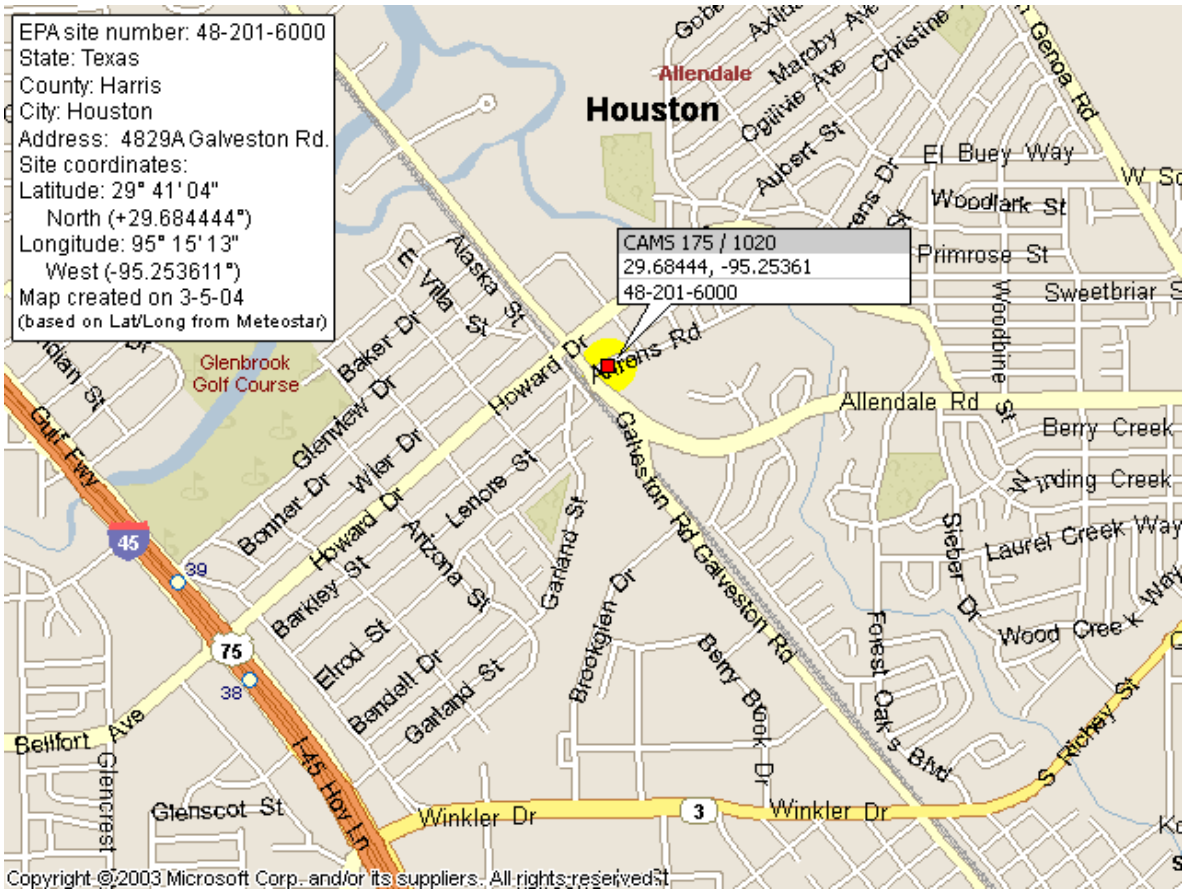


Figure 5d. Cesar Chavez monitoring site.

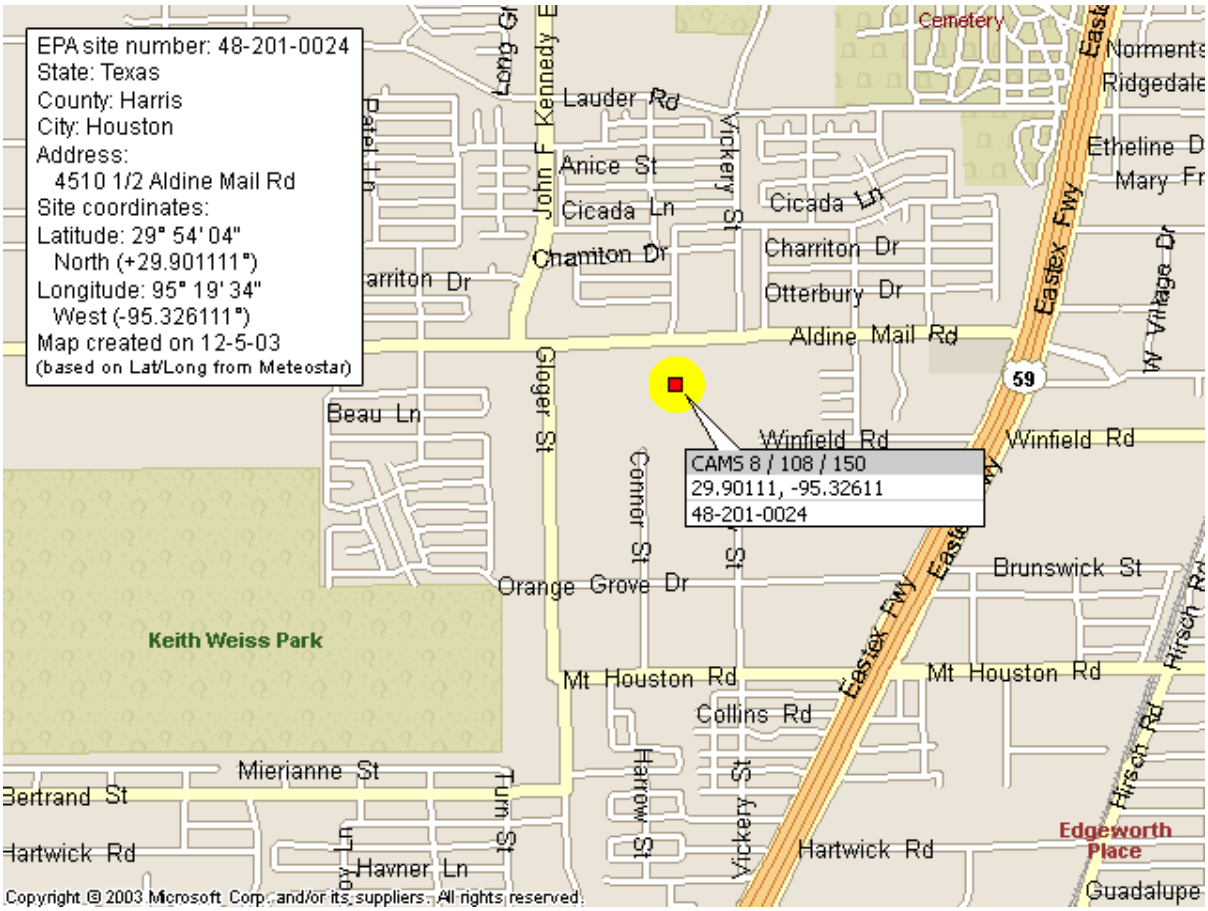


Figure 5e. Aldine Monitoring Site

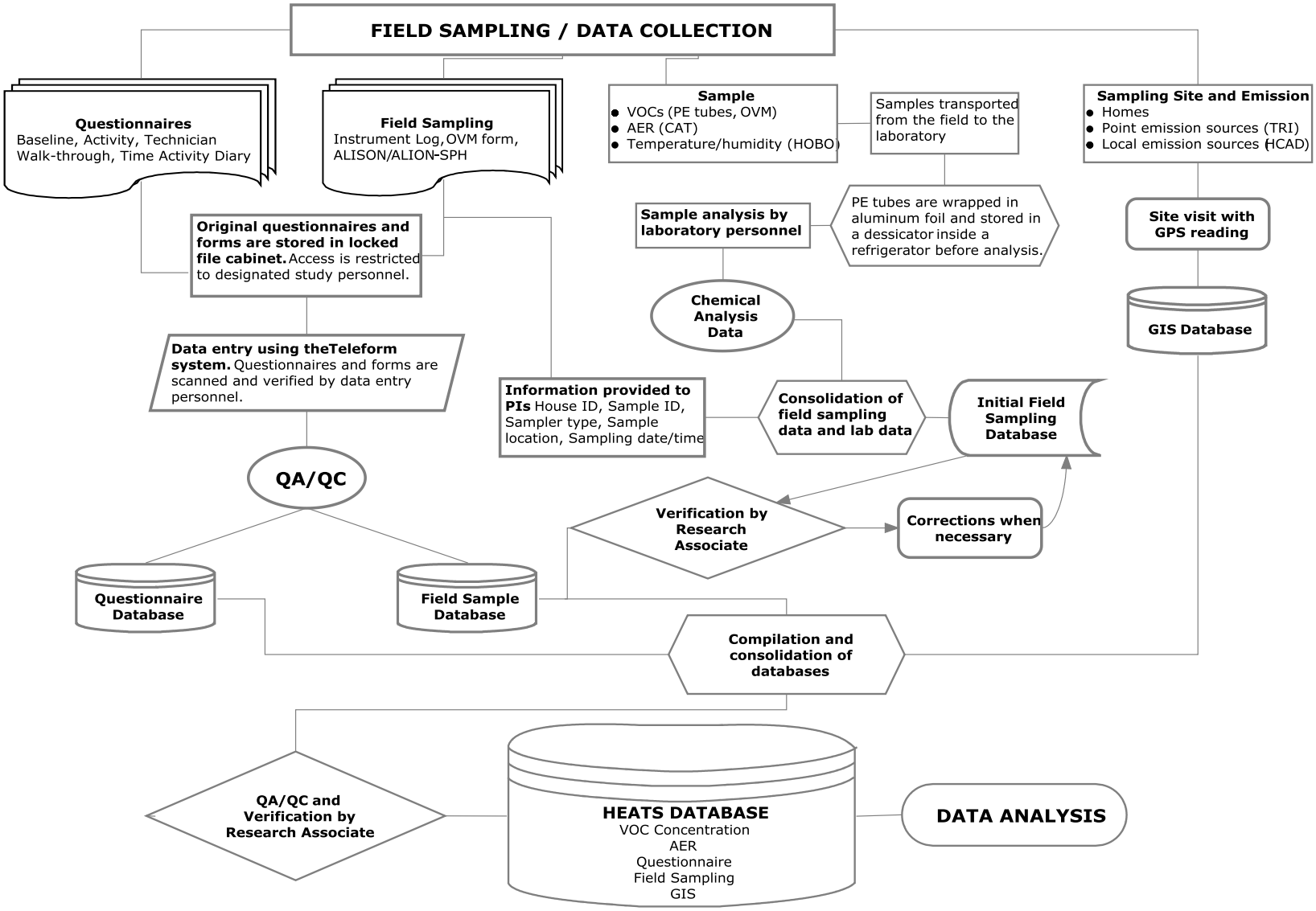


Figure 6. Diagram of Components of the HEATS

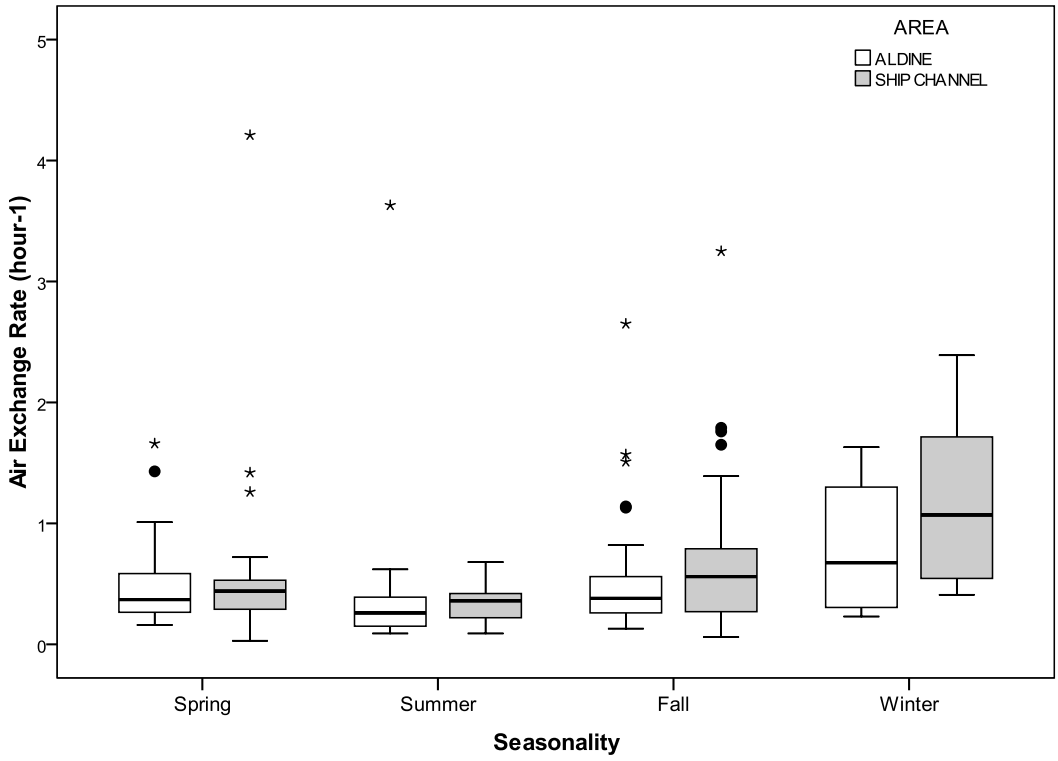


Figure 7. Air exchange rates by season and study area.

Box plots are based on the median, quartiles, and extreme values. The box represents the interquartile range (25%-75%) of values. A line across the box indicates the median. The whiskers are lines that extend from the box to the highest and lowest values, excluding outliers and extreme values. Outliers (designated with a closed circle) are values between 1.5 and 3 box lengths from either end of the box. Extreme values (designated with an asterisk) are values more than 3 box lengths from either end of the box.

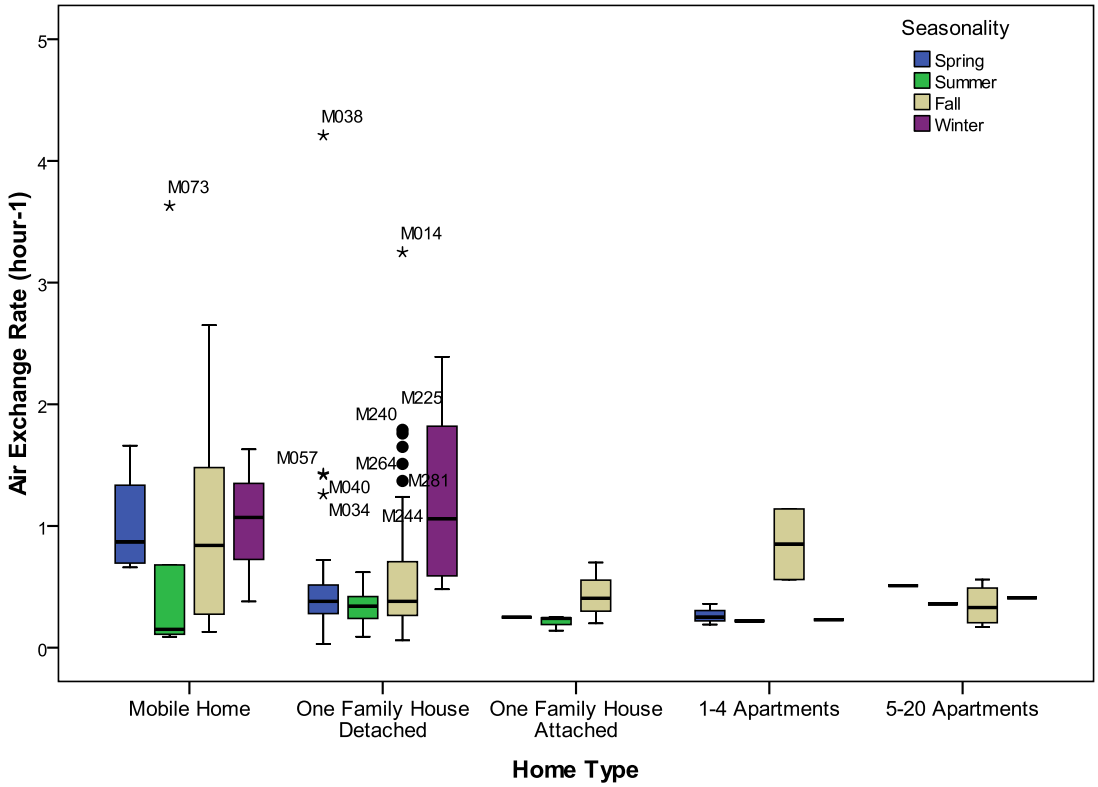


Figure 8. Air exchange rates by housing type and season.

Box plots are based on the median, quartiles, and extreme values. The box represents the interquartile range (25%-75%) of values. A line across the box indicates the median. The whiskers are lines that extend from the box to the highest and lowest values, excluding outliers and extreme values. Outliers (designated with a closed circle) are values between 1.5 and 3 box lengths from either end of the box. Extreme values (designated with an asterisk) are values more than 3 box lengths from either end of the box.

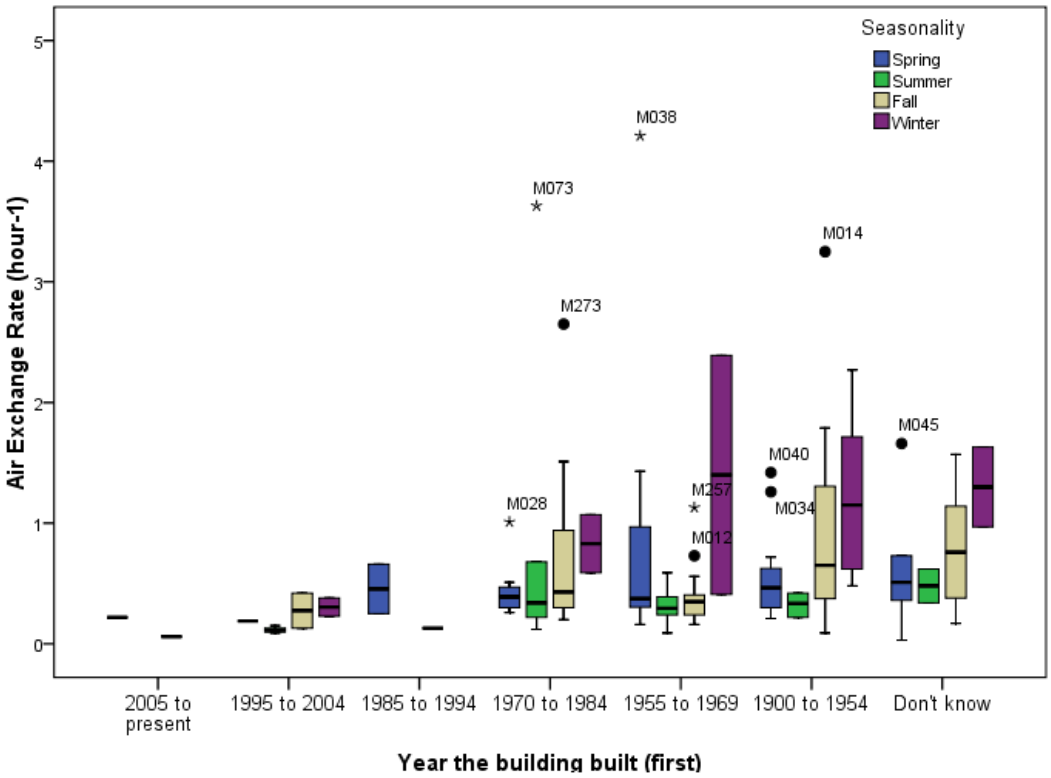


Figure 9. Air exchange rates by building age and season.

Box plots are based on the median, quartiles, and extreme values. The box represents the interquartile range (25%-75%) of values. A line across the box indicates the median. The whiskers are lines that extend from the box to the highest and lowest values, excluding outliers and extreme values. Outliers (designated with a closed circle) are values between 1.5 and 3 box lengths from either end of the box. Extreme values (designated with an asterisk) are values more than 3 box lengths from either end of the box.

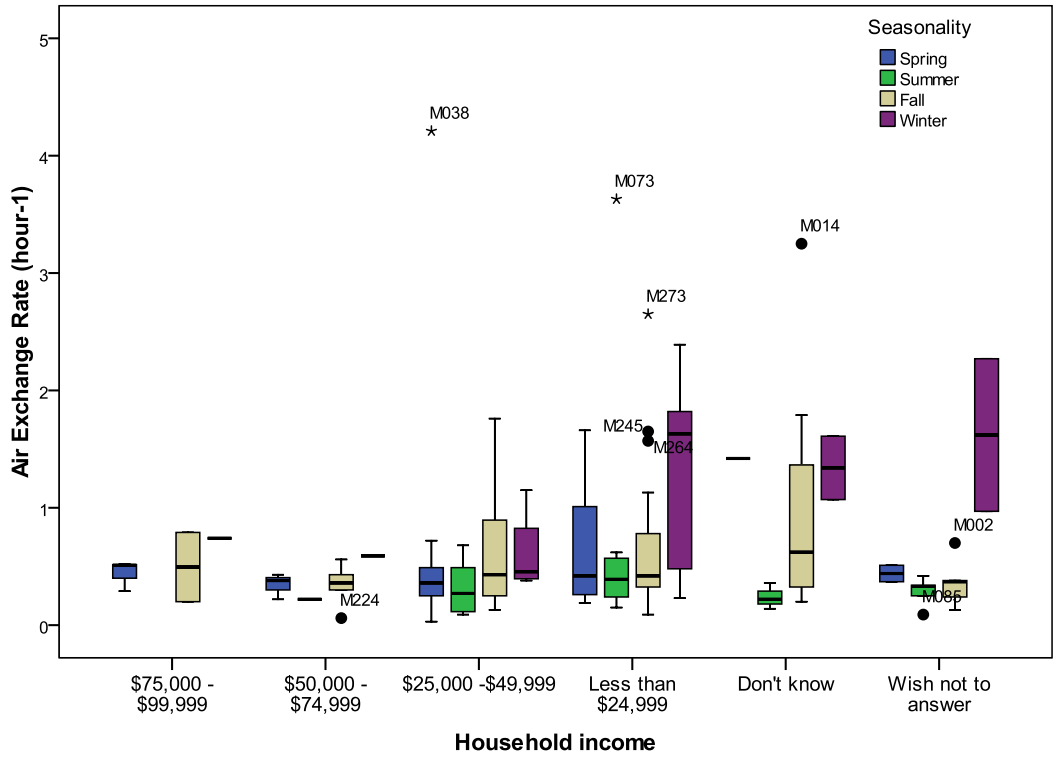
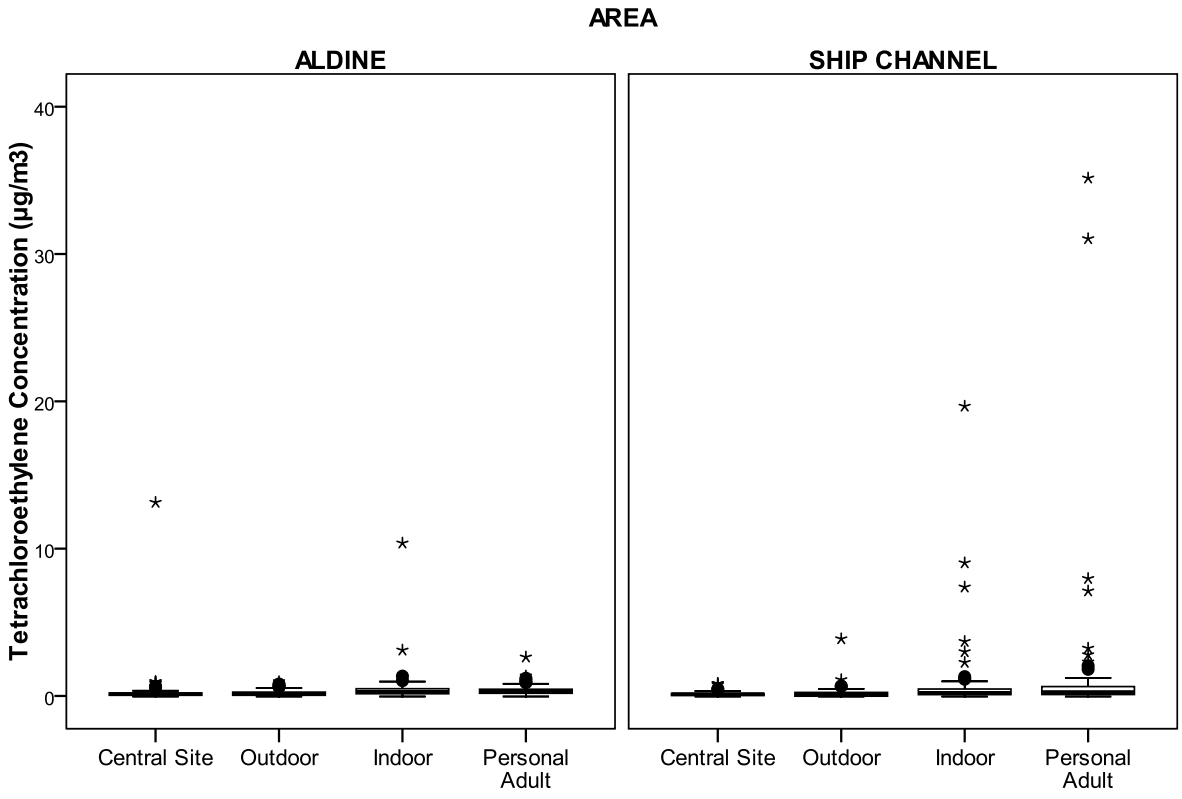


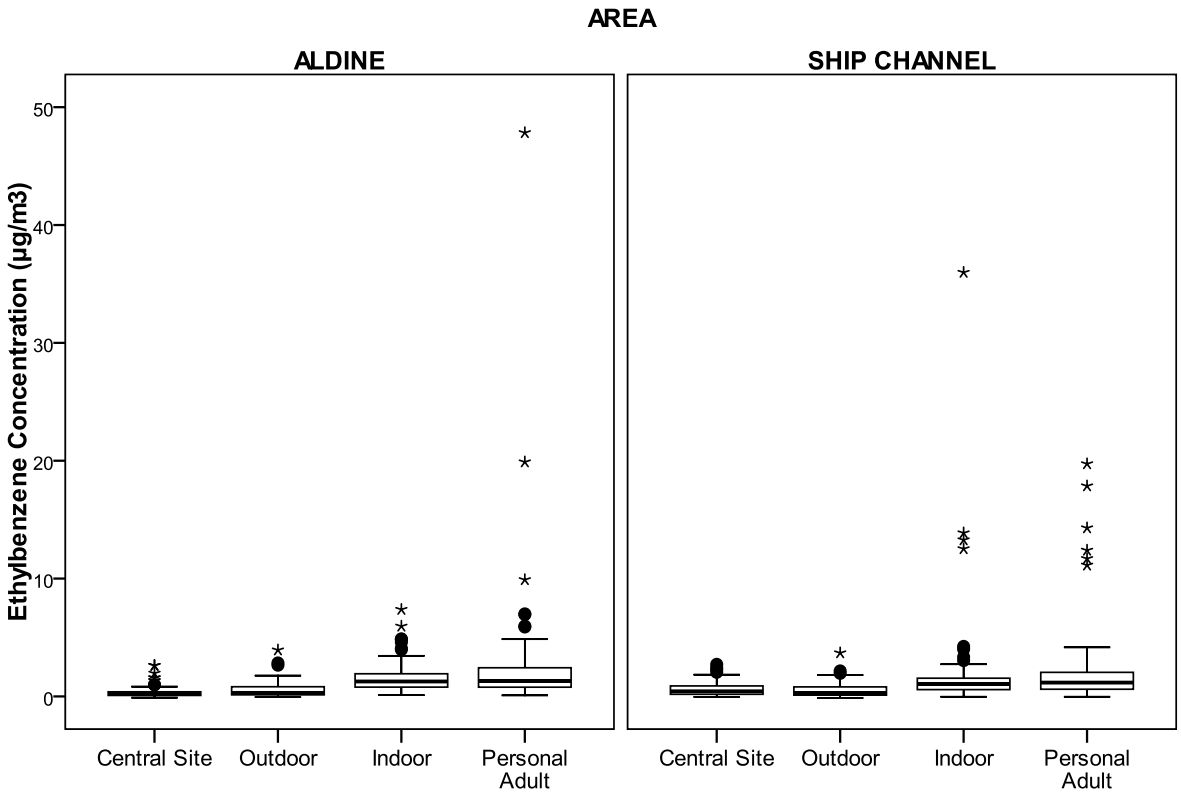
Figure 10. Air exchange rates by family income and season.

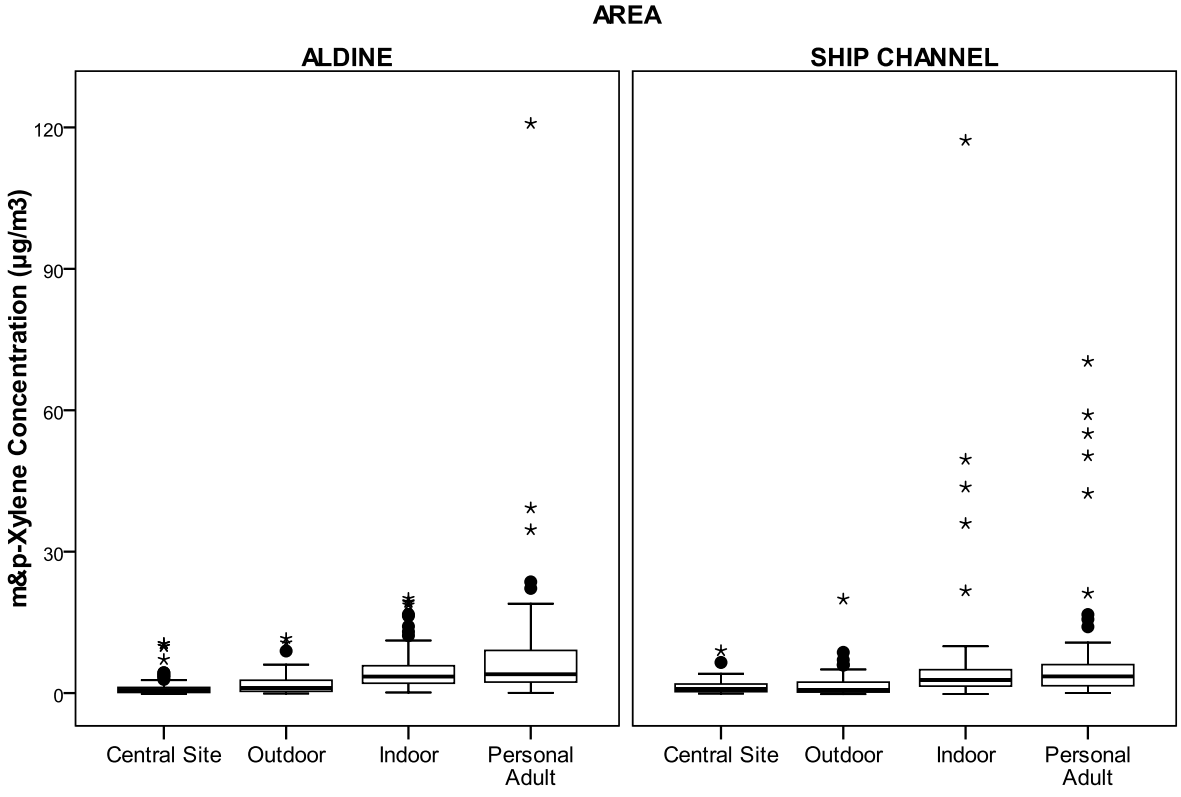
Box plots are based on the median, quartiles, and extreme values. The box represents the interquartile range (25%-75%) of values. A line across the box indicates the median. The whiskers are lines that extend from the box to the highest and lowest values, excluding outliers and extreme values. Outliers (designated with a closed circle) are values between 1.5 and 3 box lengths from either end of the box. Extreme values (designated with an asterisk) are values more than 3 box lengths from either end of the box.

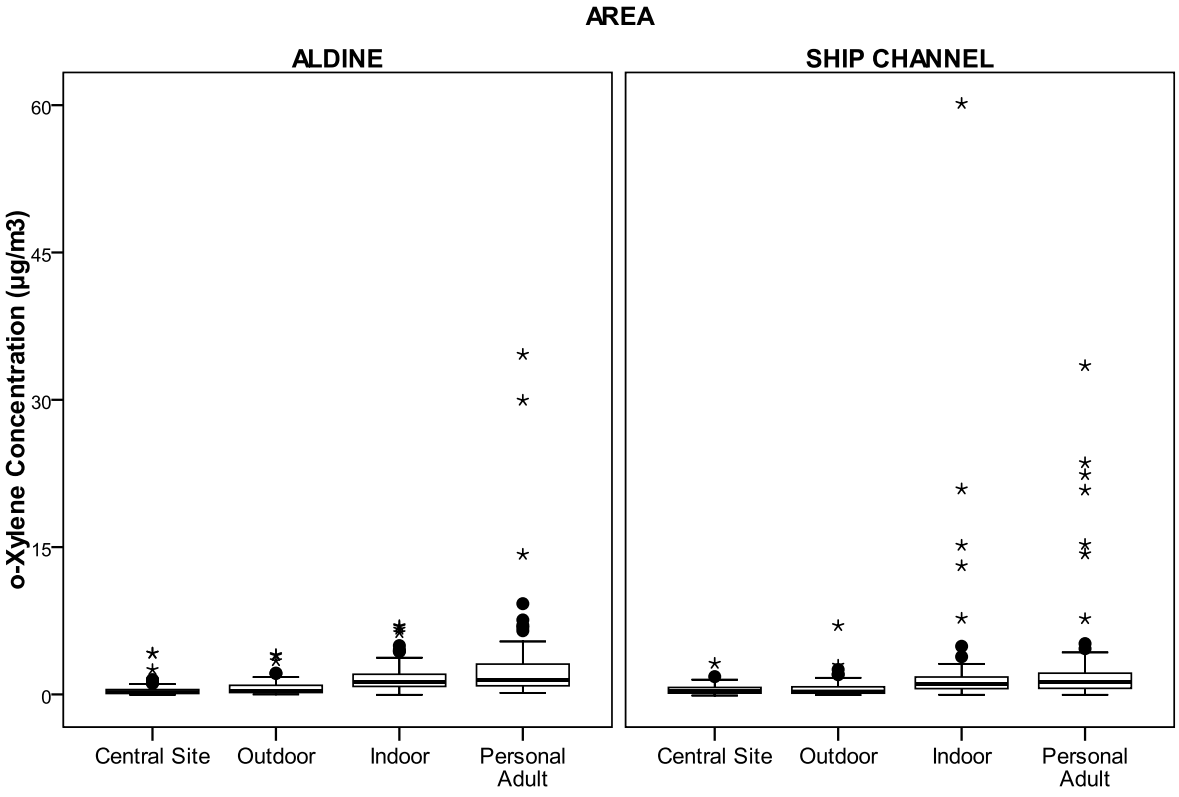
Figure 11. Box plots of VOC measurements for optimal compounds, by study area.

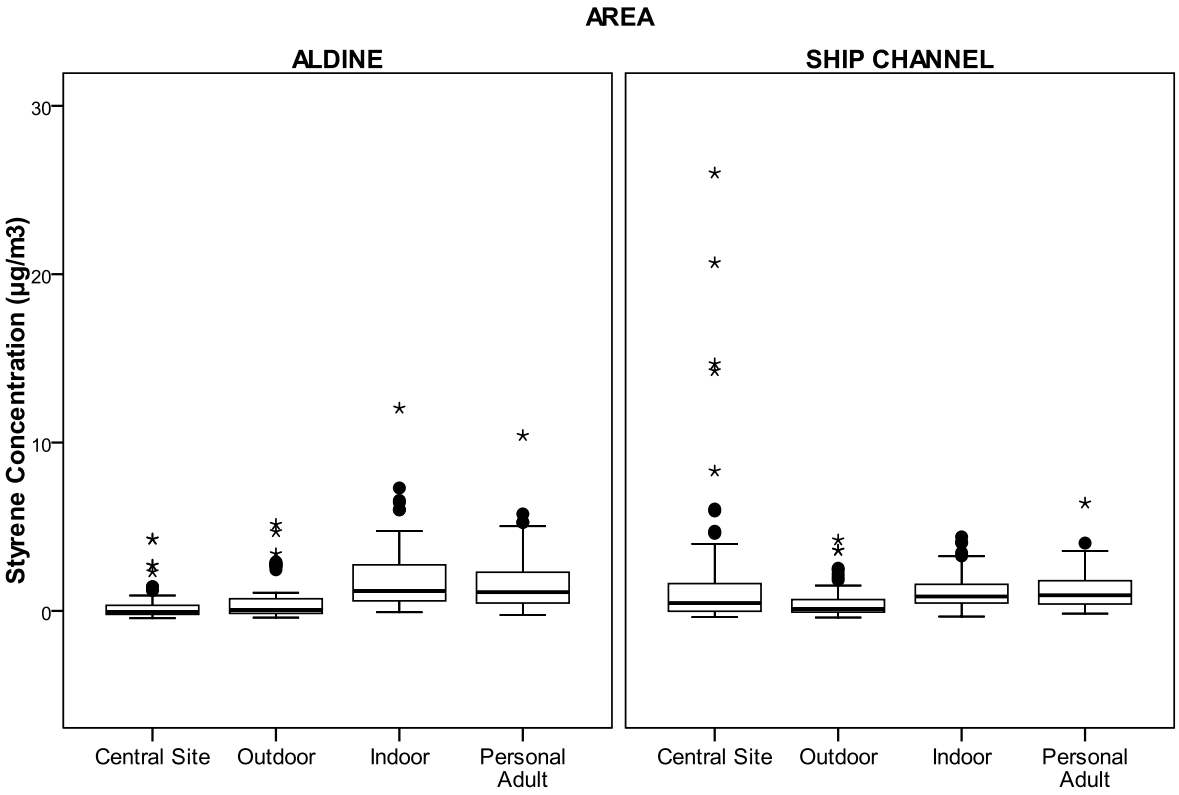
Box plots are based on the median, quartiles, and extreme values. The box represents the interquartile range (25%-75%) of values. A line across the box indicates the median. The whiskers are lines that extend from the box to the highest and lowest values, excluding outliers and extreme values. Outliers (designated with a closed circle) are values between 1.5 and 3 box lengths from either end of the box. Extreme values (designated with an asterisk) are values more than 3 box lengths from either end of the box.

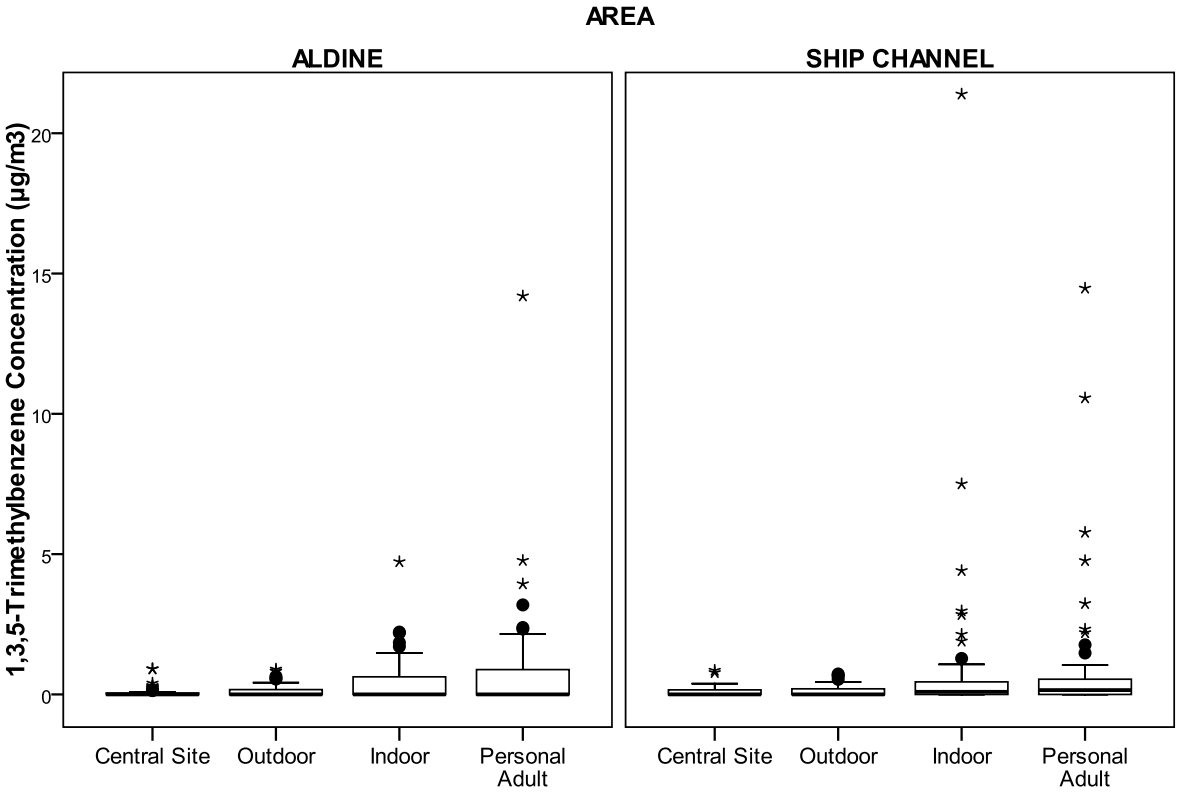


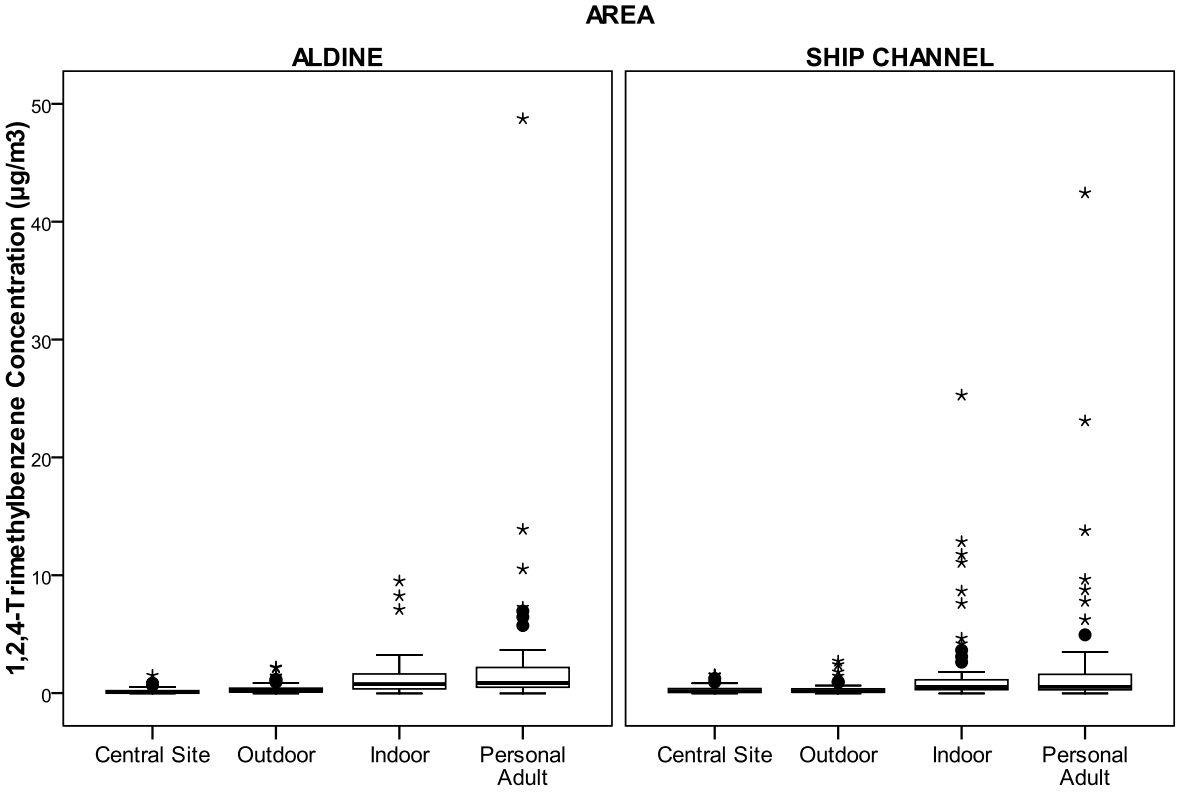

AREA
ALDINE
SHIP CHANNEL
Ethylbenzene Concentration (µg/m3)
50
40
30
20
10
0
Central Site
Outdoor
Indoor
Personal Adult

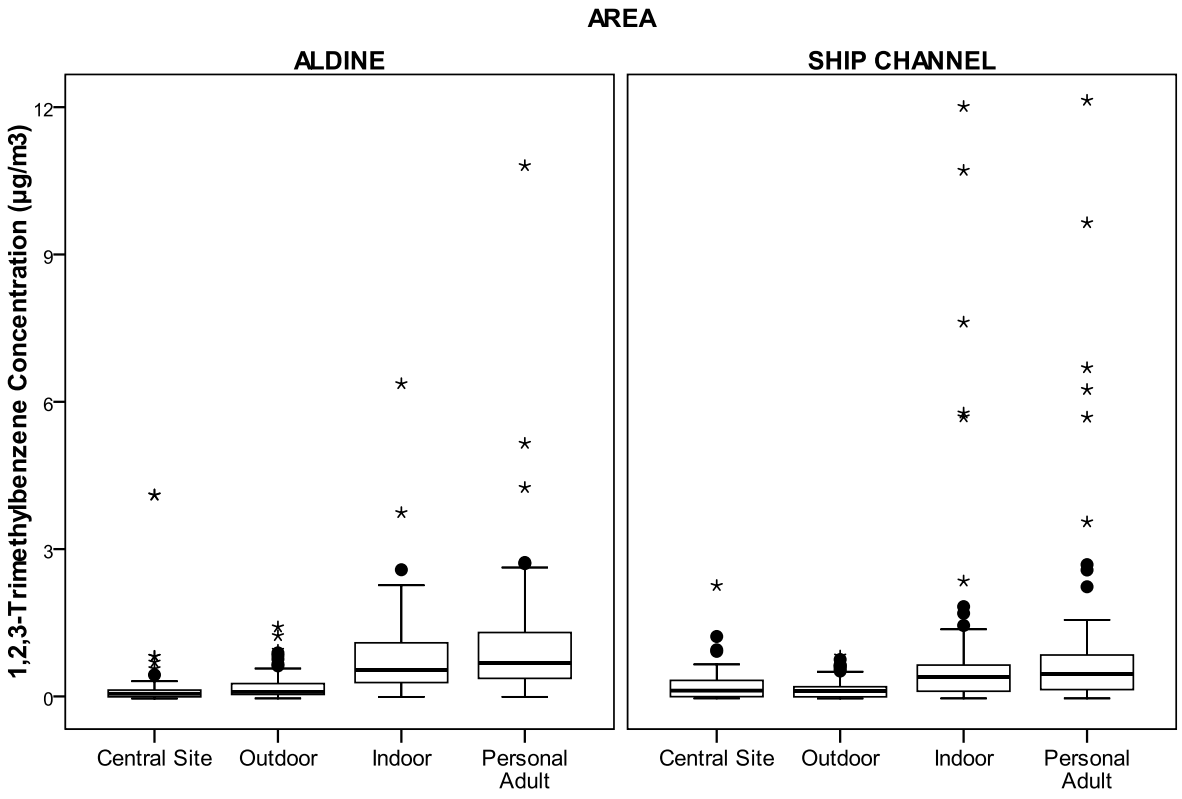

AREA
ALDINE
SHIP CHANNEL
m&p-Xylene Concentration (µg/m3)
120
90
60
30
0
Central Site
Outdoor
Indoor
Personal Adult


AREA
ALDINE
SHIP CHANNEL
o-Xylene Concentration (µg/m3)
60
45
30
15
0
Central Site
Outdoor
Indoor
Personal Adult


AREA
ALDINE
SHIP CHANNEL
Styrene Concentration (µg/m3)
30
20
10
0
Central Site
Outdoor
Indoor
Personal Adult


AREA
ALDINE
SHIP CHANNEL
1,3,5-Trimethylbenzene Concentration (µg/m3)
0
5
10
15
20
Central Site
Outdoor
Indoor
Personal Adult


AREA
ALDINE
SHIP CHANNEL
1,2,4-Trimethylbenzene Concentration (µg/m3)
0
10
20
30
40
50
Central Site
Outdoor
Indoor
Personal Adult


AREA
ALDINE
SHIP CHANNEL
1,2,3-Trimethylbenzene Concentration (µg/m3)
12
9
6
3
0
Central Site
Outdoor
Indoor
Personal Adult

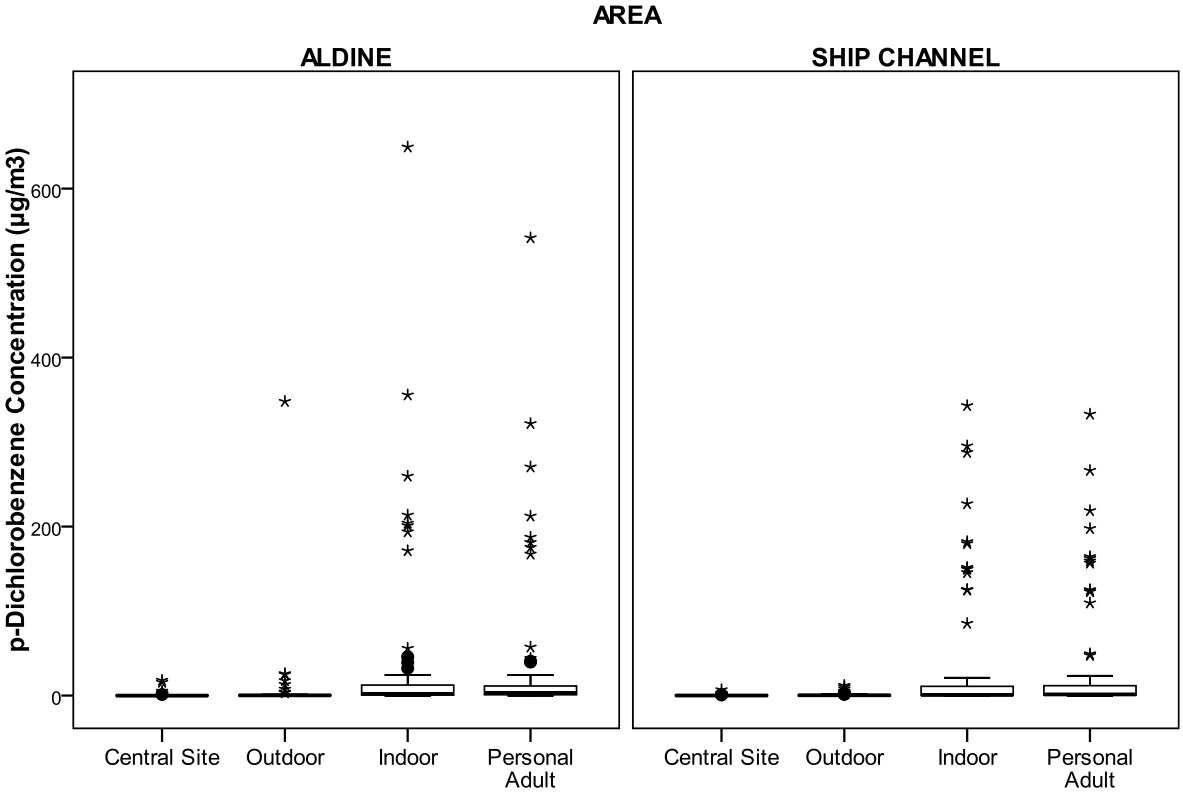
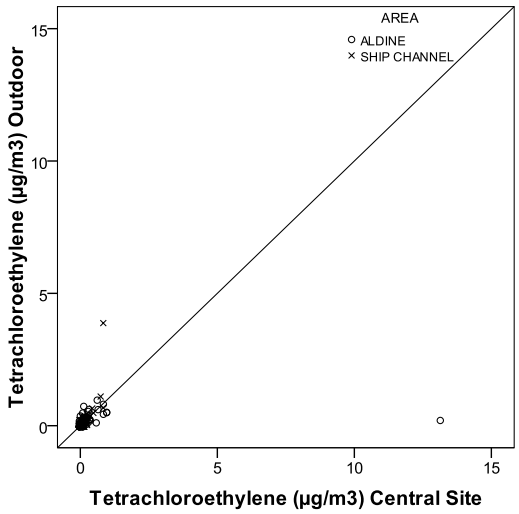

AREA
ALDINE
SHIP CHANNEL
p-Dichlorobenzene Concentration (µg/m3)
600
400
200
0
Central Site
Outdoor
Indoor
Personal Adult

Figure 12. Scatter plots for relationships between indoor, residential outdoor, personal and fixed site measurements for optimal compounds. Line indicates 1:1 relationship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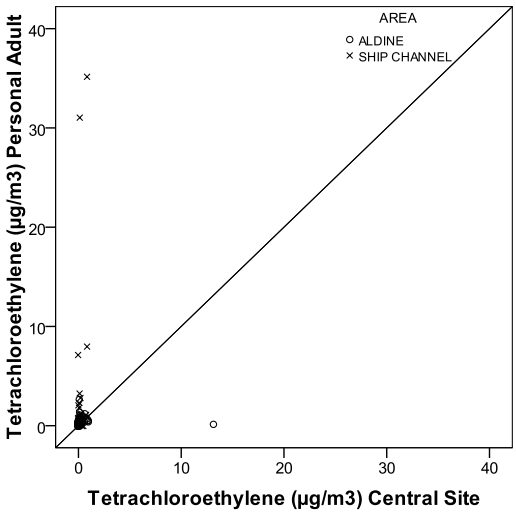
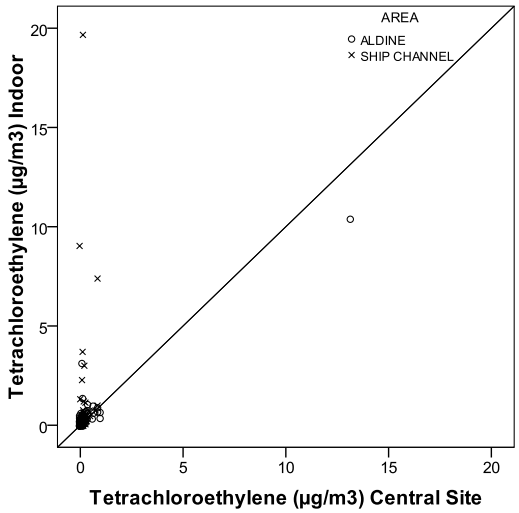
ALDINE
SHIP CHANNEL
Tetrachloroethylene (µg/m3) Outdoor
Tetrachloroethylene (µg/m3) Central Site
0
5
10
15


AREA
ALDINE
SHIP CHANNEL
Tetrachloroethylene (µg/m3) Personal Adult
Tetrachloroethylene (µg/m3) Central Site
0
10
20
30
40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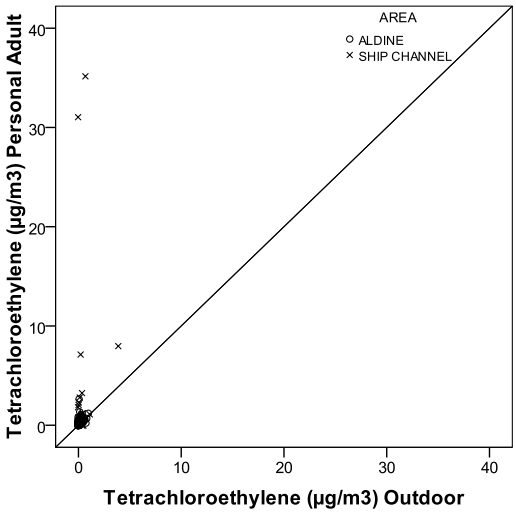
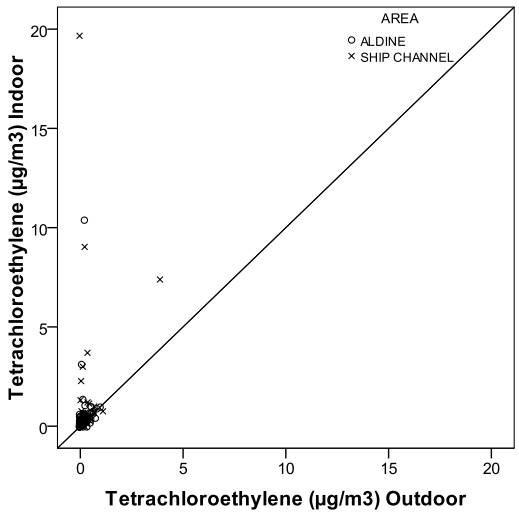
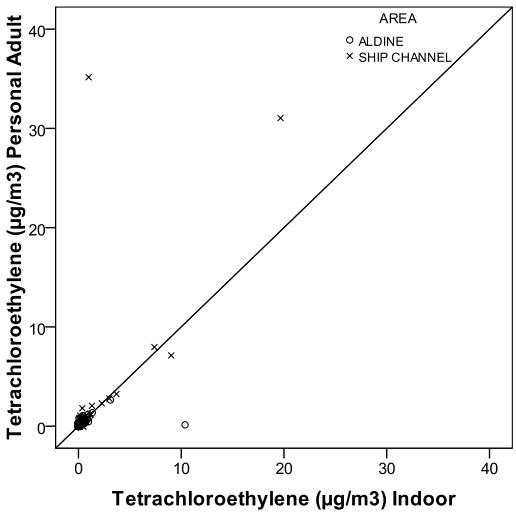
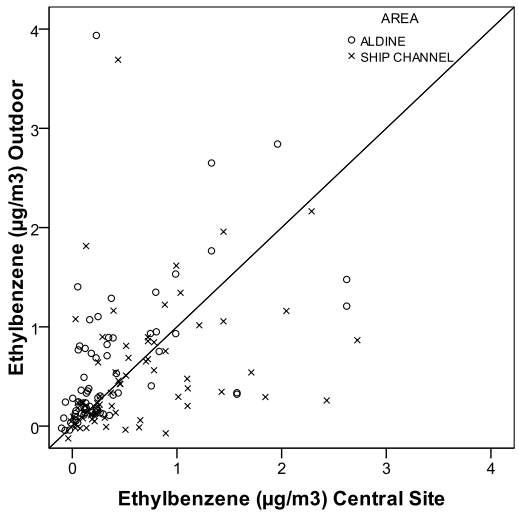
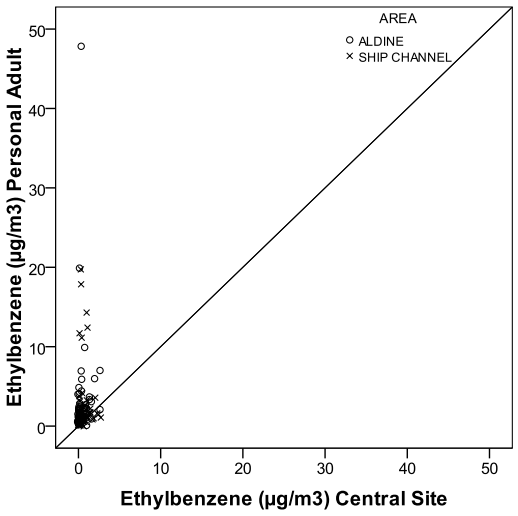
ALDINE
SHIP CHANNEL
Tetrachloroethylene (µg/m3) Indoor
Tetrachloroethylene (µg/m3) Central Site
0
5
10
15
20

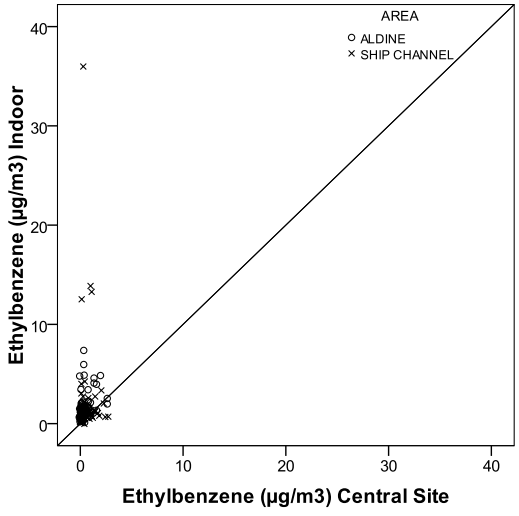

AREA
ALDINE
SHIP CHANNEL
Tetrachloroethylene (µg/m3) Personal Adult
Tetrachloroethylene (µg/m3) Outdoor
0
10
20
30
40


AREA
ALDINE
SHIP CHANNEL
Tetrachloroethylene (µg/m3) Indoor
Tetrachloroethylene (µg/m3) Outdoor
0
5
10
15
20


AREA
ALDINE
SHIP CHANNEL
Tetrachloroethylene (µg/m3) Personal Adult
Tetrachloroethylene (µg/m3) Indoor
0
10
20
30
40


AREA
ALDINE
SHIP CHANNEL
Ethylbenzene (µg/m3) Outdoor
Ethylbenzene (µg/m3) Central Site


AREA
ALDINE
SHIP CHANNEL
Ethylbenzene (µg/m3) Personal Adult
Ethylbenzene (µg/m3) Central Site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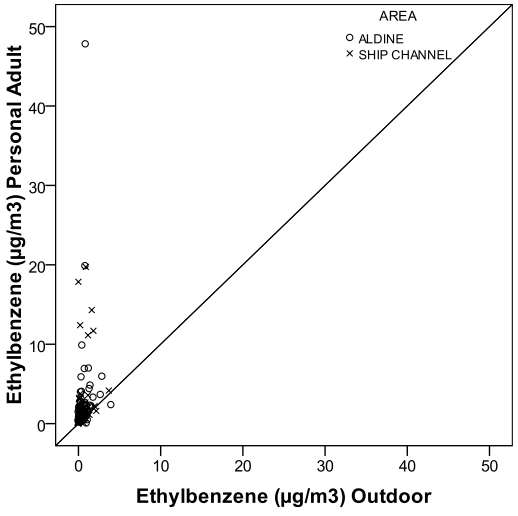
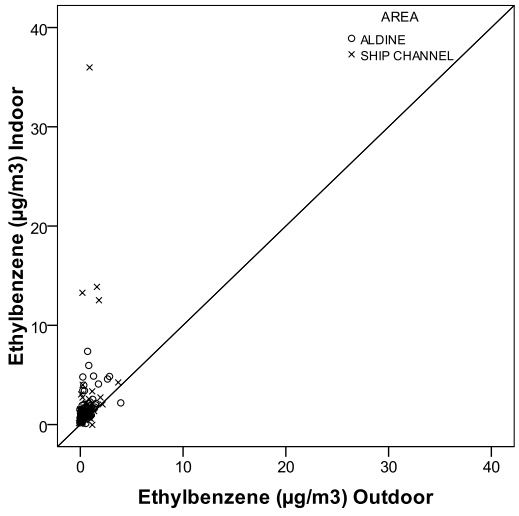
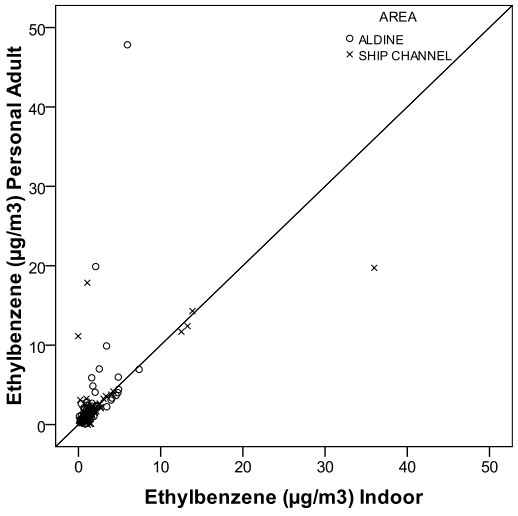
ALDINE
SHIP CHANNEL
Ethylbenzene (µg/m3) Indoor
Ethylbenzene (µg/m3) Central Site


AREA
ALDINE
SHIP CHANNEL
Ethylbenzene (µg/m3) Personal Adult
Ethylbenzene (µg/m3) Outdoor


AREA
ALDINE
SHIP CHANNEL
Ethylbenzene (µg/m3) Indoor
Ethylbenzene (µg/m3) Outdoor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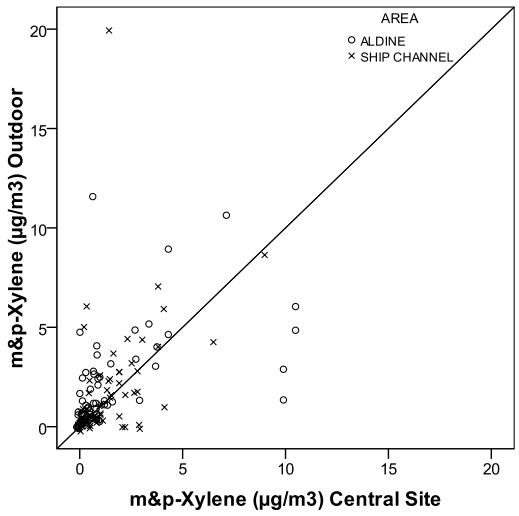
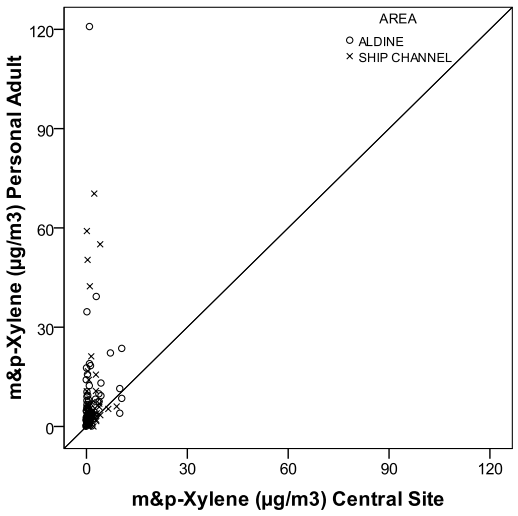
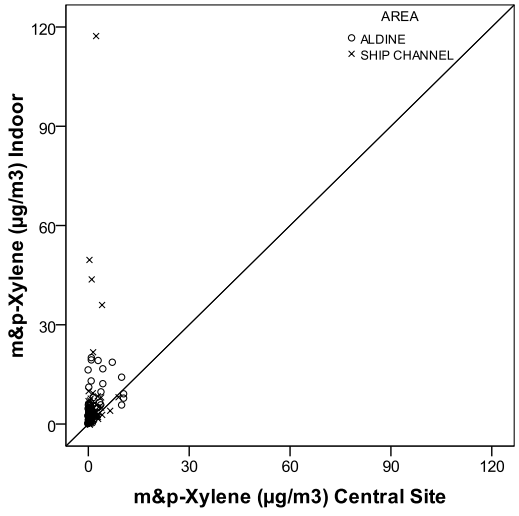
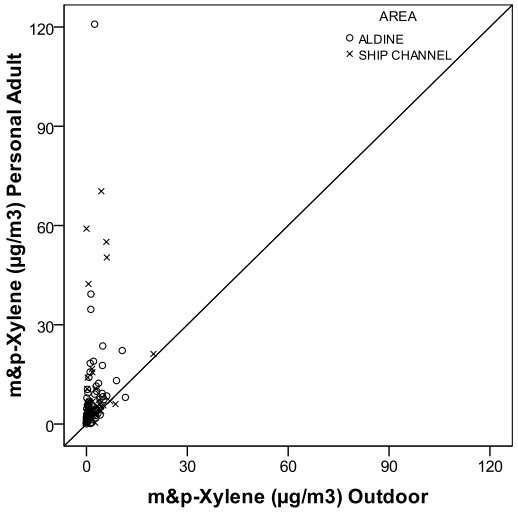
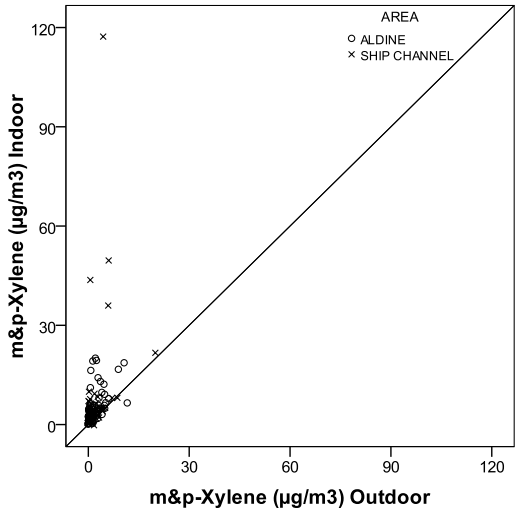
ALDINE
SHIP CHANNEL
Ethylbenzene (µg/m3) Personal Adult
Ethylbenzene (µg/m3) Indoor

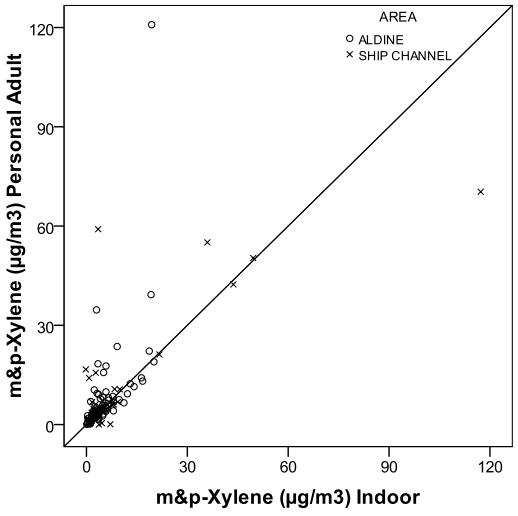

AREA
ALDINE
SHIP CHANNEL
m&p-Xylene (µg/m3) Outdoor
m&p-Xylene (µg/m3) Central Site
0
5
10
15
20

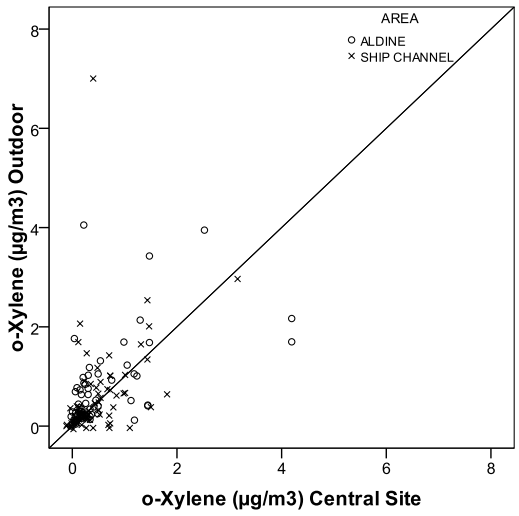

AREA
ALDINE
SHIP CHANNEL
m&p-Xylene (µg/m3) Personal Adult
m&p-Xylene (µg/m3) Central Site
0
30
60
90
120

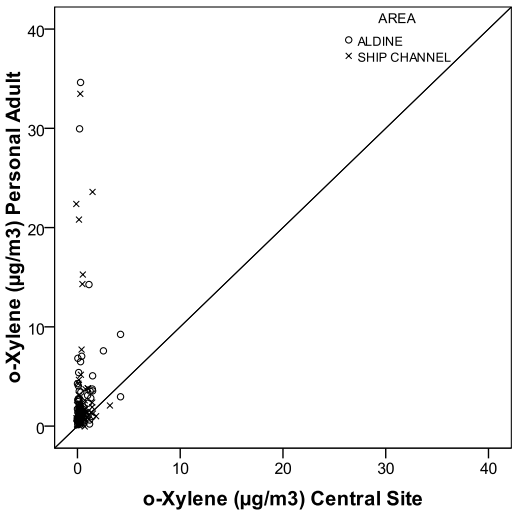

AREA
ALDINE
SHIP CHANNEL
m&p-Xylene (µg/m3) Indoor
m&p-Xylene (µg/m3) Central Site
0
30
60
90
120

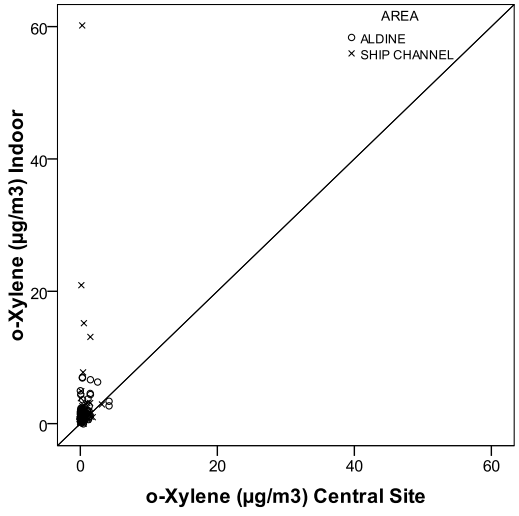

AREA
ALDINE
SHIP CHANNEL
m&p-Xylene (µg/m3) Personal Adult
m&p-Xylene (µg/m3) Outdoor
0
30
60
90
120

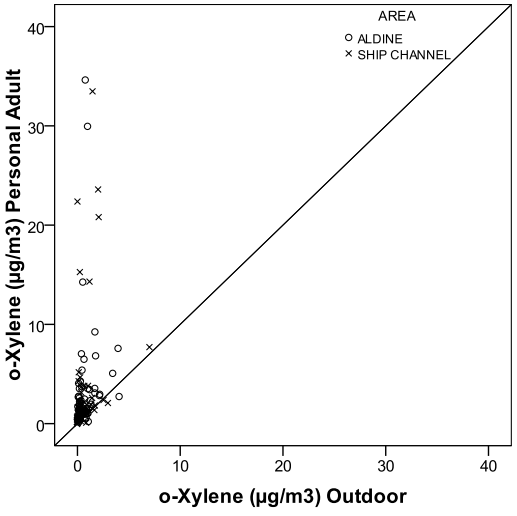

AREA
ALDINE
SHIP CHANNEL
m&p-Xylene (µg/m3) Indoor
m&p-Xylene (µg/m3) Outdoor
0
30
60
90
120

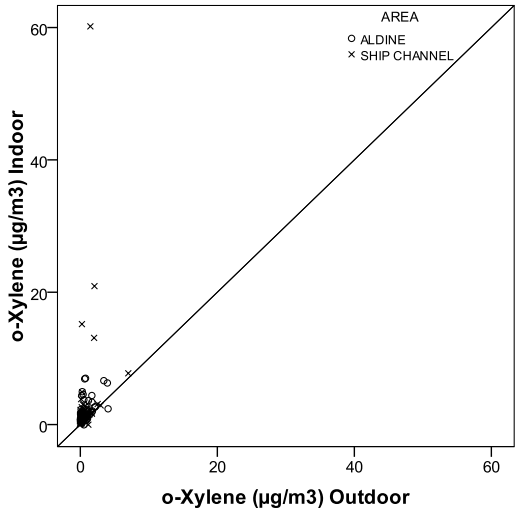

AREA
ALDINE
SHIP CHANNEL
m&p-Xylene (µg/m3) Personal Adult
m&p-Xylene (µg/m3) Indoor
0
30
60
90
120

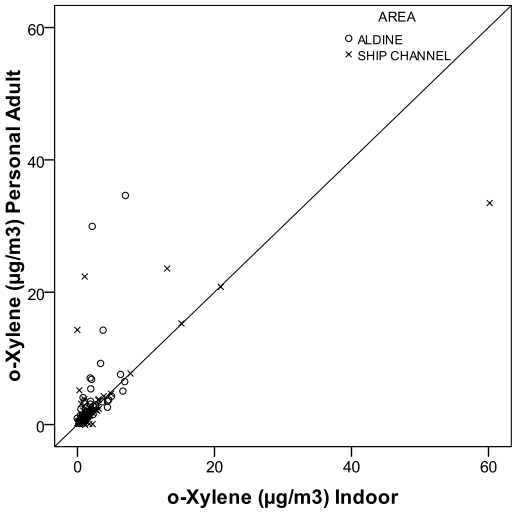

AREA
ALDINE
SHIP CHANNEL
o-Xylene (µg/m3) Outdoor
o-Xylene (µg/m3) Central Site

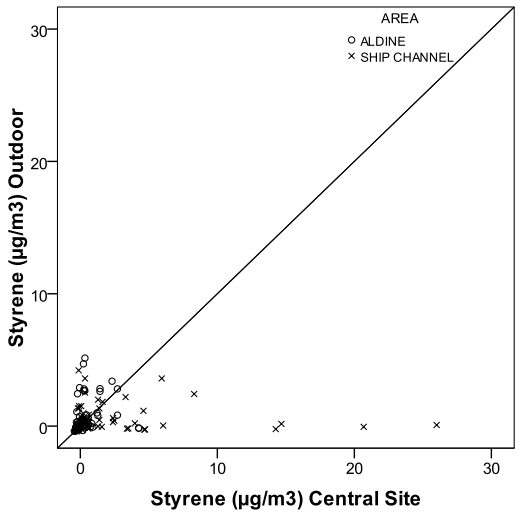

AREA
ALDINE
SHIP CHANNEL
o-Xylene (µg/m3) Personal Adult
o-Xylene (µg/m3) Central Site

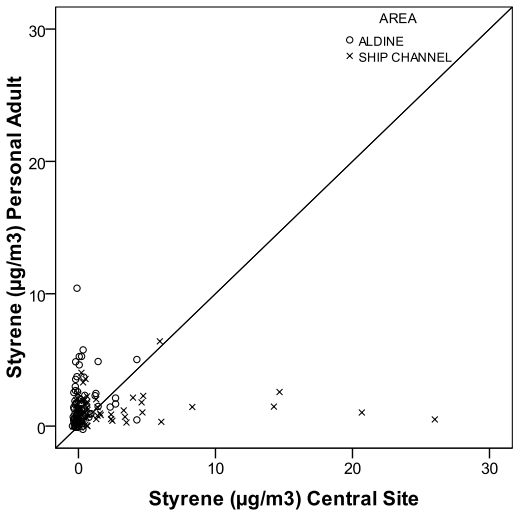

AREA
ALDINE
SHIP CHANNEL
o-Xylene (µg/m3) Indoor
o-Xylene (µg/m3) Central Site

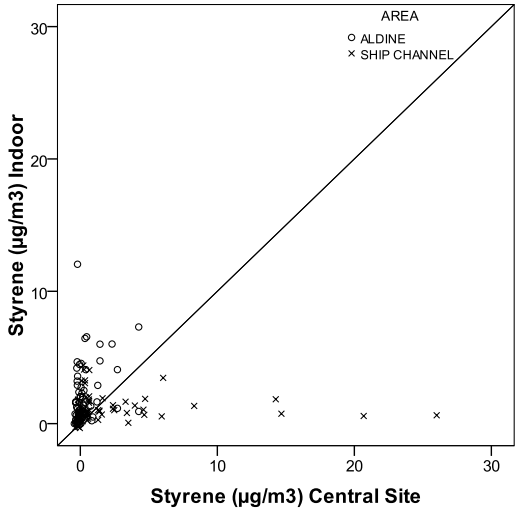

AREA
ALDINE
SHIP CHANNEL
o-Xylene (µg/m3) Personal Adult
o-Xylene (µg/m3) Outdoor

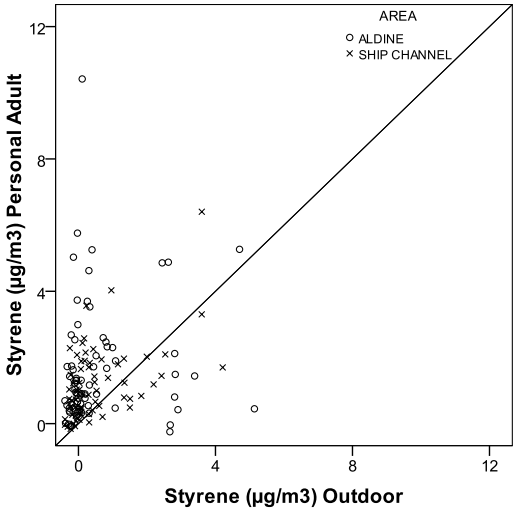

AREA
ALDINE
SHIP CHANNEL
o-Xylene (µg/m3) Indoor
o-Xylene (µg/m3) Outdoor

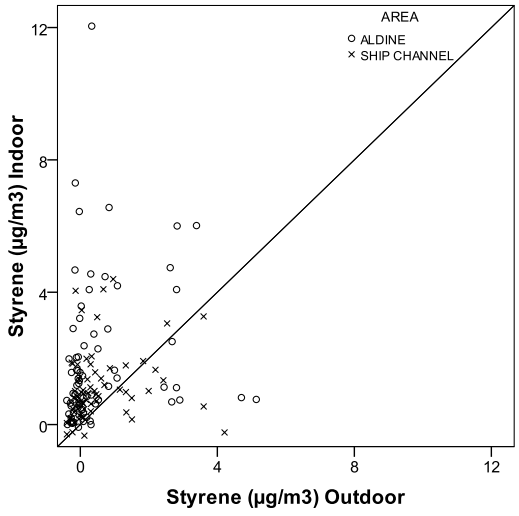

AREA
ALDINE
SHIP CHANNEL
o-Xylene (µg/m3) Personal Adult
o-Xylene (µg/m3) Indoor

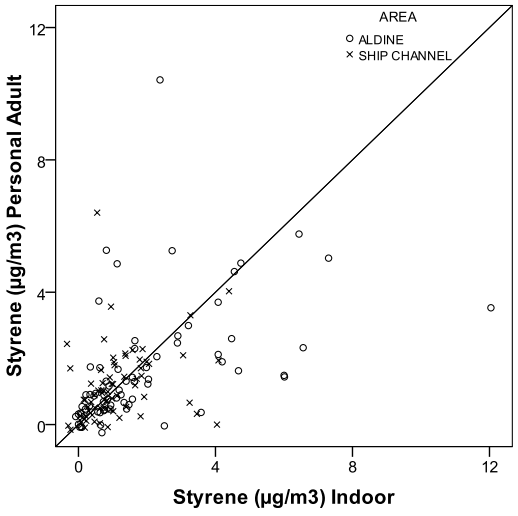

AREA
ALDINE
SHIP CHANNEL
Styrene (µg/m3) Outdoor
Styrene (µg/m3) Central Site
0
10
20
30

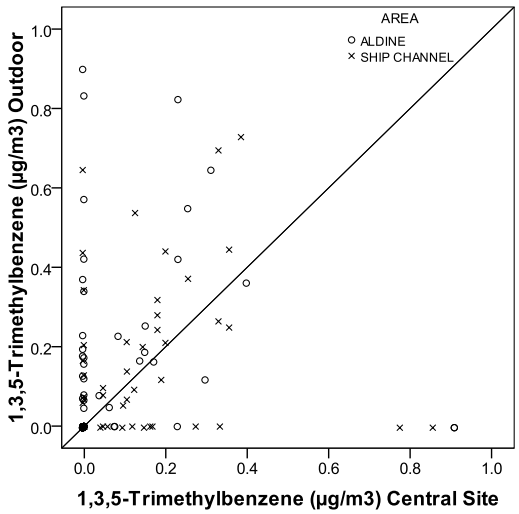

AREA
ALDINE
SHIP CHANNEL
Styrene (µg/m3) Personal Adult
Styrene (µg/m3) Central Site
0
10
20
30

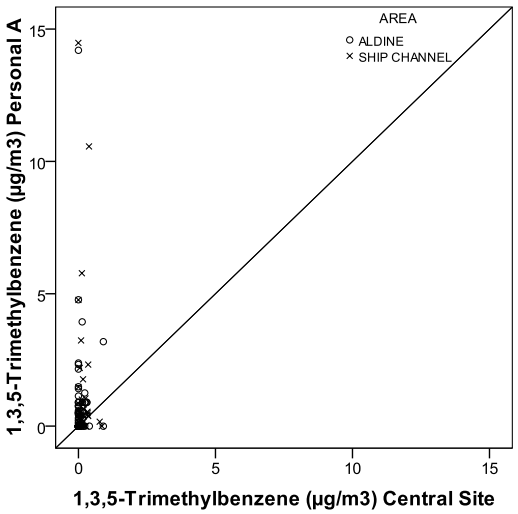

AREA
ALDINE
SHIP CHANNEL
Styrene (µg/m3) Indoor
Styrene (µg/m3) Central Site
0
10
20
30

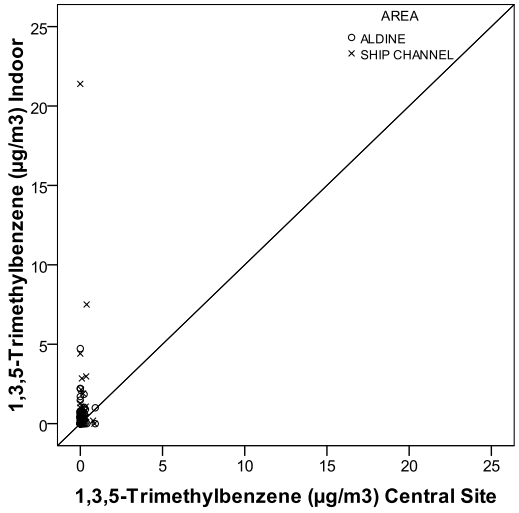

AREA
ALDINE
SHIP CHANNEL
Styrene (µg/m3) Personal Adult
Styrene (µg/m3) Outdoor
0
4
8
12

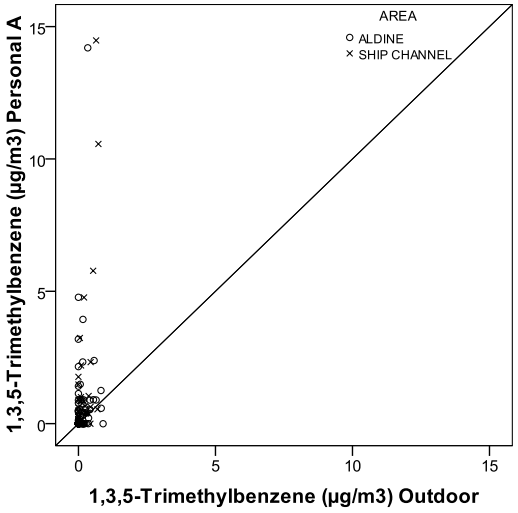

AREA
ALDINE
SHIP CHANNEL
Styrene (µg/m3) Indoor
Styrene (µg/m3) Outdoor
0
4
8
12

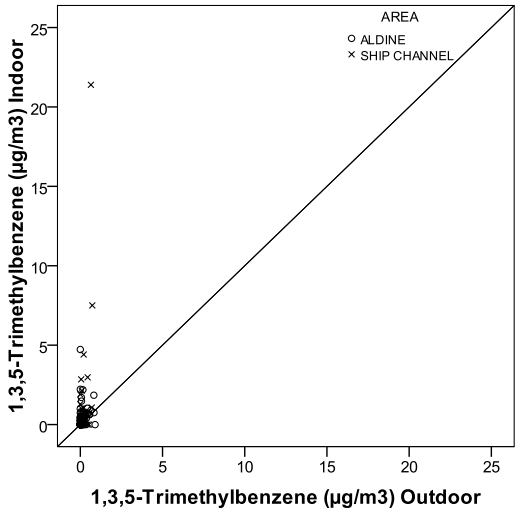

AREA
ALDINE
SHIP CHANNEL
Styrene (µg/m3) Personal Adult
Styrene (µg/m3) Indoor
0
4
8
12

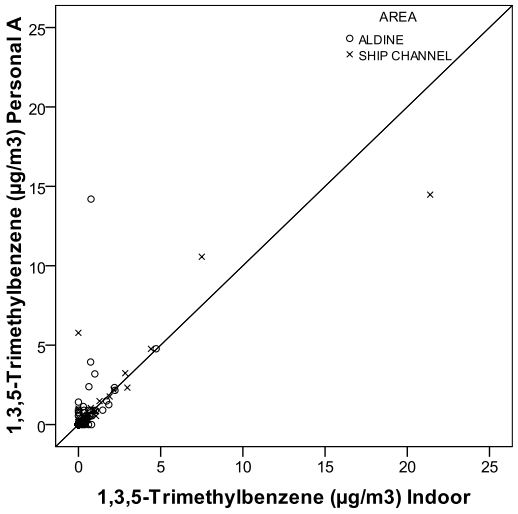

AREA
ALDINE
SHIP CHANNEL
1,3,5-Trimethylbenzene (µg/m3) Outdoor
1,3,5-Trimethylbenzene (µg/m3) Central Site

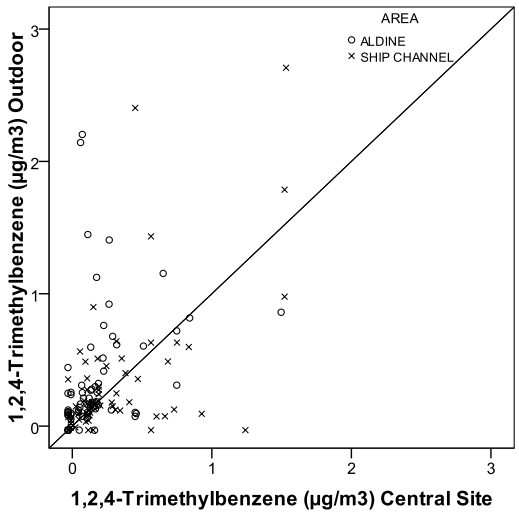

AREA
ALDINE
SHIP CHANNEL
1,3,5-Trimethylbenzene (µg/m3) Personal A
1,3,5-Trimethylbenzene (µg/m3) Central Site

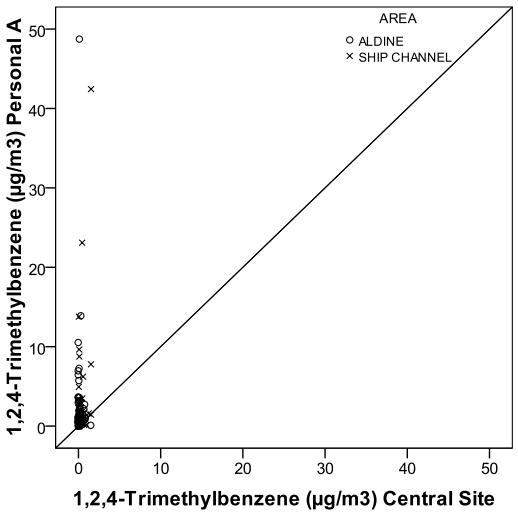

AREA
ALDINE
SHIP CHANNEL
1,3,5-Trimethylbenzene (µg/m3) Indoor
1,3,5-Trimethylbenzene (µg/m3) Central Site

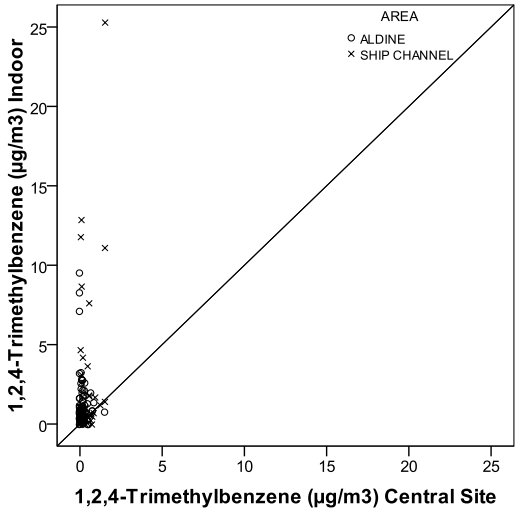

AREA
ALDINE
SHIP CHANNEL
1,3,5-Trimethylbenzene (µg/m3) Personal A
1,3,5-Trimethylbenzene (µg/m3) Outdoor

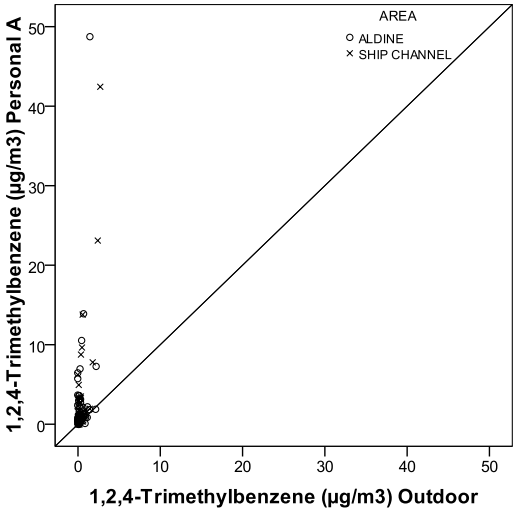

AREA
ALDINE
SHIP CHANNEL
1,3,5-Trimethylbenzene (µg/m3) Indoor
1,3,5-Trimethylbenzene (µg/m3) Outdoor

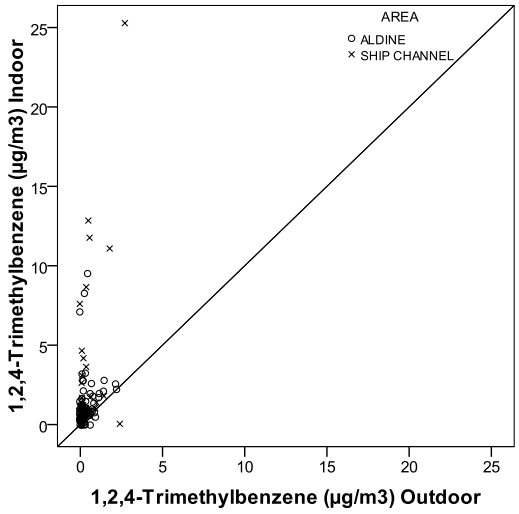

AREA
ALDINE
SHIP CHANNEL
1,3,5-Trimethylbenzene (µg/m3) Personal A
1,3,5-Trimethylbenzene (µg/m3) Indoor

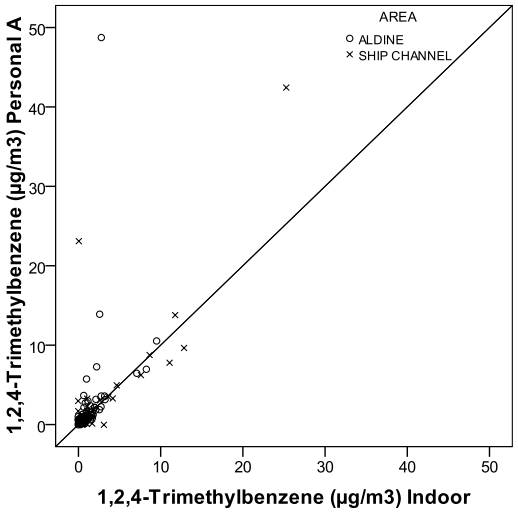

AREA
ALDINE
SHIP CHANNEL
1,2,4-Trimethylbenzene (µg/m3) Outdoor
1,2,4-Trimethylbenzene (µg/m3) Central Site

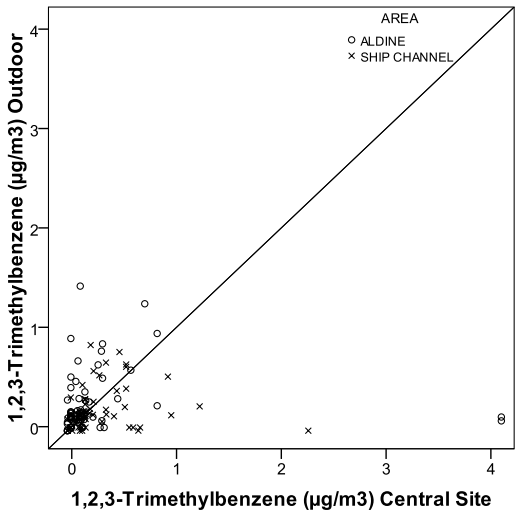

AREA
ALDINE
SHIP CHANNEL
1,2,4-Trimethylbenzene (µg/m3) Personal A
1,2,4-Trimethylbenzene (µg/m3) Central Site

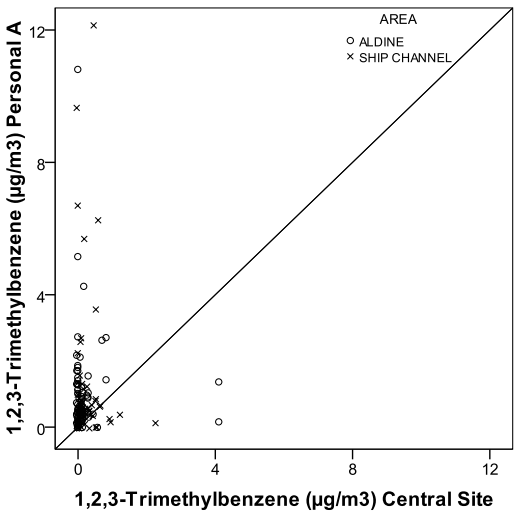

AREA
ALDINE
SHIP CHANNEL
1,2,4-Trimethylbenzene (µg/m3) Indoor
1,2,4-Trimethylbenzene (µg/m3) Central Site

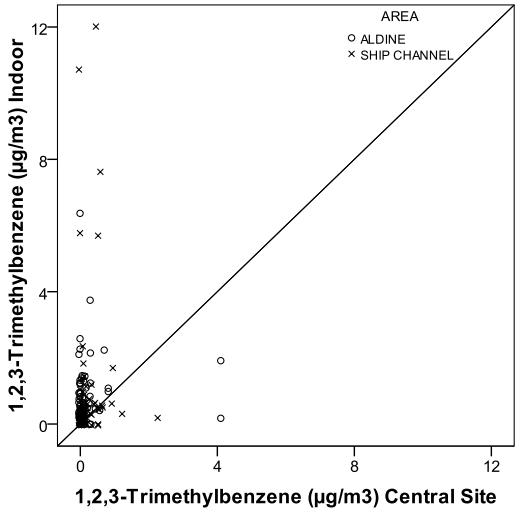

AREA
ALDINE
SHIP CHANNEL
1,2,4-Trimethylbenzene (µg/m3) Personal A
1,2,4-Trimethylbenzene (µg/m3) Outdoor

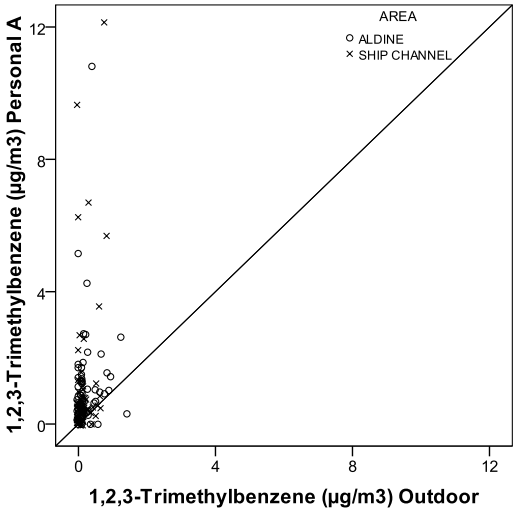

AREA
ALDINE
SHIP CHANNEL
1,2,4-Trimethylbenzene (µg/m3) Indoor
1,2,4-Trimethylbenzene (µg/m3) Outdoor

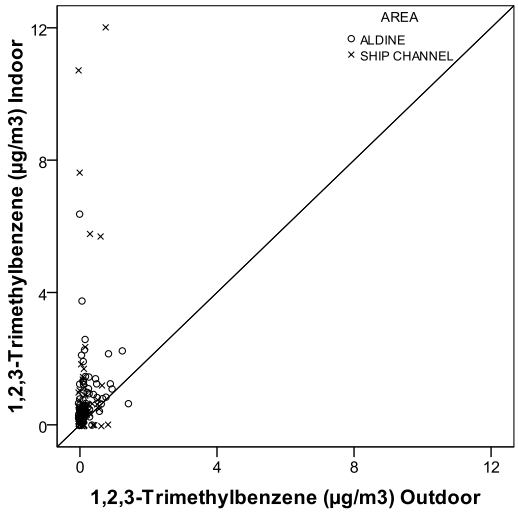

AREA
ALDINE
SHIP CHANNEL
1,2,4-Trimethylbenzene (µg/m3) Personal A
1,2,4-Trimethylbenzene (µg/m3) Indoor

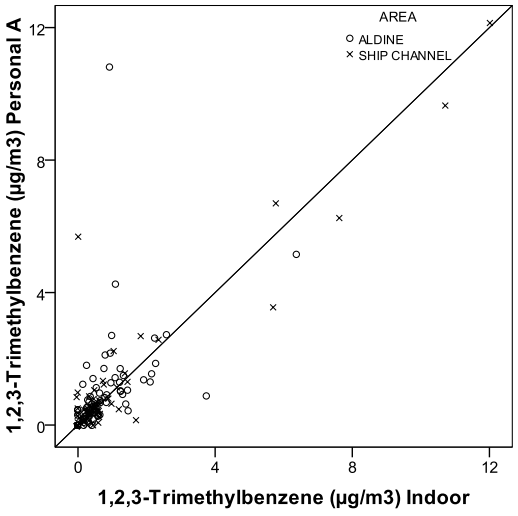

AREA
ALDINE
SHIP CHANNEL
1,2,3-Trimethylbenzene (µg/m3) Outdoor
1,2,3-Trimethylbenzene (µg/m3) Central Site

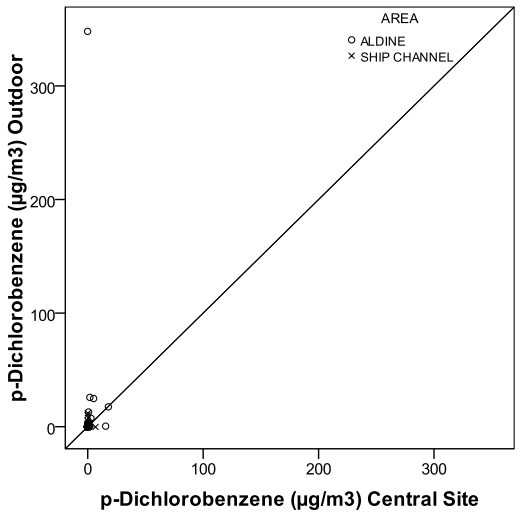

AREA
ALDINE
SHIP CHANNEL
1,2,3-Trimethylbenzene (µg/m3) Personal A
1,2,3-Trimethylbenzene (µg/m3) Central Site

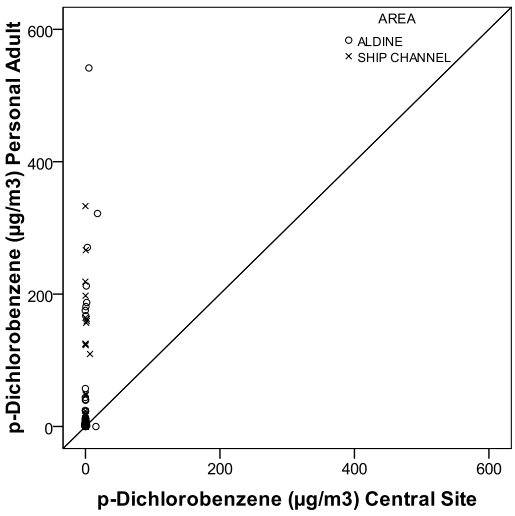

AREA
ALDINE
SHIP CHANNEL
1,2,3-Trimethylbenzene (µg/m3) Indoor
1,2,3-Trimethylbenzene (µg/m3) Central Site

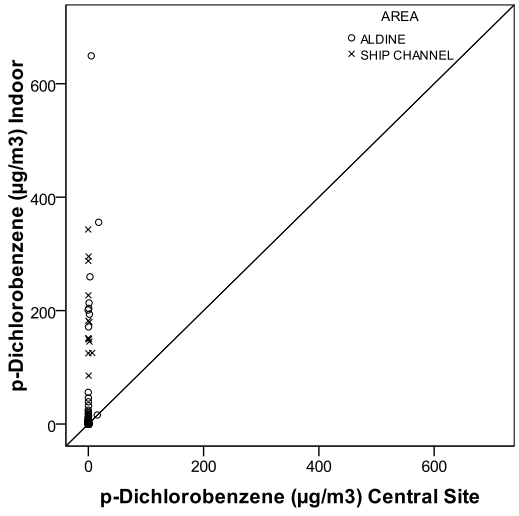

AREA
ALDINE
SHIP CHANNEL
1,2,3-Trimethylbenzene (µg/m3) Personal A
1,2,3-Trimethylbenzene (µg/m3) Outdoor

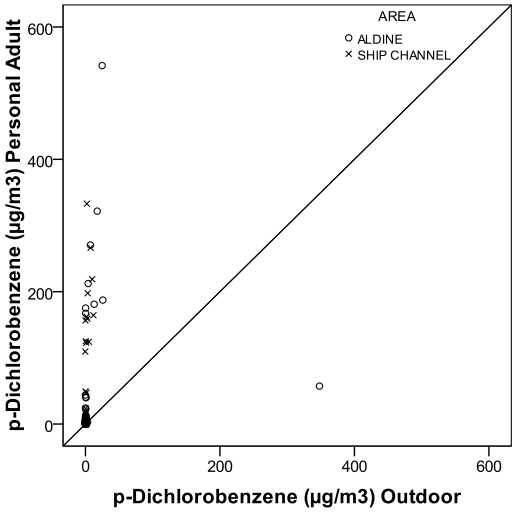

AREA
ALDINE
SHIP CHANNEL
1,2,3-Trimethylbenzene (µg/m3) Indoor
1,2,3-Trimethylbenzene (µg/m3) Outdoor

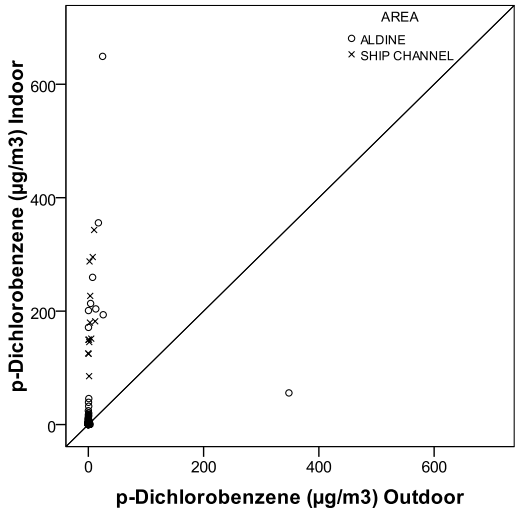

AREA
ALDINE
SHIP CHANNEL
1,2,3-Trimethylbenzene (µg/m3) Personal A
1,2,3-Trimethylbenzene (µg/m3) Indoor

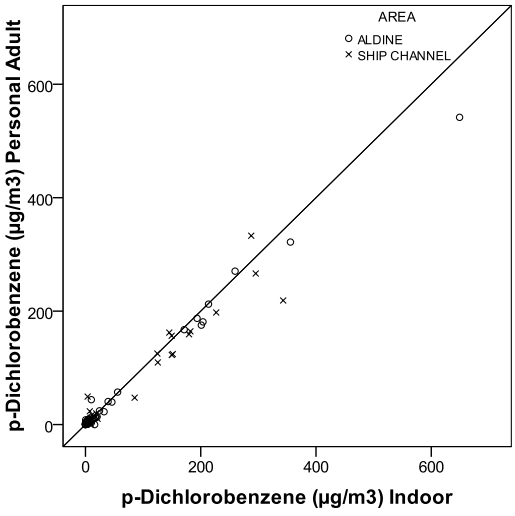

AREA
ALDINE
SHIP CHANNEL
p-Dichlorobenzene (µg/m3) Outdoor
p-Dichlorobenzene (µg/m3) Central Site
0
100
200
300


AREA
ALDINE
SHIP CHANNEL
p-Dichlorobenzene (µg/m3) Personal Adult
p-Dichlorobenzene (µg/m3) Central Site
0
200
400
600


AREA
ALDINE
SHIP CHANNEL
p-Dichlorobenzene (µg/m3) Indoor
p-Dichlorobenzene (µg/m3) Central Site
0
200
400
600


AREA
ALDINE
SHIP CHANNEL
p-Dichlorobenzene (µg/m3) Personal Adult
p-Dichlorobenzene (µg/m3) Outdoor
0
200
400
600


AREA
ALDINE
SHIP CHANNEL
p-Dichlorobenzene (µg/m3) Indoor
p-Dichlorobenzene (µg/m3) Outdoor
0
200
400
600


AREA
ALDINE
SHIP CHANNEL
p-Dichlorobenzene (µg/m3) Personal Adult
p-Dichlorobenzene (µg/m3) Indoor
0
200
400
600

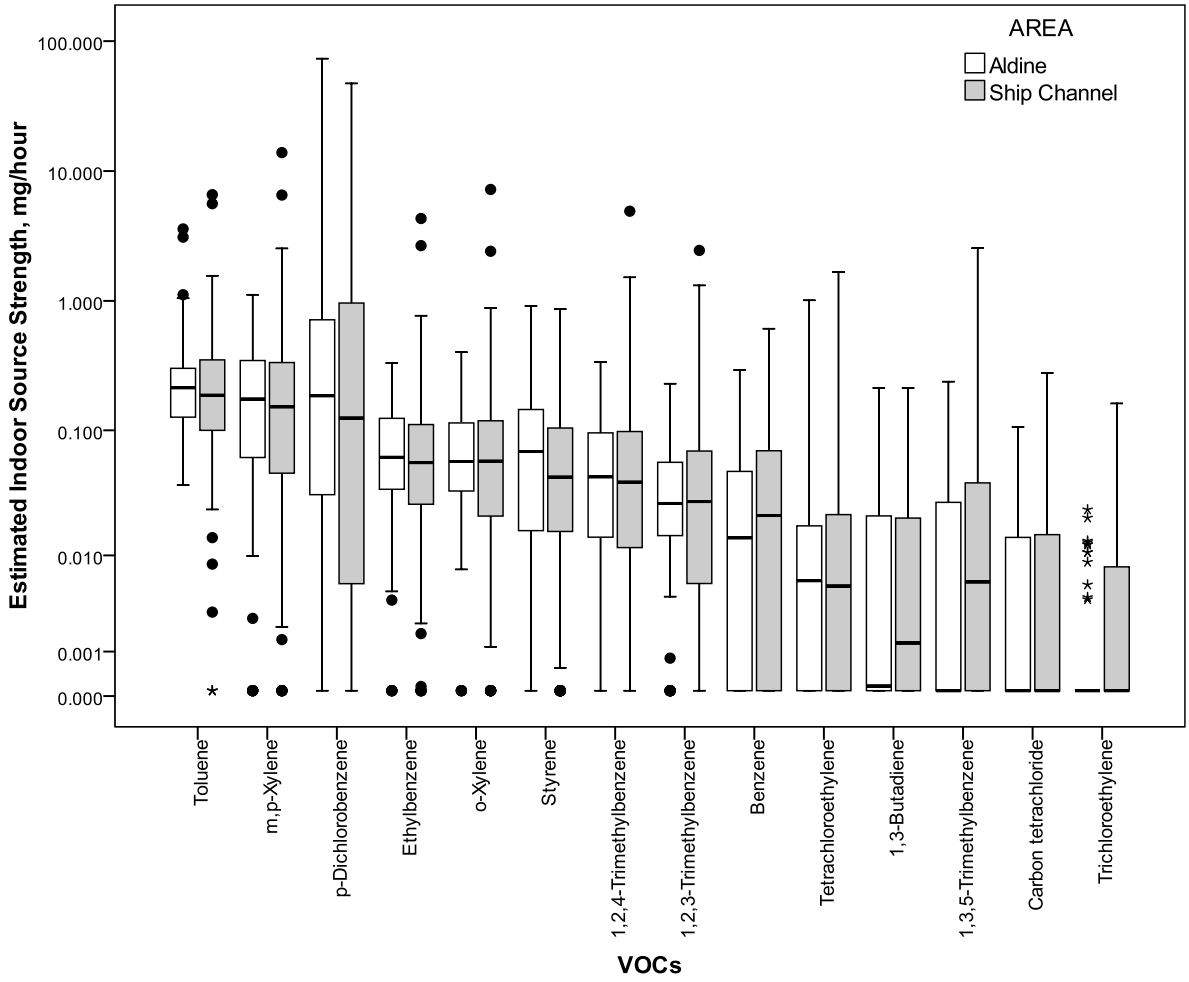


Figure 13. Estimated indoor source strength (mg/hour) by area for HEATS homes

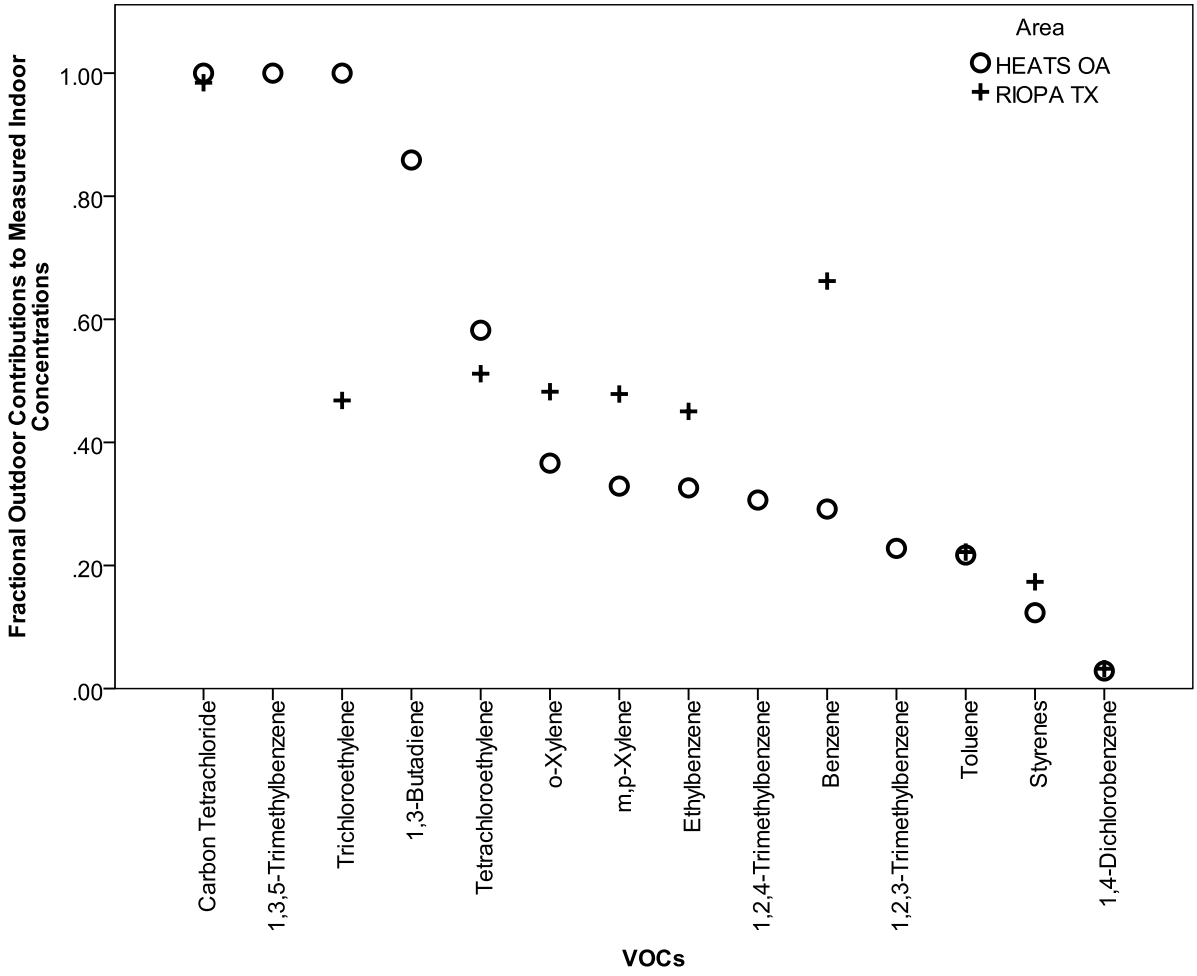


Figure 14. Fractional outdoor contributions to measured indoor concentrations of VOCs for the HEATS homes determined by the ratios of Cout/Cin. For reference, the RIOPA estimates are also shown here. The data points represent the median estimated values.

12. LIST OF APPENDICES