FINAL REPORT ON AN INDOOR ENVIRONMENTAL QUALITY ASSESSMENT OF RESIDENCES CONTAINING CHINESE DRYWALL

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U.S. Consumer Product Safety Commission
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LIST OF ABBREVIATIONS AND ACRONYMS

ACH	air changes per hour
Ag_2S	silver sulfide
AgCl	silver chloride
AHU	air handling unit
ASTM	American Society for Testing and Materials
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.
ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centers for Disease Control and Prevention
CO_2	carbon dioxide
CPSC	U. S. Consumer Product Safety Commission
CS2	carbon disulfide
CuO	copper oxide
Cu_2S	copper sulfide
CV	coefficient of variation
DNPH	2,4-dinitrophenyl hydrazine
DRIFTS	diffuse reflectance infrared Fourier transform spectroscopy
EDD	electronic data delivery
EDS	energy dispersive spectroscopy
EH&E	Environmental Health & Engineering, Inc.
EPA	U.S. Environmental Protection Agency
FOSC	Field Operations Support Center
FTIR	Fourier transform infrared
GC/MS	gas chromatography/mass spectrometry
GC/SCD	gas chromatography method utilizing a sulfur chemiluminescence detector
H_2S	hydrogen sulfide
HF	hydrogen fluoride
HPLCUV	high performance liquid chromatography coupled with an ultraviolet detector
HVAC	heating, ventilating, and air-conditioning
IC	ion chromatography
LOD	limit of detection
ml/min	milliliters per minute
MRL	minimum reporting limit
NDIR	non-dispersive infrared
NIOSH	National Institute for Occupational Safety and Health
NO_2	nitrogen dioxide
O_3	ozone
OSHA	U.S. Occupational Safety and Health Administration
ppb	parts per billion
ppm	parts per million
QA/QC	quality assurance, quality control
QAPP	quality assurance project plan
ref	referent group
RfC	reference concentration
SEM	scanning electron microscopy
RMSE	root mean square error
SO_2	sulfur dioxide
VOC	volatile organic compound

LIST OF ABBREVIATIONS AND ACRONYMS (Continued)

XPS	x-ray photoelectron spectroscopy
XRF	x-ray fluorescence
$\mu g/m^3$	micrograms per cubic meter
°C	degrees Celsius
°F	degrees Fahrenheit

1.0 EXECUTIVE SUMMARY

1.1 SYNOPSIS

In late December 2008, the U.S. Consumer Product Safety Commission (CPSC) began to receive drywall related complaints from consumers with media reports identifying the potentially problematic drywall as “Chinese drywall.” The complaints were reported to include odors emanating from the drywall, corrosion of metal items inside the homes, and short-term health effects that were generally upper respiratory in nature. CPSC wanted to assess the environmental conditions that exist in representative complaint homes constructed with “Chinese drywall” and determine if those conditions could contribute to the health symptoms and material degradation being reported by some residents.

Fifty-one homes in the Southeast U.S. were investigated in 2009 (41 complaint homes; 10 non-complaint homes). Each home investigation included: 1) objective source characterization using Fourier transform infrared spectroscopy (FTIR) and x-ray fluorescence (XRF); 2) characterization of the indoor and outdoor environment including measurements of airborne compounds in multiple rooms using both short-term active sampling and two-week passive sampling (volatile organic compounds [VOCs], aldehydes, reduced sulfur gases, acids) as well as indicators of building performance (air exchange rate, temperature, dew point); and 3) assessment of corrosion potential in each home as determined by visual inspection and analysis of corrosion coupons consisting of silver and metal strips deployed during the two-week sampling period. Statistical analyses were performed to examine the relationship from source, to environment, to effect using the measured parameters.

Results from this study indicate that the concentrations of strontium measured with XRF and carbonate ion (carbonate) using FTIR can be used in combination to reliably identify suspect drywall. Complaint homes were found to have significantly greater rates of copper and silver corrosion than non-complaint homes. Indoor air of complaint homes was more likely to contain low-level hydrogen sulfide compared to non-complaint homes. Moreover, hydrogen sulfide concentrations were positively associated with dew point, suggesting a possible interaction of the two that may be important for release or effects of the gas. Hydrogen sulfide was also associated with both copper and silver corrosion. Formaldehyde concentrations were consistent between complaint and non-complaint homes, indicating they were related to sources inside the home and not the suspect drywall, and were also associated with corrosion in some rooms. There was suggestive evidence that the rate of silver corrosion associated with formaldehyde was dependent upon the presences of hydrogen sulfide, suggesting a potential synergistic effect with formaldehyde; it is unknown if the effect is due to formaldehyde itself or if formaldehyde is a surrogate for some other main effect (e.g., formic acid). All of the homes in the study had air exchange rates that are consistent with ”tight” homes and that may influence the relationships among hydrogen sulfide, formaldehyde, and other materials in the complaint homes.

1.2 INTRODUCTION AND OBJECTIVES

This document, entitled “Final Report on an Indoor Air Quality Assessment of Residences Containing Chinese Drywall,” was prepared on behalf of CPSC by Environmental Health & Engineering, Inc. (EH&E). This final report contains information and data that has been compiled by EH&E on 51 homes (41 complaint homes and 10 non-complaint homes) evaluated as part of the overall study. All field work was completed between July 27 and September 30, 2009.

This investigation was designed to identify critical parameters related to the potential for suspect imported Chinese drywall to adversely affect health and property by carefully examining the relationship between possible sources, environmental modifiers, and effects in homes. Although a variety of health concerns have been reported, this study was not intended to address this issue directly. The primary effect variable that has been utilized throughout this study is that of corrosion of metal surfaces. Corrosion of new metal surfaces is a direct and objective measure of a significant environmental outcome and serves as an integrated measurement that will directly account for the wide variety of corrosive gases that could be present in indoor environments.

The specific aims of this study were to:

- Identify sensitive and specific markers of suspect imported Chinese drywall that could be used to positively identify potentially impacted homes.

- Characterize the indoor and outdoor concentrations of various airborne compounds. These include reduced sulfur gases, sulfur dioxide, aldehydes, VOCs, inorganic acids, and organic acids of representative complaint and non-complaint homes.

- Identify various building characteristics of subject homes, including: surface area of Chinese drywall, air exchange rates, temperature, indoor relative humidity, and dew point.

- Evaluate the use of the rate of corrosion of metal objects in both complaint and non-complaint homes as an integrated measure of effect consistent with the environmental parameters measured in the homes.

- Examine relationships among drywall properties, building characteristics, constituents of indoor air, and rates of corrosion.

- Evaluate measures that could potentially serve as indicators of respiratory and mucosal irritation.

- Develop a meaningful and sensitive sampling protocol that could readily be deployed in the field for future studies.

Although multiple studies have been performed by various federal and state agencies and several private entities, no consensus regarding the cause or resolution of the adverse environmental conditions found in homes containing Chinese drywall has been developed at this time. This is primarily due to the fact that emissions from Chinese drywall represent a complex, dynamic, unstable mixture of low-level contaminants. They are likely highly reactive and therefore may be rapidly scavenged from the air through the corrosion on metal surfaces, reactions with other compounds, or adsorption on various surfaces and therefore may not be present in ambient air for a long enough period of time to permit accurate characterization.

1.3 METHODS

This study was designed to be a detailed characterization of the indoor environment found in representative complaint homes that were selected by CPSC from their existing incident reporting database. This study also includes results from non-complaint residences that were recruited by CPSC to participate in this study based on their age of construction, proximity to complaint homes, and an understanding they were constructed without the use of Chinese drywall.

The methods used to achieve the specific aims of this study are described in detail in the body of the report. The following section provides a brief overview for guidance in interpreting the results.

- **Markers of Chinese Drywall.** Real-time measurements for strontium concentrations were made in the field using XRF to identify markers of imported Chinese drywall. Core sampling of drywall was also performed in each room of the subject homes and the samples returned to the laboratory for additional XRF analysis, as well as characterization using FTIR spectroscopy.

- **Characterization of Indoor and Outdoor Airborne Compounds.** Active, short duration samples were collected for a number of indoor contaminants. These included reduced sulfur gases, aldehydes, VOCs, inorganic and organic acids. Additionally, in order to improve the limit of detection for many of the compounds of interest, as well as to utilize longer integration periods that are consistent with the period of exposure of the metal coupons, passive samplers were utilized to collect hydrogen sulfide, aldehydes, ozone, sulfur dioxide, nitrogen dioxide, and hydrofluoric acid over a two-week period.

- **Building Characteristics.** Detailed mapping of the elemental composition of the drywall was performed using XRF throughout each study home. Air exchange rate measurements were collected using a standard tracer gas dilution procedure using carbon dioxide as the tracer gas. Temperature and indoor relative humidity were tracked over a two-week period utilizing continuous data logging sensors.

- **Characterization of Metal Corrosion.** Pre-cleaned copper and silver coupons were placed in multiple locations in each home and were employed to determine the rate of corrosion at the subject homes over a two-week sampling period. Inspections of a variety of metal surfaces within each home were performed, and numerical rating criteria were implemented to characterize the amount of corrosion in each residence.

- **Examination of Relationships among Drywall Properties and Building Characteristics.** Detailed statistical analysis was performed using correlation and regression analyses to identify factors and potential effect modifiers that could explain the corrosion effects found in the homes containing Chinese drywall compared to non-complaint homes. Statistical analysis included compiling descriptive statistics, scatter plots, and box plots. Bivariate statistical relationships were assessed using Spearman rank correlation and Wilcoxon rank sum tests. Generalized linear models were used for analysis of variance and multivariate regression, with linear mixed effects models used to account for within-home correlation in analyses that included multiple measures in a home (e.g., air samples taken at the same time in two rooms).

1.4 RESULTS

The results are described in detail in the body of this report. Key points are as follows.

- The study found that the concentrations of strontium and carbonate ion (carbonate) determined in drywall can be used in combination to reliably characterize suspect imported drywall. Portable XRF and FTIR instruments were used to measure strontium and carbonate respectively in both samples of known origin, to effectively calibrate their response, and in the field to characterize samples of unknown origin.

- Corrosion on metal surfaces was found to be significantly greater in the complaint houses than in the non-complaint houses. The corrosion effect was significant both when quantitative measures utilizing the corrosion coupons were used to measure the rate of corrosion, as well as when corrosion on ground wires found in the home was observed and rated by trained technicians.

- The average air exchange rates measured in each home were similar for both the complaint and non-complaint homes. The air exchange rate study also showed that the houses in the sample were tightly sealed with short-term average air exchange rates ranging from 0.05 to 0.8 air changes per hour (ACH) with a median of 0.19 ACH. This value is contrasted with the value of 0.4 ACH, which has been reported by many investigators (ASHRAE 2005) as the median of the current U.S. housing stock. These low air exchange rates may play an important role in the effect of gases and indoor environmental conditions on corrosion and possible exposures to indoor contaminants.

- Hydrogen sulfide gas was found in the majority of complaint and in two non-complaint homes as well as in some outdoor samples. The concentrations of hydrogen sulfide were significantly higher in complaint homes compared to non-complaint homes

- Hydrogen sulfide concentrations in air were associated with higher dew points for complaint homes. A positive association was observed between elevated dew points and hydrogen sulfide concentrations for homes with imported drywall. Hydrogen sulfide was present where the dew point reached typical room temperatures and condensation of water vapor would be expected.

- Carbon disulfide concentrations varied between complaint and non-complaint homes, with median concentrations of 2.4 and 0.74 micrograms per cubic meter ($\mu g/m^3$) respectively. Statistical tests, while showing no difference, were limited by a reduced sample size for the carbon disulfide measurements.

- Organic acids were detected in both complaint and non-complaint homes with no statistical difference observed between the two classifications of homes.
- Hydrogen sulfide and formaldehyde concentrations in indoor air were associated with corrosion rates in the study homes. For silver, a potential interactive effect was seen with formaldehyde; the effect of formaldehyde on corrosion rates was dependent upon the presence of hydrogen sulfide. Formaldehyde may be a marker of some other factor associated with corrosion (e.g., formic acid).

- Concentrations of aldehydes in the indoor air of both complaint and non-complaint homes did not differ significantly, but were generally greater than levels reported in the scientific literature for residences in various areas of the United States. These results may not be directly comparable for a number of reasons, chiefly related to the age of the homes from the various studies. However, when the data from this study's houses are compared to data from recently constructed homes, the levels of formaldehyde and other aldehydes are comparable. This shows the importance of understanding the age of the home and other building characteristics when assessing the significance of some of these other compounds.

1.5 LIMITATIONS

This study was designed to characterize the air quality in homes that had health and/or corrosion complaints suspected to be associated with certain types of drywall. This "suspect" drywall is believed to originate and be imported from the People's Republic of China. However, at this time there is insufficient evidence to support or refute the assertion that all Chinese-origin or imported drywall exhibits the health or corrosive characteristics reported in complaint homes.

The intent of this sampling and analysis program was to elucidate the relationships between suspect drywall and environmental conditions existing in the home that could be characterized by use of objective measurements such as the rate of corrosion on metal surfaces. This study was designed as an in situ investigation in which the house was characterized in the "lived in" condition. (Certain exceptions to this "lived in" characterization, where the houses were unoccupied during the testing, were found to have a negligible impact on the primary findings.) So as to not possibly miss an important interaction effect, no attempt was made to restrict occupant activities, manipulate the mechanical systems or remove materials from the residence prior to, or during, sampling.

The indoor environment of the complaint homes is complex, dynamic and in many ways challenging to characterize due to the low concentrations of the contaminants present and the highly reactive nature of many of the species of interest. It is also probable that there are important interactions between the materials emitted from the suspect drywall and airborne compounds present in the indoor environment that may be associated with other sources, as well as specific home characteristics, that could cause, or be a significant contributor to, the complaints reported.

2.0 INTRODUCTION

2.1 OVERVIEW AND OBJECTIVES

This report was prepared on behalf of CPSC by EH&E and describes an investigation of the relationship between indoor environmental quality and imported drywall in residential buildings. This study is one component of a multifaceted investigation being led by CPSC to evaluate the emissions from imported Chinese drywall. CPSC wanted to assess the environmental conditions that exist in representative homes constructed with this drywall and determine if those conditions could contribute to the health symptoms and material degradation being reported by some residents (CPSC 2009a).

The objective of the in-home investigation was to characterize the indoor environment in representative complaint homes in detail, obtain air samples and other objective measurements that could be used for future risk assessments and examine homes for evidence of health stressors that could plausibly be related to drywall based on complaints and scientific information compiled by CPSC and EH&E. This was an exploratory study in which indoor environmental conditions for a sample of complaint homes were compared to conditions in a sample of non-complaint homes, and considered the context of normative values and relevant health benchmarks. The study design was not intended to compare homes individually but rather to compare two groups of homes (complaint versus non-complaint) under exposure conditions that would be considered typical under normal occupancy. Activities in this scope of work included the following elements:

- Identify objective markers of imported drywall.
- Measure reduced sulfur gases, sulfur dioxide, aldehydes, volatile organic compounds (VOCs), inorganic acids, and organic acids in indoor and outdoor air of representative complaint and non-complaint homes.
- Ascertain building characteristics of test homes including surface area, air exchange rate, indoor temperature, and indoor relative humidity.
- Determine the rate of corrosion for copper and silver objects in homes.

- Examine relationships among drywall properties, building characteristics, constituents of indoor air, and rates of corrosion.

- Evaluate measures that could potentially serve as indicators of respiratory and mucosal irritation.

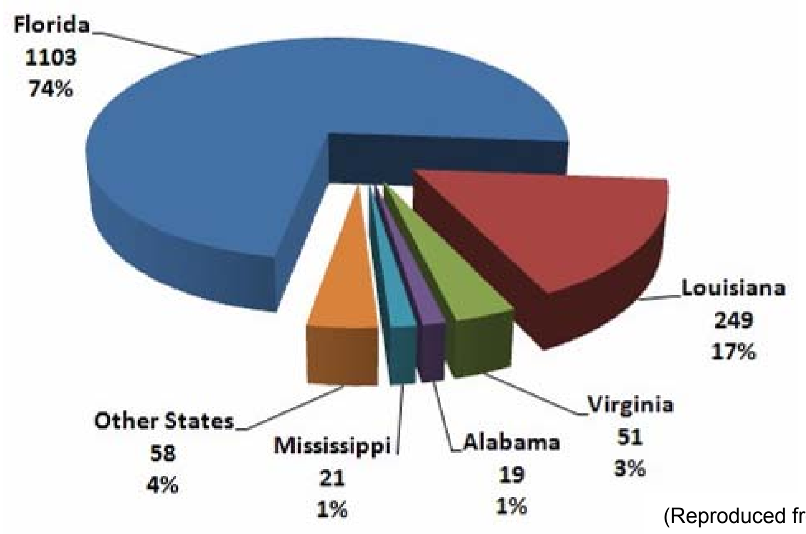
2.2 BACKGROUND

In late December 2008, CPSC began to receive drywall related complaints from consumers (CPSC 2009c). The complaints are reported to include odors emanating from the drywall, corrosion of metal items inside the homes, and short-term health effects that were generally upper respiratory in nature.

CPSC staff investigated four complaint homes in March 2009 and reported a noxious odor inside the homes, varying levels of corrosion in electrical outlets, circuit breakers, plumbing fixtures, and air-conditioning coils, and personally experienced respiratory irritation, headache, and eye irritation while inside the homes (CPSC 2009c). CPSC staff reported that the health symptoms dissipated after leaving the homes.

Following the preliminary site visits, CPSC in conjunction with the U.S. Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention (CDC), and the Agency for Toxic Substances and Disease Registry (ATSDR) initiated a multi-agency approach to investigate the drywall-related complaints. Information on the overall investigation and inter-agency coordination is available elsewhere (CPSC 2009a).

As of September 2009, CPSC had received about 1,501 incident reports from 24 states and the District of Columbia (CPSC 2009b). The majority of reports are from Florida, followed by Louisiana, Virginia, and other states (Figure 2.1).



(Reproduced from CPSC 2009c)

Figure 2.1 Number and Percentage of Drywall Complaints Received as of September 2009

A number of reports related to imported drywall were completed by other groups prior to initiation of the CPSC in-home study. Results of an early in-home study in south Florida conducted on behalf of a supplier of building materials were released in 2006 (CTEH 2007). In 2008, a study conducted on behalf of a homebuilder was released that examined levels of sulfide gases inside of homes reported to contain imported drywall (ENVIRON 2008). Also in 2008, investigators from a research center in Germany described their measurements of odorous emissions from drywall under laboratory conditions in a paper presented at a scientific conference (Burdack-Freitag et al. 2008). The State of Florida Department of Health and the EPA released results of preliminary sampling of drywall and copper materials in March and May 2009, respectively (EPA 2009a; Unified Engineering Inc. 2009). Findings contained in these reports were considered in the design of the present study in addition to other information gathered by CPSC and various agencies.

2.3 ORGANIZATION OF THE REPORT

Following this introduction, the design of the in-home investigation is presented in Section 3. That section includes the specific aims of the study, basic information on the homes enrolled, schedule, and sampling plan. Section 4 contains details of the methods used to collect and analyze samples from the test homes as well as the quality assurance and quality control procedures implemented. Results of the field sampling and laboratory analyses are summarized in Section 5 in the form of summary statistics for individual analytes in the test homes. Associations between constituents of indoor air and measures of corrosion as well as multivariate relationships among constituents of imported drywall, indoor air, and corrosion and other characteristics of the primary measurements are also provided in Section 5. A discussion of the study findings is presented in Section 6 including comparisons of results for complaint homes to corresponding levels observed in non-complaint homes. Finally, conclusions drawn from the in-home study are presented in Section 7.

3.0 STUDY DESIGN

3.1 OVERVIEW

As noted in Section 2, the objective of this investigation was to assess levels of a variety of environmental conditions in homes believed to be constructed with imported drywall based on criteria established by CPSC, henceforth referred to as complaint homes. The same methods were used to assess environmental conditions in a sample of non-complaint homes also identified by CPSC. EH&E assessed environmental conditions of 51 homes between July 27 and September 30, 2009, consisting of 41 complaint and 10 non-complaint homes located in five states.

Both integrated and discrete observations of environmental conditions were obtained from complaint and non-complaint homes, details of which are provided below. Integrated observations included two measures of corrosion: (i) rates of corrosion determined from copper and silver coupons exposed to indoor air in each home for two weeks and (ii) inspection and semi-quantitative rating of copper ground wires in accessible electrical outlets. Discrete measurements included short-term (grab sample to 4 hour average) and long-term (2 week) average concentrations of numerous organic and inorganic gases in indoor and outdoor air of participating homes. The elemental and mineral composition of drywall in homes was assessed in the field using non-destructive methods. Multiple bulk samples of drywall (including 400 square centimeters [cm^2] and 1 cm^2 samples) were obtained from each home and returned to the laboratory for further analysis and archiving. To account for factors that could modify source-pathway-effect relationships, baseline physical and indoor air quality parameters were also determined for complaint and non-complaint homes including geographic coordinates, orientation, area, ventilation characteristics, air exchange rate, indoor temperature, and indoor relative humidity. All homes were evaluated under indoor environmental exposure conditions that were typical of those experienced by occupants. Potential indoor sources such as cleaning supplies, air fresheners, etc. were not removed from the home, although homeowners were requested to not use these products throughout the sampling period.

Summary statistics generated from the field data and observations obtained from complaint homes were compared to corresponding measures obtained from a sample of non-complaint homes selected by CPSC. Relationships between rates of corrosion and discrete measures of organic and inorganic gases were explored using correlation analysis and other descriptive methods. Multivariate models were used to examine multi-factorial relationships among the corrosion, indoor air quality, drywall composition, and housing characteristics information gathered from participating homes.

3.2 STUDY POPULATION

The study population was comprised of 51 residential buildings, primarily detached single-family residences in five states including 41 homes that submitted drywall related incident reports to CPSC between December 23, 2008, and June 5, 2009, (complaint) and 10 non-complaint homes selected from the same neighborhoods as complaint homes. CPSC recruited all homes into the study.

3.2.1 Eligibility Criteria

Potential target homes for the study were selected by CPSC based on specific criteria that considered geography and reports of health effects and corrosion. In terms of geography, homes were selected from communities in coastal Florida (Gulf and Atlantic coast) and coastal areas of Louisiana, Mississippi, Alabama, and Virginia as these states ranked high in complaint frequency in reports received by CPSC (CPSC 2009b).

To select the complaint homes, CPSC used information gathered from incident reports to develop an ordinal scale for severity of a complaint. For this ranking system, homes were assigned a score from 0 to 7 based on the number of factors noted in the incident report. These factors included; 1) heating, ventilating, and air-conditioning (HVAC) corrosion, 2) plumbing corrosion, 3) wiring corrosion, 4) appliance failures/corrosion, 5) the presence of odor, 6) health issues, and 7) period of construction (between 2006 and 2007). For example, an incident report that identified only the presence of odor would be assigned a ranking of 1, while a report that identified HVAC corrosion, plumbing corrosion, wiring corrosion, health effects, odor, and constructed between 2006 and

2007 would be assigned a ranking of 6. The distribution of ranking score for the 41 complaint homes based on the CPSC criteria is provided in Table 3.1.

Table 3.1 Distribution of Ranking Classification of Complaint Homes

	Ranking Classification					
	2	**3**	**4**	**5**	**6**	**7**
Number of Homes	1	7	6	8	11	8

Ranking classification represents combination of the following number of factors
- HVAC corrosion
- plumbing corrosion
- wiring corrosion
- appliance failures/corrosion
- presence of odor
- health issues
- period of construction between 2006 and 2007

Non-complaint homes were located geographically proximate to complaint homes such that they would have similar ambient conditions to that of the complaint homes. These homes had no observed or reported corrosion and residents had not reported recent onset of health effects. The non-complaint homes had similar attributes to the complaint homes including the period of construction, style of home, and floor area.

3.2.2 Home Locations

As described in Section 3.2, the study evaluated 51 homes in five states including Florida, Louisiana, Mississippi, Alabama, and Virginia. Figure 3.1 provides a graphical representation of the locations of the study homes.

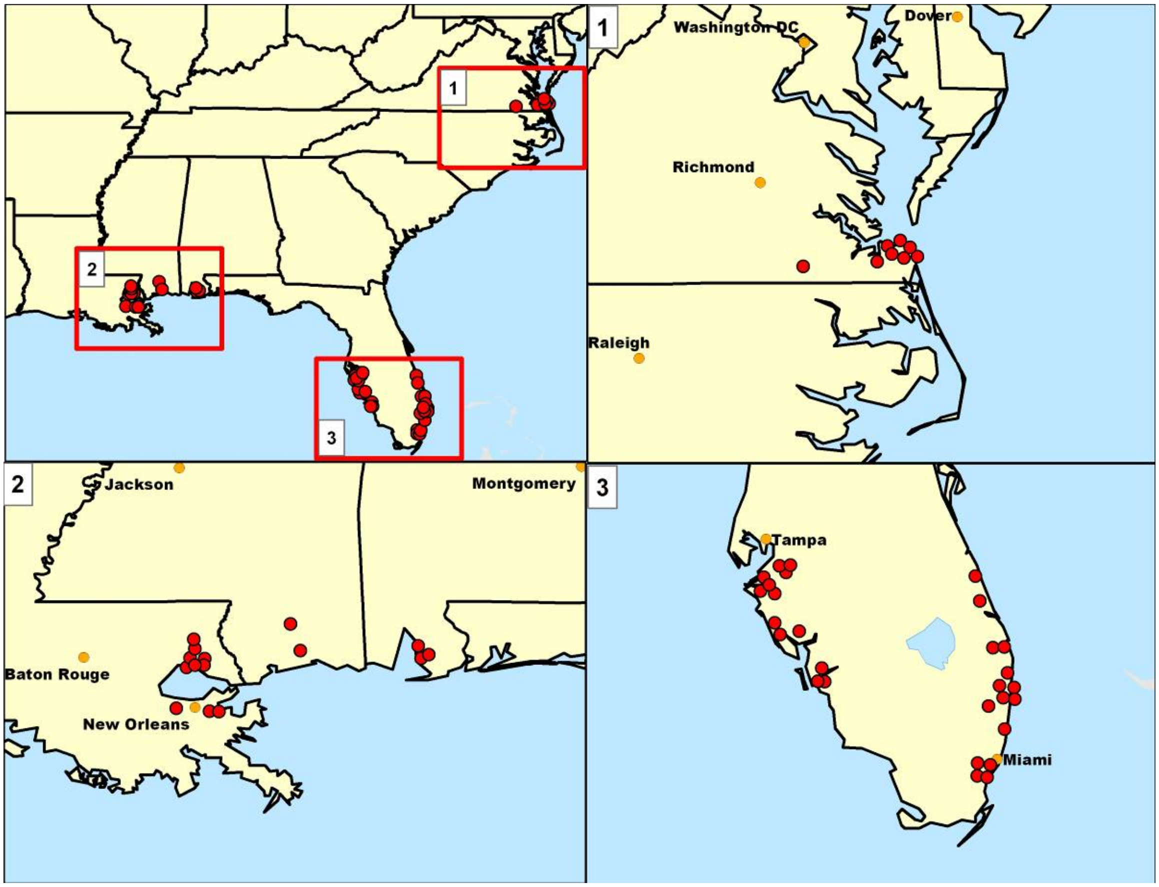


Figure 3.1 Locations of Participating Homes

3.2.3 Home Characteristics

Selected descriptive characteristics of the participating homes are summarized by state and status in Table 3.2. Complaint and non-complaint homes were approximately 3,000 square feet in size on average. Forty-six of the homes were single-family residences. The homes evaluated consisted of typical residential style construction including wood and or metal framing and concrete, brick, or wood exterior.

Table 3.2 Summary of Basic Attributes for Case and Reference Homes by State

Region	State	Status	Number of Homes	Average Home Floor Area (ft^2)	Single Family	Multi Family
Florida East	Florida	Non-complaint	2	3,350	1	1
		Complaint	13	3,307	11	2
Florida West	Florida	Non-complaint	3	2,183	3	0
		Complaint	10	2,439	10	0
Gulf Coast	Louisiana	Non-complaint	2	7,258	2	0
		Complaint	8	3,141	8	0
Gulf Coast	Alabama	Non-complaint	1	2,500	1	0
		Complaint	2	2,840	2	0
Gulf Coast	Mississippi	Non-complaint	0	–	–	–
		Complaint	2	2,750	2	0
Virginia	Virginia	Non-complaint	2	4,350	2	0
		Complaint	6	3,050	4	2

ft^2 square feet

3.3 FIELD ACTIVITIES

3.3.1 Integrated Measures—Corrosion

Objective measures of corrosion rates were obtained from copper and silver coupons placed at four locations within each home—the forced air supply register, the central living area, the master bedroom and a second bedroom—as well as at an outdoor location. The coupons were exposed to indoor air for two weeks and rates of corrosion were quantified from the thickness of the resulting corrosion layer. To complement the rates of corrosion determined from the coupons, evidence of existing corrosion in each home was obtained from an inspection of copper ground wires in accessible electrical outlets and other accessible metal objects such as air handlers and water pipes. The metal objects in these locations were inspected and the extent of corrosion was recorded on a 3 point ordinal scale.

3.3.2 Discrete Measures—Gases in Indoor Air

Discrete observations of organic and inorganic gases were obtained through active and passive sampling of indoor and outdoor air of complaint and non-complaint homes. Active air sampling involved collection of grab samples of whole air for subsequent analysis of reduced sulfur gases and 2 to 4 hour time-integrated samples for aldehydes, inorganic acids, organic acids, and VOCs. Passive samplers for sulfur dioxide, aldehydes, hydrogen sulfide, ozone, nitrogen dioxide, and hydrofluoric acid were deployed for two weeks in each home.

Contemporaneous samples for each active (including time-integrated and grab samples) and passive sampling system were obtained at three indoor locations in each home. These locations included the central living area, the master bedroom, and a second bedroom on the opposite side of the residence. An outdoor sampling location, free from interferences, i.e., away from roadways, exhausts, etc. was also selected for placement of samplers.

A summary of the types of indoor air samples obtained from complaint and non-complaint homes and the corresponding sampling durations is provided in Table 3.3.

Table 3.3 CPSC Study Core Assessment and Environmental Monitoring Parameters

Monitoring Parameter	Sampling Duration
Volatile organic compounds (active)*	120 minutes
Aldehydes (active)	200 minutes
Inorganic acids (active)	200 minutes
Organic acids (active)	200 minutes
Reduced sulfur gases	Grab sample
Sulfur dioxide (passive)	2 weeks
Aldehydes (passive)	2 weeks
Hydrogen sulfide (passive)	2 weeks
Ozone (passive)	2 weeks
Hydrofluoric acid (passive)	2 weeks
Nitrogen dioxide (passive)	2 weeks

CPSC U. S. Consumer Product Safety Commission

* Volatile organic compound (VOC) sampling was not selected as a core measurement parameter and was conducted in a subset of the participating homes. VOC samples were collected in 31 of the 51 homes studied.

3.3.3 Characterization of Drywall

Another specific aim of this investigation was to evaluate various objective indicators of imported drywall that would be useful in characterizing homes. To identify objective indicators, EH&E conducted a preliminary laboratory study in which selected elemental and mineral characteristics of imported drywall samples obtained from CPSC were contrasted with those of domestic drywall samples. Sensitive and specific methods of identifying imported drywall based upon elemental composition determined by x-ray fluorescence (XRF) and mineral composition determined by Fourier transform infrared spectroscopy (FTIR) spectroscopy were identified during this study. These methods were employed in the field to characterize the amount of imported and domestic drywall in complaint and non-complaint homes. At least one field measurement of elemental and mineral composition was obtained from each interior wall of complaint and non-complaint homes. In addition to measurements made in the field, multiple bulk samples were obtained from each study home and returned to the EH&E facility in Needham, Massachusetts, for further characterization and archiving.

3.3.4 Residential Characteristics

To account for other factors that could influence source-pathway-effect relationships, physical attributes and indoor air quality parameters of the study homes were also obtained by field personnel. These factors included square footage, ventilation design, air exchange rate, temperature, and relative humidity.

Temperature and relative humidity monitors were placed at two or three of the sampling locations (depending on the characteristics of the home) and were set to continuously log conditions over the course of the two week sampling period.

Field personnel also conducted a visual inspection of the home and completed a baseline questionnaire, including an inspection to document general home construction related characteristics and the visual assessment of corrosion noted in Section 3.3.1.

3.4 SAMPLING SCHEDULE

The field activities in each home were completed during two site visits to the home. During the first site visit, field activities were implemented by a three person team (accompanied by a CPSC investigator) and were completed over the course of a nine to ten hour visit (8:00 a.m. to 5:00 p.m.) The second site visit occurred approximately two weeks after the first, and field activities during the second visit were completed by a single field investigator. The sequence of activities completed in each home are described below and summarized in the daily activity schedule provided as Table 3.4.

Table 3.4 General Schedule of Field Sampling and Inspection Activities Implemented as Part of the CPSC Study

Day 1	
8:00 – 8:30 a.m.	• Arrive at test home to unpack, setup and calibrate equipment.
8:30 – 9:00 a.m.	• Select three indoor and one outdoor air sampling locations • Set up and start continuous temperature and relative humidity monitors • Set up active air monitoring equipment for volatile organic compounds, aldehydes, organic and inorganic acids
9:00 – 11:00 a.m.	• Start active air sampling • Begin home inspection and questionnaire • Begin XRF wall survey
11:00 a.m. – 12:00 p.m.	• End active air sampling • Begin bulk sampling of drywall from areas behind electrical outlet and switch plates • Set up and start continuous carbon dioxide monitors • Begin carbon dioxide release throughout the home (air exchange rate assessment)
1:00 – 3:00 p.m.	• Continue and complete home inspection activities and questionnaire • Continue and complete XRF wall survey • Continue and complete drywall bulk sampling of areas behind electrical outlet and switch plates
3:00 – 4:00 p.m.	• Set up and start passive air sampling equipment for sulfur dioxide, nitrogen dioxide, hydrogen fluoride, hydrogen sulfide, aldehydes, and ozone • Set up and expose silver and copper coupons
4:00 – 5:00 p.m.	• Collect reduced sulfur samples
5:00 p.m.	• Depart the test home
Day 12 to 15	
Time varies	• Collect passive air samplers • Collect temperature and relative humidity monitors • Collect silver and copper coupons

XRF x-ray fluorescence

Field personnel arrived at each subject home at approximately 8:00 a.m. and began the unpacking, set-up, and calibration of equipment. Once inside the home, the field personnel selected the indoor and outdoor locations where all active and passive environmental sampling and monitoring were to be conducted. Following the selection of the indoor sites, temperature and relative humidity monitors were placed at two or three of the locations (depending on the characteristics of the home) and were set to continuously log conditions over the course of the two week monitoring period.

At 9:00 a.m. active air sampling equipment was set up at the indoor locations and at the outdoor location to measure VOCs (implemented in a subset of homes), aldehydes, inorganic acids, and organic acids. VOC samplers were set up in two or three indoor locations with one duplicate, and at one outdoor location. One field blank was included for every ten samples. Similarly, aldehydes, inorganic acids, and organic acids were collected at three indoor locations with one duplicate and one field blank or shipping blank. The active air sampling systems were started at approximately 9:00 a.m. and sampled for approximately 200 minutes. While active air samples were being collected, field personnel began a survey of all walls in the home using a handheld XRF analyzer. During this time, field personnel also initiated the visual home inspection to document general home construction related characteristics and visual assessment for corrosion and completing the questionnaire.

Once the active air sampling was completed, field personnel collected small bulk samples of drywall from behind the cover plates of light switches and electrical boxes. The number of bulk samples collected varied based on the size of the home. Generally twenty to twenty-five samples were collected in each home. In addition, at each of the light switch and electrical boxes where bulk samples were collected, field personnel documented the condition of the copper electrical ground in terms of the level of corrosion identified. The drywall at each of these light switches and electrical boxes was also scanned utilizing a handheld XRF analyzer. Following the completion of active air sampling, the home air exchange rate was evaluated by releasing carbon dioxide (CO_2) throughout the home and monitoring the decay in CO_2 concentration over time. CO_2 monitors were placed at the three indoor sampling locations and continuously recorded the concentration of the gas over the test period.

During the afternoon hours, field personnel continued with the XRF wall survey, the home inspection/questionnaire, and the bulk sampling. Once CO_2 monitoring was completed, passive air sampling equipment for sulfur dioxide (SO_2), nitrogen dioxide (NO_2), hydrogen fluoride (HF), hydrogen sulfide (H_2S), aldehydes, and ozone (O_3) were set up and the passive air sampling program was started. Passive air samplers were placed at the three indoor locations and one outdoor location. One duplicate and one field blank or shipping blank was obtained from each home. The passive air samplers were deployed for approximately two weeks.

To measure the integrated rate of corrosion, copper/silver coupons were placed at the three indoor sampling locations, at one outdoor location, and at the outlet of a supply air register for the air conditioning unit serving the home. Finally, grab samples of whole air for analysis of reduced sulfur gases was initiated late in the day in order to ensure that samples were received by the laboratory within 24 hours of the sample collection time. Samples for reduced sulfur gas analysis were obtained from the three indoor locations, with one duplicate, and from one outdoor location.

A single field investigator returned to the home approximately two weeks following the date of the initial survey to collect the passive air samplers, temperature and relative humidity monitors, and copper/silver coupons.

4.0 SAMPLING AND ANALYTICAL METHODS

4.1 INTRODUCTION

EH&E conducted a series of measurements in each complaint and non-complaint home to assess multiple environmental parameters. The following sections describe the sampling and analytical procedures used to collect data in each home included in the study, the procedures used to analyze and process the data, and a general outline of the quality assurance, quality control (QA/QC) procedures implemented by EH&E.

4.2 SOURCE DRYWALL MEASUREMENTS

Material characteristics of representative sections of drywall from each complaint and non-complaint home were determined using x-ray fluorescence (XRF) and Fourier transform infrared (FTIR) spectrometry. As described below, the elemental composition analysis was conducted using XRF in the field at each home. More detailed analyses, using a combination of XRF and FTIR were subsequently obtained in the laboratory from the bulk samples of drywall collected and archived from each home.

4.2.1 X-Ray Fluorescence (XRF) Analysis

An XRF Spectrometer (Innov-X ALPHA™ Handheld XRF, Innov-X Systems, Inc., Woburn, Massachusetts) provided on-site and laboratory metals analysis in this study. This device is a handheld portable XRF analyzer and was used to identify and quantify the elements in representative wall surfaces in each home as well as in the bulk samples collected from each home.

At least one XRF measurement was obtained from each wall and ceiling surface in all of the homes included in the study. In-home measurements were taken through any wall coatings such as paint or plaster. The elemental scanning profile for each location was stored on the internal flash memory card of the XRF. The location of each measurement was marked on a floor plan and recorded in the master field log binder. Data files were downloaded daily and saved on a central file server. In addition, drywall bulk samples collected from each of the homes were scanned, analyzed and downloaded with the XRF software package in EH&E's main facility. Between 10 and 49 (average 23) bulk samples of drywall, depending on the size of the home, were collected from each test house and analyzed using XRF at EH&E's facility. Analysis of the drywall samples removed from the home was conducted on the bulk material and not through paint or paper layers.

4.2.2 Fourier Transform Infrared (FTIR) Analysis

Bulk samples of drywall collected from the study homes were tested using FTIR at EH&E's main facility. FTIR measurements were obtained using the A2 Technologies Exoscan instrument, a full scanning Fourier transform mid-infrared spectrometer, equipped with a Michelson interferometer and non-hydroscopic optics. The diffuse reflectance Exoscan was configured for porous and rough surfaced materials. It has an optical design that focuses an infrared light beam perpendicular to the sample surface resulting in diffusely scattered infrared light. This scattered infrared light interacts with the sample and is subsequently reflected back to the detector in the Exoscan. This diffuse reflectance configuration provides spectra for drywall analysis. The diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS) technique has been widely accepted as a highly sensitive means of measuring inorganic compounds. DRIFT spectra of pure non-diluted minerals are different in appearance from more traditional FTIR spectra due to several very intense absorbance bands that appear as negative peaks (specular) and multiple weaker absorbance bands which are observed as positive peaks (diffuse). DRIFT technology was used in this study to obtain FTIR measurements.

The representative drywall bulk samples collected from each of the homes, between 10 and 49 (average 23) bulk drywall samples depending on the size of the home, were collected from each house and analyzed using FTIR. Each sample was scanned, analyzed, and the results downloaded with the A2 Technologies Microlab PC software package.

4.3 AIR SAMPLING METHODS

Air samples were collected in representative areas of each home and analyzed using standard reference methods. Table 4.1 summarizes the air sampling methods used, the analytes or groups of analytes, and the analytical methods used throughout this study. A complete list of the specific analytes is described in Sections 4.3.1 through 4.3.6.

Table 4.1 Summary of Air Sampling Methods

Analyte(s)	Sampling Method	Analytical Method	Reference Method	Report Section
Reduced Sulfur Gases	Whole air, grab, Tedlar bags	GC/SCD	ASTM D5504	4.3.1
VOCs	Whole air, SUMMA canister	GC/MS	EPA TO-15	4.3.2
Aldehydes (active)	Sorbent tube	HPLC	EPA TO-11A	4.3.3
Passive Diffusion • Aldehydes • Hydrogen sulfide • Ozone • Sulfur dioxide* • Nitrogen dioxide* • Hydrofluoric acid*	Radiello Diffusive Sampling System	Various, see section 4.3.4	Various, see section 4.3.4	4.3.4
Inorganic acids	Sorbent tube	Ion chromatography	NIOSH 7903	4.3.5
Organic acids	Sorbent tube	Ion chromatography	NIOSH 2011	4.3.5
Temperature and relative humidity	Real-time monitor	Thermistor, thin-film capacitive sensor	Manufacturer	4.3.6

GC/SCD	gas chromatography method utilizing a sulfur chemiluminescence detector
ASTM	American Society for Testing and Materials
VOC	volatile organic compound
GC/MS	gas chromatography/mass spectrometry
EPA	U.S. Environmental Protection Agency
HPLC	high performance liquid chromatography
NIOSH	National Institute for Occupational Safety and Health

* Sulfur dioxide, nitrogen dioxide, and hydrofluoric acid collection and analysis performed using the same cartridge.

4.3.1 Reduced Sulfur Gases

Grab air samples were collected and analyzed for a suite of twenty reduced sulfur gases during the study. Whole air samples were collected into Tedlar Bags (Zefon International) using the SKC Vac-U-Chamber™. The Vac-U-Chamber is a rigid box that allows air sampling bags to be filled directly (without sample air passing through a pump) from ambient atmospheres through use of negative pressure differentials; all surfaces that came in contact with sample air were constructed of stainless steel or Teflon tubing (SKC Cat. No. 231-940). The sampling pumps used to fill/evacuate the chambers were adjusted to a nominal flow rate of 1.0 liter per minute and each grab sample was collected for approximately 30 – 45 seconds for a total volume of approximately 0.5 to 0.75 liters for each sample.

Air samples were collected at three indoor locations and one outdoor location per test house. In addition, one duplicate sample was collected per sample set at each home (the analytical laboratory was blinded to all sample designations including duplicate samples). Due to the reactive nature of many reduced sulfur gases, the reference method (American Society for Testing and Materials [ASTM] Method D5504) recommends that sample analysis occur within 24-hours of collection. To satisfy this requirement, the reduced sulfur samples were collected at each test home and shipped to the analytical laboratory via first priority overnight delivery.

The reduced sulfur compound analysis was performed according to ASTM Method D5504 *Standard Test Method for Determination of Sulfur Compounds in Natural Gas and Gaseous Fuels by Gas Chromatography and Chemiluminescence*. ASTM D5504 is a gas chromatography method with a sulfur chemiluminescence detector (GC/SCD). The chemical analyses were conducted by Columbia Analytical Services, Inc., Simi Valley, California. Table 4.2 shows the reduced sulfur compound analytes and the laboratory reporting limits for each analyte. Statistical analysis of duplicate samples is further discussed in Section 4.7.9.

Table 4.2 Targeted Reduced Sulfur Gases and Laboratory Reporting Limits

Compound	CAS #	Laboratory Reporting Limit ($\mu g/m^3$)
2,5-Dimethylthiophene	638-02-8	23
2-Ethylthiophene	872-55-9	23
3-Methylthiophene	616-44-4	20
n-Butyl Mercaptan	109-79-5	18
Carbon Disulfide	75-15-0	7.8
Carbonyl Sulfide	463-58-1	12
Diethyl Disulfide	110-81-6	12
Diethyl Sulfide	352-93-2	18
Dimethyl Disulfide	624-92-0	9.6
Dimethyl Sulfide	75-18-3	13
Ethyl Mercaptan	75-08-1	13
Ethyl Methyl Sulfide	624-89-5	16
Hydrogen Sulfide	7783-06-4	7
Isobutyl Mercaptan	513-44-0	18
Isopropyl Mercaptan	75-33-2	16

Table 4.2 Continued

Compound	CAS #	Laboratory Reporting Limit ($\mu g/m^3$)
Methyl Mercaptan	74-93-1	9.8
n-Propyl Mercaptan	107-03-9	16
Tetrahydrothiophene	110-01-0	18
Thiophene	110-02-1	17
tert-Butyl Mercaptan	75-66-1	18

CAS#	Chemical Abstract Service number
$\mu g/m^3$	micrograms per cubic meter

4.3.2 Volatile Organic Compounds

Whole air samples for VOCs were collected with individually cleaned and certified SUMMA canisters obtained from Columbia Analytical Services, Inc. located in Simi Valley, California. Each flow controller used to fill the SUMMA canisters during sampling was also calibrated and conditioned by Columbia Analytical Services, Inc. prior to each use. Flow controllers were calibrated for two-hour sample durations. Canisters were protected from radiant heat as well as moisture prior to, during, and after sampling.

In the homes selected for VOC sampling, SUMMA canister samples were collected at two to three indoor locations and at one outdoor location. A duplicate sample was collected for every 10 primary samples collected and sent to the analytical laboratory as a blinded sample. A minimum of one field blank sample was sent to the laboratory for analysis for every ten primary samples collected. These procedures were used to assess potential canister contamination during shipping, preparation or analysis of the samples. Statistical analysis of blank and duplicate samples is further discussed in Section 4.7.9.

VOC samples were analyzed using gas chromatography/mass spectrometry (GC/MS). The analyses were performed according to EPA Method TO-15 from EPA's Second Edition *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*. Table 4.3 shows the specific VOCs and the laboratory reporting limits.

Table 4.3 Targeted Volatile Organic Compounds (VOCs) and Laboratory Reporting Limits

Compound	CAS #	Laboratory Reporting Limits ($\mu g/m^3$)
1,1,1-Trichloroethane	71-55-6	0.12 – 0.62
1,1,2,2-Tetrachloroethane	79-34-5	0.12 – 0.62
1,1,2-Trichloroethane	79-00-5	0.12 – 0.62
1,1,2-Trichlorotrifluoroethane	76-13-1	0.12 – 0.62
1,1-Dichloroethane	75-34-3	0.12 – 0.62
1,1-Dichloroethene	75-35-4	0.12 – 0.62
1,2,4-Trichlorobenzene	120-82-1	0.12 – 3.1
1,2,4-Trimethylbenzene	95-63-6	0.61 – 3.1
1,2-Dibromo-3-chloropropane	96-12-8	0.61 – 3.1
1,2-Dibromoethane	106-93-4	0.12 – 0.62
1,2-Dichloro-1,1,2,2-tetrafluo	76-14-2	0.61 – 3.1
1,2-Dichlorobenzene	95-50-1	0.12 – 0.62
1,2-Dichloroethane	107-06-2	0.12 – 0.62
1,2-Dichloropropane	78-87-5	0.12 – 0.62
1,3,5-Trimethylbenzene	108-67-8	0.61 – 3.1
1,3-Butadiene	106-99-0	0.12 – 0.62
1,3-Dichlorobenzene	541-73-1	0.12 – 0.62
1,4-Dichlorobenzene	106-46-7	0.12 – 0.62
1,4-Dioxane	123-91-1	0.61 – 3.1
2-Butanone (MEK)	78-93-3	0.61 – 3.1
2-Hexanone	591-78-6	0.61 – 3.1
2-Propanol (isopropyl alcohol)	67-63-0	0.61 – 3.1
3-Chloro-1-propene (allyl chloride)	107-05-1	0.12 – 0.62
4-Ethyltoluene	622-96-8	0.61 – 3.1
4-Methyl-2-pentanone	108-10-1	0.61 – 3.1
Acetone	67-64-1	6.1 – 31
Acetonitrile	75-05-8	0.61 – 1.4
Acrolein	107-02-8	0.61 – 3.1
Acrylonitrile	107-13-1	0.61 – 3.1
Benzene	71-43-2	0.12 – 0.62
Benzyl chloride	100-44-7	0.12 – 0.62
Bromodichloromethane	75-27-4	0.12 – 0.62
Bromoform	75-25-2	0.61 – 3.1
Bromomethane	74-83-9	0.12 – 0.62
Carbon disulfide	75-15-0	0.61 – 3.1
Carbon tetrachloride	56-23-5	0.12 – 0.62
Chlorobenzene	108-90-7	0.12 – 0.62
Chloroethane	75-00-3	0.12 – 0.62
Chloroform	67-66-3	0.12 – 0.62
Chloromethane	74-87-3	0.12 – 0.62
Cumene	98-82-8	0.61 – 3.1
Cyclohexane	110-82-7	0.61 – 3.1
Dibromochloromethane	124-48-1	0.12 – 0.62
Dichlorodifluoromethane (CFC 1)	75-71-8	0.61 – 3.1
Ethanol	64-17-5	6.1 – 31
Ethyl acetate	141-78-6	0.61 – 6.2
Ethylbenzene	100-41-4	0.61 – 3.1

Table 4.3 Continued

Compound	CAS #	Laboratory Reporting Limits ($\mu g/m^3$)
Hexachlorobutadiene	87-68-3	0.12 – 3.1
Methyl Methacrylate	80-62-6	0.61 – 6.2
Methyl tert-Butyl Ether	1634-04-4	0.12 – 0.62
Methylene Chloride	75-09-2	0.61 – 3.1
Naphthalene	91-20-3	0.24 – 3.1
Propene	115-07-1	0.61 – 3.1
Styrene	100-42-5	0.61 – 3.1
Tetrachloroethene	127-18-4	0.12 – 0.62
Tetrahydrofuran (THF)	109-99-9	0.61 – 3.1
Toluene	108-88-3	0.61 – 3.1
Trichloroethene	79-01-6	0.12 – 0.62
Trichlorofluoromethane	75-69-4	0.12 – 0.62
Vinyl acetate	108-05-4	6.1 – 31
Vinyl chloride	75-01-4	0.12 – 0.62
alpha-Pinene	80-56-8	0.61 – 3.1
cis-1,2-Dichloroethene	156-59-2	0.12 – 0.62
cis-1,3-Dichloropropene	10061-01-5	0.61 – 3.1
d-Limonene	5989-27-5	0.61 – 3.1
m,p-Xylenes	179601-23-	0.61 – 3.1
n-Butyl acetate	123-86-4	0.61 – 3.1
n-Heptane	142-82-5	0.61 – 3.1
n-Hexane	110-54-3	0.61 – 3.1
n-Nonane	111-84-2	0.61 – 3.1
n-Octane	111-65-9	0.61 – 3.1
n-Propylbenzene	103-65-1	0.61 – 3.1
o-Xylene	95-47-6	0.61 – 3.1
trans-1,2-Dichloroethene	156-60-5	0.12 – 0.62
trans-1,3-Dichloropropene	10061-02-6	0.61 – 3.1

CAS#	Chemical Abstract Service number
$\mu g/m^3$	micrograms per cubic meter

Acetonitrile was not determined during analysis for several VOC samples.

4.3.3 Aldehydes (Active Air Sampling)

Active air samples were collected and analyzed according to EPA Method TO-11A for aldehydes, including formaldehyde, using 2,4-dinitrophenylhydrazine (DNPH) coated sorbent tubes with a built-in ozone scrubber (SKC Cat. No. 226-120). Each tube was connected to a personal sampling pump adjusted to a nominal flow rate of 500 milliliters per minute (ml/min) that ran for approximately 200 minutes. Pump filters were inspected and batteries conditioned (i.e., charged) before each sampling period in order to reduce the possibility of faults during sampling. Pump flows were verified by a calibrated flow meter (Bios Drycal, Drycal) at the start and end of the sampling period. The flow rates measured at the start and end of sampling were averaged in order to calculate the total volume of air sampled. Start and end flows used to calculate the sample volumes were within 2.6% on average.

Active aldehyde samples were collected at three indoor locations and one outdoor location per study house. At one indoor station per house, duplicate samples for aldehyde analysis were collected. A minimum of one field and one shipping blank were collected and analyzed for every 10 primary samples collected. All aldehyde samplers were refrigerated before and after sample collection. Duplicate and blank samples were sent to the analytical laboratory in a blinded fashion. Statistical analysis of blank and duplicate samples is further discussed in Section 4.7.9.

In the EPA Method TO-11A, aldehydes in the sample air react with DNPH to form stable hydrazones, which are extracted from the silica gel and analyzed by high performance liquid chromatography coupled with an ultraviolet detector (HPLCUV). The aldehyde analyses were conducted by Columbia Analytical Services, Inc., Simi Valley, California. Table 4.4 lists twelve aldehyde compounds assessed during the study and the associated laboratory reporting limits for each aldehyde.

Table 4.4 Targeted Aldehydes and Laboratory Reporting Limits

Compound	CAS #	Laboratory Reporting Limits (μg/m^3)*
2,5-Dimethylbenzaldehyde	5779-94-2	8.9 – 22
Acetaldehyde	75-07-0	8.9 – 14
Benzaldehyde	100-52-7	8.9 – 14
Butyraldehyde	123-72-8	8.9 – 14
Crotonaldehyde, total	4170-30-3	8.9 – 24
Formaldehyde	50-00-0	8.9 – 14
n-Hexaldehyde	66-25-1	8.9 – 14
Isovaleraldehyde	590-86-3	8.9 – 14
Propionaldehyde	123-38-6	8.9 – 14
m,p-Tolualdehyde	104-07-0	18 – 29
o-Tolualdehyde	529-20-4	8.9 – 14
Valeraldehyde	110-62-3	8.9 – 14

CAS#	Chemical Abstract Service number
μg/m^3	micrograms per cubic meter

* Calculated based on the reporting limit in μg/sample using the nominal air sampling volume of 0.1 m^3.

4.3.4 Passive Diffusive Sampling

Passive air samples have been demonstrated as a valid tool in residential exposure assessment (Pellizzari et al. 2001; WHO 2000). Passive monitors were utilized to collect two-week integrated samples for sulfur dioxide, nitrogen dioxide, hydrofluoric acid, hydrogen sulfide, aldehydes, and ozone using Radiello Diffusive Sampling Systems (Buzica et al. 2008; Cocheo et al. 1996; Sigma-Aldrich 2006; Swaans et al. 2007). For each analyte there is a specific chemiadsorbing cartridge and sampling protocol. The diffusive sampler is composed of two surfaces, a diffusive surface and an adsorbing surface. The sampling process is driven by the concentration gradient as the gaseous molecules cross the diffusive surface towards the adsorbing surface. The molecules are trapped by the selected adsorbing material in each type of passive diffusion sampler (Sigma-Aldrich 2006). The specific passive sampling system and the analytical technique used for each class of analyte is shown in Table 4.5

Table 4.5 Summary of Target Parameters, Passive Air Sampling

Analyte	Radiello Badge Type	Analytical Method*
Aldehydes	165	Aldehydes by Radiello 165, HPLC-UV
Hydrogen sulfide	170	Hydrogen sulfide by Radiello 170 Spectrophotometer at 665 nm
Ozone	172	Ozone by Radiello 172 Spectrophotometer at 430 nm
Sulfur dioxide**	166	Sulfur dioxide by Radiello 166 Ion Chromatography
Nitrogen dioxide**	166	Nitrogen dioxide by Radiello 166 Spectrophotometer at 537 nm
Hydrofluoric acid (as F)**	166	Hydrofluoric acid by Radiello 166 Ion Chromatography

HPLC	high performance liquid chromatography
UV	ultra violet
nm	nanometer

* Analytical methods provided by Fondazione Salvatore Laboratory, Radiello Manual, Supelco Edition.
** Sulfur dioxide, nitrogen dioxide, and hydrofluoric acid analysis conducted using one cartridge.

Three indoor locations and one outdoor sampling location were selected in each home. At one indoor station per house, a duplicate sampling device for each analyte was used to assess repeatability of these methods. To begin sampling, the adsorbent cartridge was transferred from the sealed storage tube into the diffusive body and was screwed onto the supporting plate. Field personnel recorded the start time and date on the field log sheet, and the assembled device was attached to the sampling tripod at a sampling height of approximately 4 feet. To achieve the desired limit of detection, the sampling devices were deployed for 13 to 15 days in each of the test homes. Upon completion of the sampling period a field investigator retrieved the sampling device, sealed the chemiadsorbing cartridge into the storage tube and shipped the sample to the analytical laboratory. All samples were temperature controlled before and after the sampling period and QA/QC samples were sent to the analytical laboratory in a blinded manner. Statistical analysis of blank and duplicate samples is further discussed in Section 4.7.9.

The concentrations of H_2S, SO_2, NO_2, HF, O_3, and several aldehydes measured in each study home were calculated using Equation 4.1:

$$C = \frac{m}{Q_k * t} * 1{,}000{,}000 \qquad \text{(Equation 4.1)}$$

Where:

C = concentration in μg/m^3

m = mass in μg

Q_k = analyte specific sampling rate, adjusted for temperature at the sampling site, in ml/min

t = sample duration in minutes

1,000,000 = conversion factor, ml/m^3

Where appropriate, sampling rates for indoor samples were adjusted to account for different temperatures and their potential effect on the sampling rate by using the mean indoor temperature measured in each home. For outdoor samples, the sampling rates were adjusted using the mean outside temperature over the sampling period.[1] The reported passive sampling results were adjusted for temperature in accordance with Equation 4.2, which is provided by the manufacturer of the passive diffusion samplers (Sigma-Aldrich 2006).

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[1] Outside temperatures were obtained from the nearest National Weather Service weather station.

$$Q_k = Q_{298} * \left(\frac{K}{298} \right)^{\exp} \qquad \text{(Equation 4.2)}$$

Where:

Q_k = analyte specific sampling rate, adjusted for temperature at the sampling site, in ml/min

Q_{298} = analyte specific sampling rate at 298 K (25 °C) in ml/min

K = temperature at the sampling site, in degrees kelvin

exp = diffusion sampler-specific factor (provided by manufacturer)

Analyte specific sampling rates at 298 K (Q_k) and the sampler-specific factor (exp) are listed in Table 4.6, and are all provided by the manufacturer, based on a standard temperature of 298 K (Sigma-Aldrich 2006). No temperature adjustments are recommended for SO_2 or HF because the sampling rate for SO_2 has been shown to be constant over temperatures of -10 through 40 °C and the temperature influence on sampling rates for HF is currently being studied (Sigma-Aldrich 2006). No sampling rate adjustments for relative humidity or wind speeds are recommended because rates have been shown to be constant over wide ranges of relative humidity and wind speed conditions (Sigma-Aldrich 2006).

Table 4.6 Sampling Rates for Targeted Analytes for Passive Sampling

Compound	CAS #	Sampling Rate in ml/min at 298 K (Q_{298})	exp
Acetaldehyde	75-07-0	84	0.35
Acrolein	107-02-8	33	0.35
Benzaldehyde	100-52-7	92	0.35
Formaldehyde	50-00-0	99	0.35
Hexanal	66-25-1	18	0.35
Isopentanal	590-86-3	61	0.35
Butanal*	123-72-8	11	0.35
Pentanal	110-62-3	27	0.35
Propanal	123-38-6	39	0.35
Hydrogen sulfide	7783-06-4	69	3.8
Nitrogen dioxide	10102-44-0	78	7.0
Sulfur dioxide	7446-09-5	119	7.0
Ozone	10028-15-6	25	1.5
Hydrofluoric acid	7664-39-3	187	7.0

CAS#	Chemical Abstract Service number
ml/min	milliliters per minute
K	degrees kelvin
exp	sampler-specific factor provided by manufacturer

* Butanal coelutes with isobutanal and methyl ethyl ketone. The corresponding peak was reported by the laboratory as butanal.

All analysis of the diffusive sampling media was conducted by Air Toxics Ltd. located in Folsom, California. The various analytes collected by each type of passive system are summarized in Table 4.7, which also lists the laboratory reporting limits achieved for the analysis.

Table 4.7 Passive Sampling, Targeted Analytes and Laboratory Reporting Limits

Compound	CAS #	Laboratory Reporting Limits ($\mu g/m^3$)*
Aldehydes		
Acetaldehyde	75-07-0	0.5 – 5
Acrolein	107-02-8	0.3 – 2.5
Benzaldehyde	100-52-7	0.3 – 2.5
Formaldehyde	50-00-0	0.3 – 2.5
Hexanal	66-25-1	1 – 10
Isopentanal	590-86-3	0.3 – 2.5
Butanal	123-72-8	0.3 – 2.5
Pentanal	110-62-3	0.3 – 2.5
Propanal	123-38-6	0.3 – 2.5
Other		
Hydrogen sulfide	7783-06-4	0.5 – 0.7
Hydrofluoric acid as fluoride	7664-39-3	5.3
Nitrogen dioxide	10102-44-0	0.2 – 0.3
Ozone	10028-15-6	0.6 – 1.3
Sulfur dioxide	7446-09-5	17

CAS#	Chemical Abstract Service number
$\mu g/m^3$	micrograms per cubic meter

* Reporting limits provided by the laboratory in $\mu g/m^3$, based on the analyte specific sampling rate and a nominal sampling time for each sample batch.

4.3.5 Inorganic and Organic Acids

Active air samples for analysis of inorganic and organic acids were collected using silica gel tubes (SKC Cat. No. 226-10-03) and personal sampling pumps set to draw at 500 ml/min over a sampling period of approximately 200 minutes. Samples for inorganic and organic acids were collected and analyzed in accordance with National Institute for Occupational Safety and Health (NIOSH) Methods 7903 and 2011, respectively. Pump filters were inspected and batteries conditioned (i.e., charged) before each sampling period in order to reduce the possibility of faults during sampling. Pump flows were verified using a calibrated flow meter (Bios International, Drycal) at the start and end of the sampling period. The flow rates measured at the start and end of sampling were averaged to obtain an average flow rate. Start and end flows used to calculate the sample volumes were within 7.3%.

For each test home, three indoor locations and one outdoor sampling location were selected to collect samples for analysis of inorganic and organic acids. At one indoor station per house, a duplicate sample was collected for inorganic and organic acids to assess repeatability of these methods. All samples were refrigerated before and after the sampling day and were sent to the analytical laboratory blinded. A minimum of one field blank and one shipping blank was collected and analyzed for every 10 primary samples collected. Statistical analysis of blank and duplicate samples is further discussed in Section 4.7.9.

Analysis for inorganic and organic acids was conducted using ion chromatography (IC) according to NIOSH Methods 7903 and 2011, respectively, by Liberty Mutual Industrial Hygiene Laboratory in Hopkinton, Massachusetts. Table 4.8 lists the analytes for the acid samples and the laboratory reporting limits achieved for the analysis during the study.

Table 4.8 Targeted Organic and Inorganic Acids and Laboratory Reporting Limits

Compound	CAS #	Laboratory Reporting Limits (μg/m^3)*
Organic Acids		
Acetic acid	64-19-7	23
Butyric acid	107-92-6	23
Formic acid	64-18-6	15
Propionic acid	79-09-4	23
Inorganic Acids		
Hydrochloric acid	7647-01-0	46
Hydrobromic acid	10035-10-6	23
Hydrofluoric acid as fluoride	7664-39-3	30
Nitric acid	7697-37-2	15
Phosphoric acid	7664-38-2	15
Sulfuric acid	7664-93-9	23

CAS# Chemical Abstract Service number
μg/m^3 micrograms per cubic meter

* Calculated based on the reporting limit in μg/sample using the nominal air sampling volume of 0.1 m^3.

4.3.6 Relative Humidity/Temperature

Real-time temperature and relative humidity measurements were collected in each home using U10-003 HOBO® Temperature Relative Humidity Data Loggers manufactured by Onset Computer Corporation, Bourne, Massachusetts. The temperature sensor is a thermistor and relative humidity is measured by a thin-film capacitive sensor. The temperature sensor has a range of -20 degrees Celsius (°C) to 70 °C (-4 to 158 degrees Fahrenheit [°F]) with accuracy of ± 0.4 °C at 25 °C (± 0.7 °F at 77 °F). The sensor is factory rated to achieve a resolution of 0.1 °C at 25 °C (0.2 °F at 77 °F). The relative humidity sensor has a range of 25% to 95% with accuracy of ± 3.5% from 25% to 85%. The sensor is factory rated to achieve a resolution of 0.07%. As recommended by the manufacturer, the accuracy of the temperature and relative humidity sensors is verified annually, and the instrument is repaired or replaced, if necessary. The data loggers were programmed to record 5 minute average measurements with a sampling rate of 5 seconds. A minimum of two temperature and humidity monitoring locations were selected in each of the homes: one typically in the central room of the house and the second typically in the master bedroom. If the home had two stories, one monitor was placed on each floor. Temperature and relative humidity measurements were collected for approximately 13 – 15 days in each home.

4.4 AIR EXCHANGE RATE

The air exchange rates in each test home were assessed using the method outlined in ASTM Standard E741-00, *Standard Test Method for Determining Air Change Rate in a Single Zone by Means of a Tracer Gas Dilution*. Air exchange rate determinations utilized CO_2 as a tracer given that this gas is readably available in the field and can be measured using portable real-time instruments. The tests were conducted by introducing approximately five pounds of CO_2 throughout the home, allowing the gas to mix, and recording the decaying part of the tracer curve over time.

CO_2 concentrations were measured continuously at multiple locations inside the home using a Q-Trak Model 8551 Indoor Air Quality Monitor, manufactured by TSI, Inc. (St. Paul, Minnesota). The CO_2 sensor utilized by this monitor is non-dispersive infrared (NDIR) and is accurate within 3% (or 50 parts per million [ppm] at 25 °C (78 °F) of the reading. Prior to each air exchange rate test, the sensors were calibrated at zero using hydrocarbon free air and spanned to approximately 1,000 ppm of CO_2. Air exchange rates were calculated from the CO_2 decay results using the regression method after correcting for estimated outdoor air CO_2 concentrations. For the purpose of this analysis, outdoor air CO_2 concentrations were assumed to be 400 ppm.

4.5 CORROSION ASSESSMENT

In order to evaluate corrosion of metal building components, EH&E conducted a detailed inspection of each home to qualitatively determine the extent of corrosion found on specific surfaces as well as to deploy devices to quantitatively measure the corrosion rate in each home over time.

4.5.1 Visual Inspection

Detailed visual inspections were performed on the electrical grounding wires, air handling units (AHUs), plumbing components, and appliances. Notes were also made regarding other home contents that could show visible evidence of corrosion.

Grounding wires were evaluated on a three point scale. A score of one indicated no visible corrosion, two indicated moderate visible corrosion and three indicated significant visible corrosion. Field team members performed cross reference evaluations during training to ensure consistency between teams in the field. Visual corrosion ratings were recorded in the master field log binder. Examples of grounding wires and the associated evaluation are provided in Figure 4.1.

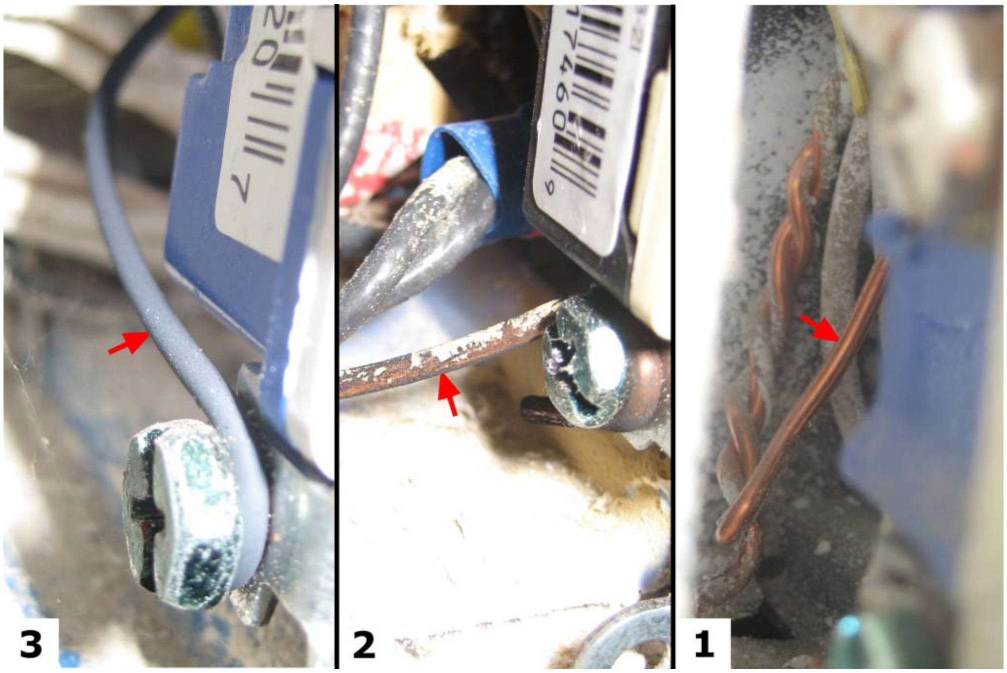


Figure 4.1 Example of Visual Corrosion Ratings, Electrical Ground Wire (3—Significant Visible Corrosion, 2—Moderate Visible Corrosion, 1—No Visible Corrosion)

AHU inspection focused on the cooling coils and associated copper refrigerant lines. Surfaces were photographed and all locations were logged into the master field log binder. Appliances and fixtures including accessible refrigerator components, hot water heaters, faucets, plumbing lines, and other items indicating patterns of corrosion were logged and photographed.

4.5.2 Corrosion Classification Coupons

Corrosion classification coupons were used to determine the integrated corrosion rate present in the study homes. The corrosion coupons used in this study contained copper and silver metal and were supplied by Purafil, Inc., research and development laboratory in Doraville, Georgia. Pre-cleaned copper and silver corrosion coupons were placed at four indoor locations and one outdoor location for an approximately two week period (range of 12 to 15 days). Due to the limited availability of obtaining sufficient copper/silver coupon kits as the study progressed, duplicate samples were collected early in the study and represented approximately five percent of the total coupon samples collected. At the end of the sampling period, the corrosion coupons were collected, placed in sealed containers and returned to Purafil for analysis. The laboratory measured the thickness of several copper and silver compounds including silver sulfide (Ag_2S), silver chloride (AgCl), Ag unknown, copper sulfide (Cu_2S), copper oxide (CuO), and Cu unknown present in the sample corrosion coupons. The laboratory normalized the data using the actual period of exposure and reported the result in units of “angstroms per 30 days of exposure.” The laboratory reporting limit for the analysis was 32 angstroms per 14 days of exposure. Corrosion rates were compared with reference values contained in the Instrumentation, Systems, and Automation Society (ISA) standard ISA-71.04-1985, *Environmental Conditions for Process Measurement and Control Systems: Airborne Contaminants*.

According to ISA, the use of corrosion coupons and measurement of corrosion accumulation is referred to as “reactivity monitoring” and the method provides a quantitative measure of the overall corrosion potential of an environment. Copper has been selected by ISA as a primary standard because extensive data exist that correlate copper film formation with reactive (corrosive) environments. Four levels of corrosion severity have been established for this standard.

G1 Mild—Defined as an environment sufficiently well-controlled such that corrosion is not a factor in determining equipment reliability. Less than 300 angstroms corrosion buildup per 30 days of exposure.

G2 Moderate—Defined as an environment in which the effects of corrosion are measurable and may be a factor for determining equipment reliability. Less than 1,000 and greater than 300 angstroms corrosion buildup per 30 days of exposure.

G3 Harsh—Defined as an environment in which there is a high probability that a corrosive attack will occur on metallic equipment surfaces. These harsh levels should prompt further evaluation resulting in environmental controls or specially designed and packaged equipment. Less than 2,000 and greater than 1,000 angstroms corrosion buildup per 30 days of exposure.

GX Severe—Defined as an environment in which only specially designed and packaged equipment would be expected to survive. Specifications for equipment in this class are a matter of negotiation between user and supplier. Greater than or equal to 2,000 angstroms corrosion buildup per 30 days of exposure.

4.5.3 Elemental Composition Analysis

A subset of the corrosion coupons exposed to the atmospheres within complaint homes underwent further analytical/spectroscopic testing to characterize the corrosion films present utilizing optical and electron beam analytical methods. This additional analysis was completed on six copper and silver coupon sets that were selected from complaint homes where high visual corrosion rankings were observed from copper ground wire inspections as described in Section 4.5.1. Four of the coupon sets selected were those that had been placed at the AHU supply air register, and two of the coupon sets were selected from other indoor locations within the home.

Coupon sets were sent under chain of custody to Corrosion Testing Laboratories, Inc., Newark, Delaware for analysis by visual, light microscopy, scanning electron microscopy (SEM) utilizing energy dispersive spectroscopy (EDS) and x-ray photoelectron spectroscopy (XPS). SEM/EDS were performed to identify the primary elemental composition of the corrosion layer on the coupons. Because the SEM/EDS method tends to provide results at greater surface depths, XPS analysis was utilized to identify elemental composition at the surface layer of the samples.

4.6 PROCEDURES FOR STATISTICAL ANALYSIS OF DATA

All statistical analyses of the study data were performed using SAS statistical software, version 9.1 (Cary, North Carolina). Field blank samples (discussed in Section 4.7) were analyzed to determine if field samples should be blank corrected. Based on statistical analysis of the field and shipping blank data (refer to Section 4.7.9) samples were not blank corrected. Values below the laboratory reporting limit, generally defined as 3x the method detection limit, were substituted using one-half of the reporting limit in statistical analyses. As described in Section 4.7.9, good agreement was observed between paired primary samples and duplicates; samples and duplicates were averaged for all statistical analyses.

Statistical analysis included compiling descriptive statistics, scatter plots and box plots. Box plots depict the mean, median, 10th, 25th, 75th, and 90th percentiles, as well as individual points beyond the 10th and 90th percentiles. Bivariate statistical relationships were assessed using Spearman correlation and linear regression. Generalized linear models were used for analysis of variance and multivariate regression. Outcome variables were natural log-transformed to satisfy normality assumptions. The multivariate linear models for predictors of corrosion followed the general form:

$$ln(corrosion) = \beta_0 + \beta_1 * analyte + \beta_2 * modifying\ variable + \beta_3 * modifying\ variable + \varepsilon$$

where *ln(corrosion)* is the natural log-transformed silver or copper corrosion level, *analyte* is the concentration of the target analyte in indoor air, *modifying_variables* are potential modifiers of the relationship (e.g., air exchange rate, temperature), and ε is model error.

Linear mixed effects models were used to account for within-home correlation in analyses that included multiple measures in a home (e.g., air samples taken at the same time in two rooms). Fixed effects were modeled with a random effect for each home and fit using restricted maximum likelihood. Random effects models assumed a compound symmetry covariance matrix. The compound symmetry covariance structure was determined to be valid based on additional modeling using a repeated measures design and comparing covariance matrices using Akaike's Information Criteria (AIC) and likelihood ratio tests.

Covariate selection for multivariate models was determined based on bivariate relationships at the α=0.10 level. Statistical significance for all statistical analyses was defined at the α=0.05 level.

4.7 QUALITY ASSURANCE AND QUALITY CONTROL PROCEDURES

This section describes the overall project QA/QC measures used to design, implement, and report the results of the study and analysis described in this Report. Every effort was made in each phase of the project to ensure completeness and accuracy of data collection, analytical methods, data entry, calculation procedures, and reporting of results.

As described in this report, EH&E conducted a series of inspections and environmental measurements in the complaint and non-complaint homes selected for inclusion in this study by CPSC. All sampling and analytical procedures for the project utilized appropriate and valid monitoring procedures approved and recommended in relevant published sources, either from regulatory agencies, such as the EPA, U.S. Occupational Safety and Health Administration (OSHA), other cognizant governmental organizations such as NIOSH, consensus standard organizations such as ASTM, or the peer-reviewed scientific literature. The following sections describe specific measures and procedures implemented to assure quality of the data collected and reported.

4.7.1 Quality Assurance Project Plan

A quality assurance project plan (QAPP) was developed as a critical component of the study. The QAPP documented the standardized quality assurance protocols that were established for the study, including protocols for data collection, data entry, laboratory analysis, data management, and data analysis. This included:

- Criteria for determining acceptable data quality, including information on target precision, accuracy, and data capture for all study variables
- Sample handling and custody procedures
- Calibration and performance evaluation procedures
- Data reduction and reporting procedures

The QAPP is included as Appendix B to this document.

4.7.2 Project Organization(s) and Responsibilities

EH&E's project manager was responsible for overall implementation, documentation, and delivery of the project and had the responsibility of ensuring the accuracy, precision, and completeness of all data presented. The Project Executive was responsible for technical oversight of the overall project and for ensuring that high data quality objectives were met by the Project Manager and the project team. Prior to release, all deliverables at EH&E are reviewed and approved by qualified Senior Level staff, with relevant qualifications and expertise, whose responsibilities include ensuring the accuracy and appropriateness of technical information presented. All members of the project team were trained in, and responsible for, data validation and quality control checks during each of their tasks.

4.7.3 Quality Assurance and Quality Control Samples

As detailed above, in addition to the primary samples collected during the study, a number of quality control samples were collected and analyzed in each sample set to evaluate the quality and reasonableness of the data collected during the study. The types and frequency of QA/QC samples collected during the study are outlined in Table 4.9.

Table 4.9 Quality Assurance and Quality Control Samples Collected During the Project

Sample Type	Frequency	Definition
Duplicate sample	Minimum of one per sample set and one per every 10 primary samples	A sample collected concurrently with a primary field sample to assess repeatability of methods.
Field blank	Minimum of one per sample set and one per every 10 primary samples	A sample prepared by the field team that represents the procedure for preparing for integrated sampling, and is handled as such, but is not actually used for sampling. This is sent in a blinded fashion to the laboratory. The results of the field blanks can be used to determine whether there was any contamination in the preparation, handling or shipping process in the field, or during the analysis of the samples by the laboratory.
Shipping Blank	Minimum of one per sample set and one per every 10 primary samples	An unused sample that is not handled in the field other than to have it incorporated into a regular sample shipment and sent in a blind fashion to the laboratory. The results of shipping blanks can be used to determine whether there was any contamination during the shipping process .

In addition to the use of different QA/QC samples in the field, QA/QC of integrated air samples included verification of pump flows by use of calibrated flowmeters at the start and end of each sampling period. The start and stop flow rates were then averaged to obtain an average flow rate. Sample duration was also calculated from the start and stop times recorded on the field data sheets. Total sample volumes were then calculated using the average flow rate and the duration of sampling as follows:

Total Sample Volume (L) = Average Flow Rate (L/min) x Total Sample Time (minutes)

4.7.4 Sample Handling

EH&E followed the requirements for holding times and sample perseveration outlined in the respective reference sampling methods used. After each day of sampling, samples were shipped to the laboratory via overnight express delivery within the holding time specified by the analytical method. The reduced sulfur air samples were shipped immediately after sampling via first priority overnight express delivery.

4.7.5 Sample Custody

All project samples were handled in accordance with appropriate chain of custody procedures. Compliance was overseen by the field team leader. The field team leader was also responsible for ensuring that all unused sample media as well as collected samples were properly cared for before, during, and after sampling. At the time of use, each sample was assigned a unique sample identification label. Each sample label was recorded on the field sample log sheets prior to sample collection. All log sheets were stored in a master field binder during the study.

4.7.6 Calibration Procedures

All measuring, monitoring, and sampling instrument calibrations, except those requiring factory calibrations, were performed in EH&E's Field Operations Support Center (FOSC) prior to shipment of instruments to the field. All instruments that are factory calibrated are checked periodically in the FOSC by comparing them against other, recently calibrated instruments. Prior to use in the field, each instrument was zeroed and span-checked with appropriate gases, or flow checked with rotameters to insure that they were operating within specification (and adjusted as necessary). Table 4.10 summarizes the calibration procedures for instruments used in the study.

Table 4.10 Calibration Procedures

Parameter	Instrument Type	Instrument	Calibration Method	Frequency
Air temperature	Thermistor, data logger	HOBO® U10-003 (Onset Computer Corp)	Calibrations performed by the manufacturer	Annual
Relative humidity	Thin-film capacitive sensor, data logger	HOBO® U10-003 (Onset Computer Corp)	Calibrations performed by the manufacturer	Annual
Carbon dioxide	Non-dispersive infrared sensor	Q-Trak Model 8551 Indoor Air Quality Monitor	Multipoint with standard gas mixtures ranging from 0 to 2,000 ppm along linear response curve.	Pre and post field measurements
Active air sampling	Air-sampling pump	Gilair-3/5 (Sensodine, Inc.) SKC Inc.	Compared against calibrated flow meter.	Pre and post measurements
Active air sampling	Flow meter	Dry-Cal DC-Lite, Bios International Corp.	Annual factory calibration	Pre and post measurements
Volatile organic compounds	SUMMA canister flow controller	6 Liter SUMMA canister	Provided pre-calibrated by laboratory	Each canister

4.7.7 Recordkeeping

4.7.7.1 Written Documentation

All data and documentation generated during the study, except that generated in electronic formats (raw data files, digital photographs), was transcribed into the appropriate collection forms which are subsequently stored in a single data collection binder. Hardcopies of final analytical laboratory reports (and the completed chains of custody) were also received and retained in EH&E's central filing system. Any changes in data entries are done in a manner that does not obscure the original entry. The reason for the revision is indicated, dated, and signed at the time of change. All original hardcopy records for the project are retained (together) in a central file system at EH&E's main office.

4.7.7.2 Electronic Documentation

Electronic documentation generated in the field during the study included digital photographs, XRF data files, carbon dioxide measurements and temperature and relative humidity data files. All files generated during the field phases of the study were downloaded and stored temporarily on a field computer under the control of the field team leader. Electronic files were then transferred from the field computer onto EH&E's central server routinely (typically at the end of each day). In order to track the various electronic data files, a standardized filing and naming system was used to clearly differentiate between files by type and the home in which they were collected. Also, field personnel documented the location of digital photographs, XRF measurements, and real-time data monitor deployments on the appropriate field forms.

4.7.8 Data Reduction, Validation, and Reporting

A systematic, standardized approach was implemented by EH&E to analyze, validate, and report the data collected during the study, including incorporating the following steps:

- Senior level staff at EH&E reviewed and verified the overall study approach, data collection strategy, methodology, appropriateness of all calculations and statistical analysis, and deliverables.
- EH&E developed a database (Microsoft Access), where all field data and laboratory results were stored.
- All (100%) field log entries and calculations were reviewed by independent staff members prior to entry into the study database.
- All (100%) of the data entry into the study database was reviewed and verified by independent, qualified personnel.
- To minimize database entry errors, EH&E requested that, when possible, all laboratory reports be provided in electronic data delivery (EDD) formats, such as Microsoft Excel so that the data could be directly imported into the central study database.
- After the database was populated, the number and sample identification labels in the database were compared with those on the field log sheets and the analytical laboratory reports (using a program coded in SAS 9.1).
- As discussed above, data summary and analysis was completed using SAS 9.1. All programming codes developed and executed for processing the data were independently reviewed by qualified personnel.

- In the limited instances where data entry or recording errors were identified during the QA/QC review processes described above, the entry was corrected in all relevant locations (back to the original entry). Corrections were noted on all original documentation.
- All of the final results underwent QA/QC review, including completeness and reasonableness checks.

4.7.9 Evaluation of Data Quality

As described above, a number of measures were implemented to ensure the collection of reproducible and accurate data during the study. This section describes the measures used to evaluate the completeness, precision, and accuracy of the data collected during the study. The completeness of the data set was evaluated by analyzing the capture efficiency for each environmental parameter targeted in the study. Accuracy was evaluated by reviewing results of blank samples. Precision was evaluated by examining the strength of the association between paired primary and duplicate samples. Paired duplicates were averaged and no blank correction was done for purposes of analysis.

4.7.9.1 Completeness

The completeness of air sampling data from the study was evaluated by examining the overall data capture efficiency for each sample group and sample type collected in the field (primary samples, duplicate samples, and field blanks and shipping blanks). Table 4.11 summarizes the data capture efficiency during the study.

Table 4.11 Summary of Data Capture Efficiency for Air Samples

	Number of Valid Samples*				Number of Void Samples				Capture Efficiency (%)	
Sample Type	**S**	**D**	**FB**	**SB**	**S**	**D**	**FB**	**SB**	**S/D**	**All**
Acids (inorganic)	193	49	30	21	39	12	0	1	82.6	84.9
Acids (organic)	194	49	30	22	15	4	1	0	92.7	93.7
Active aldehydes	194	48	32	22	6	1	0	0	97.2	97.7
Reduced sulfur	203	51	NA	NA	0	0	0	0	100	100
H_2S passive	201	51	38	17	7	1	0	1	96.9	97.2
HF passive	198	51	37	16	10	1	0	1	95.8	96.2
NO_2 passive	198	51	37	16	10	1	0	1	95.8	96.2
O_3 passive	198	50	38	17	10	2	0	1	95.4	95.9
SO_2 passive	198	51	37	16	10	0	0	1	96.1	96.5
Passive aldehydes	201	51	37	17	7	1	1	1	96.9	96.8
VOCs**	111	30	12	5	0	0	0	0	100	100
								Overall data capture efficiency	**95.0**	**95.5**

S	primary samples	H_2S	hydrogen sulfide
D	duplicates	HF	hydrogen fluoride
FB	field blanks	NO_2	nitrogen dioxide
SB	shipping blanks	O_3	ozone
NA	not applicable	SO_2	sulfur dioxide
S/D	samples/duplicates	VOC	volatile organic compound

* Data points considered in the analysis.

** Acetonitrile readings were excluded in all test homes (64% of samples) where potential contamination was a concern.

Overall, data capture efficiency was greater than 95%, and greater than approximately 85% for all individual sample types. A limited number of samples collected using sorbent media (active aldehydes, passives, and acids) were voided, primarily due to field conditions, such as pump failure, sample breakage in the field or during shipping, or when samples were adversely impacted by moisture. Data capture efficiency was 100% for whole air samples (VOCs and reduced sulfur). As discussed below, acetonitrile measurements from several homes were excluded. Although not listed in Table 4.11, no data from real-time monitoring results collected in the field (temperature, humidity, CO_2) were excluded from the analysis.

During the initial phases of data review, EH&E noted several elevated acetonitrile concentrations in both indoor and outdoor samples collected at some homes. Based on consultation with the laboratory, it was determined that these elevated measurements may be due to contamination, since acetonitrile may be liberated from DNPH during active aldehyde air sampling. DNPH is the sorbent media used for collection of the active aldehyde samples and these samples were typically deployed in close proximity to the SUMMA Canisters. Based on these findings, for the remainder of the study, an adsorbent charcoal tube was placed into the sampling train (downstream of the DNPH tube) for the active aldehyde samples. EH&E excluded all acetonitrile measurements from VOC sample sets that were collected in test homes where charcoal tubes were not in place on the aldehyde samples. All other VOC analytes were included in the data analysis.

4.7.9.2 Accuracy

Field and shipping blanks analysis were used to assess the accuracy of air sample measurements. For purposes of comparison of the air sample data analyzed in this report, the nominal laboratory reporting limit, expressed as quantity per sample and as quantity per unit volume of air sampled, was used as the metric of comparison to determine when results were below detection. The reporting limits presented are as reported by the respective analytical laboratory. EH&E did not review the methods used by the laboratories to derive these values. For passive, active aldehyde, and acid samples reporting limits per cubic meter of air sampled assumes that the nominal sample volume specified in the study protocol was collected.

Table 4.12 summarizes the number and percent of field and shipping blank results that were above detection (the reporting limit), and the limited number of individual compounds detected.

Table 4.12 Summary of Detection Frequency for Air Sample Field and Shipping Blanks

		Field Blanks			Shipping Blanks			All Blanks	Max	
Sample Group	**Compound**	**N Total**	**N Detect**	**% Non-detect**	**N Total**	**N Detect**	**% Non-detect**	**% Non-detect**	**Detected (μg/m^3)**	**Max RL (μg/m^3)**
Active aldehydes	All compounds (12)	384	0	100	264	0	100.0	100.0	–	–
Inorganic acids	Nitric acid	30	1	96.8	21	0	100.0	98.1	15	15
	Sulfuric acid	30	19	61.2	21	13	61.8	61.4	27	23
	Other compounds (5)	150	0	100	105	0	100.0	100.0	–	–
Organic acids	All compounds (4)	120	0	100	88	0	100.0	100.0	–	–
Passive aldehyde	Acetaldehyde	37	1	97.4	17	0	100.0	98.2	0.33	5
	Other compounds (8)	296	0	100	136	0	100.0	100.0	–	–
Passive other	Hydrogen sulfide (H_2S)	38	0	100	17	0	100.0	100.0	–	–
	Hydrogen fluoride (HF)	37	0	100	16	0	100.0	100.0	–	–
	Nitrogen dioxide (NO_2)	37	5	88.1	16	4	80.0	85.5	0.23	0.33
	Ozone (O_3)	38	1	97.4	17	0	100.0	98.2	1.7	1.3
	Sulfur dioxide (SO_2)	37	0	100	16	0	100.0	100.0	–	–
Volatile organic compound (VOC)	2-Butanone (MEK)	12	3	80.0	5	1	83.3	81.0	2.9	3.1
	2-Hexanone	12	0	100	5	1	83.3	94.4	0.72	3.1
	Acetone	12	2	85.7	5	1	83.3	85.0	16	31
	Acrolein	12	1	92.3	5	1	83.3	89.5	1.2	3.1
	cis-1,2-Dichloroethene	12	0	100	5	1	83.3	94.4	0.24	0.62
	Propene	12	0	100	5	1	83.3	94.4	0.63	3.1
	Other compounds (69)	818	0	100	344	0	100.0	100.0	–	–
Overall blank detection frequencies				**98.5**	–	–	**98.0**	**98.3**	–	–

N	number of data points
Max	maximum
μg/m^3	micrograms per cubic meter
RL	reporting limit

Overall, 98.3% of the blank measurements were below detection and less than 10% (11 of 112) of the individual analytes targeted during the study were detected in one or more blank sample. Also, with the exception of sulfuric acid, all compounds were detected in blanks infrequently (all less than 20% and most less than 10% detection frequency). Also, for all detected analytes, the maximum (nominal) concentration detected in blank samples was below the maximum reporting limit for the overall sample set, with the exception of ozone and sulfuric acid. Ozone was only detected in 1 of 55 blanks. Sulfuric acid was below detection in all of the test homes, both case and control. No blank correction was done in EH&E's analysis of the study data, except blank corrections performed by the laboratory as part of their standard reporting procedures.

EH&E also reviewed the quality assurance procedures implemented by the analytical laboratories to evaluate the accuracy of the air sample measurements (this analysis is summarized in Table A.1 in Appendix A). In accordance with the standard or published methodologies employed for the air sampling and analysis, laboratory quality control measures included blanks, duplicates, standards, and continuing calibration verification. These quality control metrics demonstrated excellent compliance with the accuracy requirements specified in the respective reference methods. Analytical quality assurance exceptions were noted in less then 0.2% of the air sample measurements (48 out of 28,661 measurements). The exceptions included laboratory duplicate and control standard recoveries slightly outside of the limits outlined in the reference methods and occasional exceedances of sample storage times or temperatures. EH&E also evaluated the laboratory results to determine if there was potential breakthrough and sample media saturation; no breakthrough or saturation occurred during the study.

No laboratory quality assurance flags were noted for laboratory blank samples, although analytes were detected in some laboratory blanks that were analyzed in conjunction with the active aldehyde samples. In all cases, results reported by the laboratories were blank corrected in accordance with the appropriate standard laboratory protocols.

The accuracy of the XRF instruments was ensured using several measures. First, each XRF analyzer was individually calibrated by the manufacturer prior to delivery to EH&E using standard reference materials that include many elements, including strontium. The manufacturer's calibration procedure specifically includes an assessment of the concentration of strontium in the standard reference material and values reported by the analyzer. Second, agreement between the three XRF instruments used during the field study and in subsequent analysis at EH&E's laboratory was evaluated. All analyzers were found to be in excellent agreement for strontium concentrations (Spearman r=0.98, p<0.0001). Third, EH&E evaluated the strontium concentrations measured independently by EH&E and the EPA from the same bulk samples of drywall. These independent readings also demonstrated a high level of 1:1 agreement (Spearman r=0.99, p<0.0001). Last, seven drywall samples were analyzed by the U.S. Geologic Survey for total strontium using inductively coupled mass spectrometry (ICP/MS). The same samples were analyzed using the XRF instruments and the strontium concentrations reported by both methods were found to be in excellent agreement (slope=1.06; R^2=0.997; p<0.001). In addition, internal instrument background checks were run on each instrument before use. For FTIR, internal calibration programs were run on the instrument monthly in accordance with manufacturer's recommendations.

The accuracy of real-time temperature, relative humidity, and dew point monitors was ensured in accordance with manufacturer's recommendations (annual calibration against a primary standard). Accuracy of the CO_2 monitors was maintained using a primary calibration procedure, with NIST-traceable zero and span gases, prior to field deployment, where the instrument response was set or calibrated to a primary standard device, zero or span gas, or mercury thermometers and hygrometers. Each day during the field study, the performance of each sensor was measured or verified against these primary standards. This method allows both the repeatability (precision) and the instrument accuracy to be recorded.

4.7.9.3 Precision

Measurement precision for targeted analytes was characterized by analysis of the duplicate samples collected during the field study. Numerous methods have been developed to characterize the precision of environmental measurement systems from duplicate measurements. Estimates of precision attained from the various methods are reported to be a function of the magnitude that the differences between duplicate samples deviate from normality (Hyslop and White 2009). Therefore, both a primary and secondary method was used to estimate the precision of the measurements in this study in order to ensure that a robust determination of precision was obtained. The precision estimates discussed below included all duplicate pairs where both measurements were above the laboratory reporting limit.

The primary method for estimating precision was based upon guidance from the EPA (EPA 2008). In this method, precision is calculated as the root mean square of the scaled relative differences between pairs of duplicate samples (Equation 4.3). The 1σ estimate of precision derived from this method provides a concentration range within which the actual concentration is expected to occur 68% of the time.

$$Root\ mean\ square = \sqrt{\frac{1}{n}\sum_{i=1}^{n} D_i^2} \times 100\%, \qquad \text{(Equation 4.3)}$$

where

$$D_i = \frac{(C_{i1} - C_{i2}) \big/ \sqrt{2}}{(C_{i1} + C_{i2}) \big/ 2}$$

The secondary method used to estimate precision of the study data was the coefficient of variation (CV) computed from an ordinary least squares regression of the paired duplicate samples. In this case, the CV is calculated as the root mean square error of the regression model divided by the mean of the dependent variable (the second sample of each duplicate pair).

Precision estimates for each parameter targeted during the study are listed in Table A.2 of Appendix A. Estimates of precision for the following major sample groups and for selected specific chemicals in indoor air are tabulated below.

- Air: inorganic acids, organic acids, aldehydes sampled both actively and passively, reduced sulfur gases, and volatile organic compounds.
- Specific chemicals: acetic acid, carbon disulfide, formaldehyde, formic acid, hydrogen sulfide, nitrogen dioxide, and ozone.
- Drywall: strontium by XRF and carbonate by FTIR.
- Corrosion: rates of copper and silver sulfide corrosion.

The primary estimates of precision for the major groups of chemicals measured in air are provided in Table 4.13. Precision ranged from 4.4% for inorganic acids to 21% for VOCs.

Table 4.13 Primary Estimate of Measurement Precision for Groups of Analytes in Indoor Air by Sampling Method

Group of Analytes	Number of Pairs	Precision (%)
Acids, inorganic	5	4.4
Acids, organic	70	6.9
Aldehydes, active samples	364	10.5
Aldehydes, passive samples	375	6.9
Reduced sulfur gases	3	8.8
Volatile organic compounds	1,005	21.0

The high precision shown in Table 4.13 is illustrated in the scatter plots presented in Figure 4.2. The secondary estimates of precision inset in the figure agree well with the corresponding primary estimates with one exception. The agreement for duplicate pairs of VOC samples (Figure 4.2 f) is somewhat lower than the agreement for other groups according to the secondary method for estimating precision. However, examination of sample and duplicate measurements for individual compounds indicates that this high variability is accounted for by a limited number of individual compounds. These compounds include several that were typically detected at low levels in some homes (1,1,2-trichlorotrifluoroethane, trichlorofluoromethane, and naphthalene) and two common indoor VOCs (acetone and ethanol) that are not relevant to the findings or conclusions of this study. Excluding these compounds from the regression analysis results in improved agreement between the sample and duplicate pairs for the VOC sample group (coefficient of variation=27.4, RMSE=7.0).

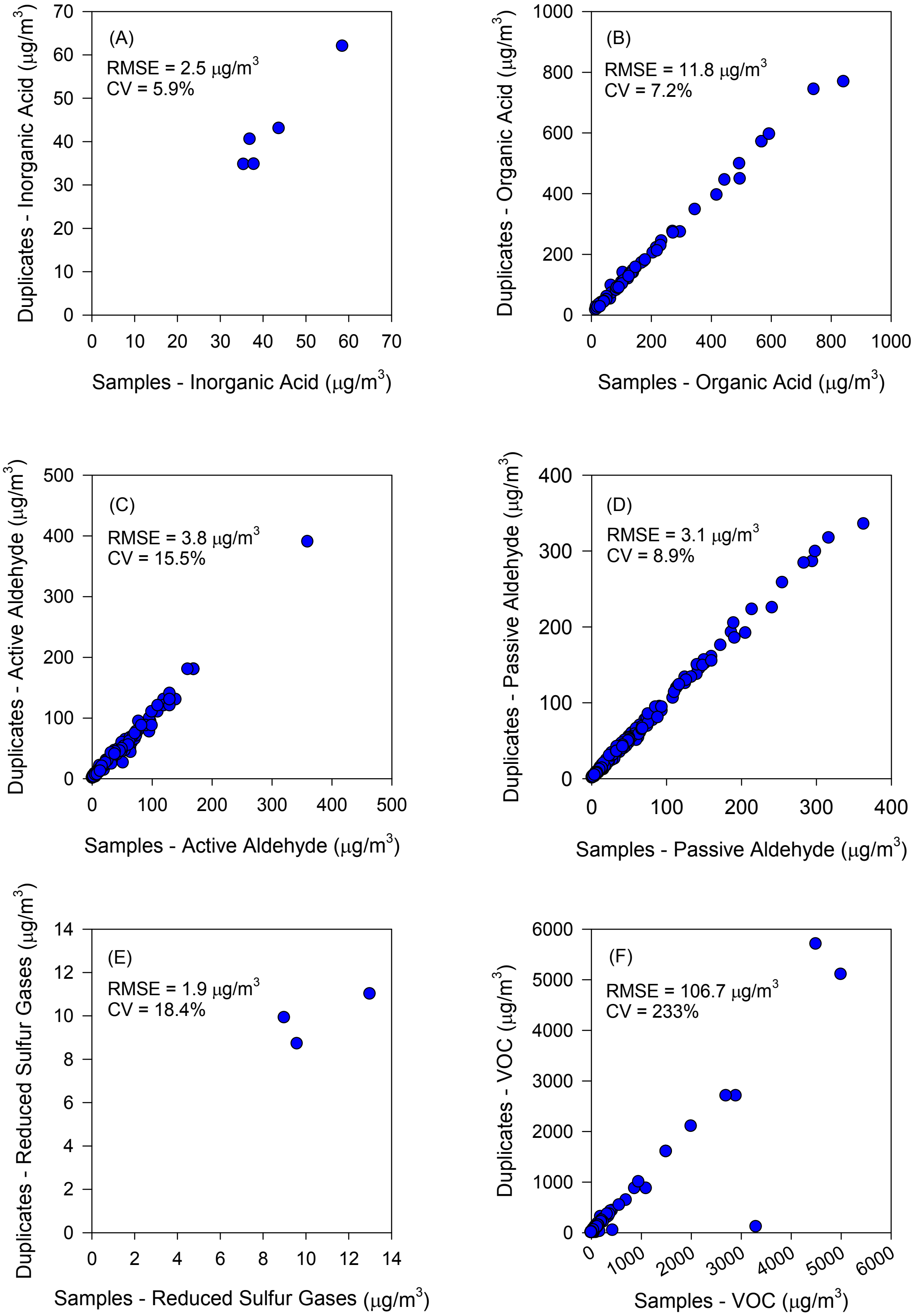


Figure 4.2 Comparison of Paired Duplicate Air Sample Measurements by Group

Table 4.14 contains the primary estimates of precision determined for a selection of specific analytes that includes many of the reactive species that were sampled in complaint and non-complaint homes. Precision was less than 15% for all of the species except nitrogen dioxide. As detailed in Section 5, NO_2 was found to be present at normal indoor concentrations for the complaint and non-complaint homes in this study.

Table 4.14 Primary Estimate of Measurement Precision for Specific Analytes in Indoor Air

Analyte	Number of Pairs	Precision (%)
Acetic acid	47	5.9
Carbon disulfide (reduced sulfur)	3	8.8
Carbon disulfide (SUMMA canister)	14	6.1
Formaldehyde (active)	48	10.0
Formaldehyde (passive)	51	3.9
Formic acid	23	8.5
Hydrogen sulfide (passive)	28	12.5
Nitrogen dioxide	48	18.5
Ozone	1	6.7

Scatter plots and secondary estimates of precision are shown in Figure 4.3 for acetic acid, formic acid, carbon disulfide (SUMMA), formaldehyde (active and passive), and hydrogen sulfide (passive). There was good agreement between the primary and secondary estimates of precision for these analytes.

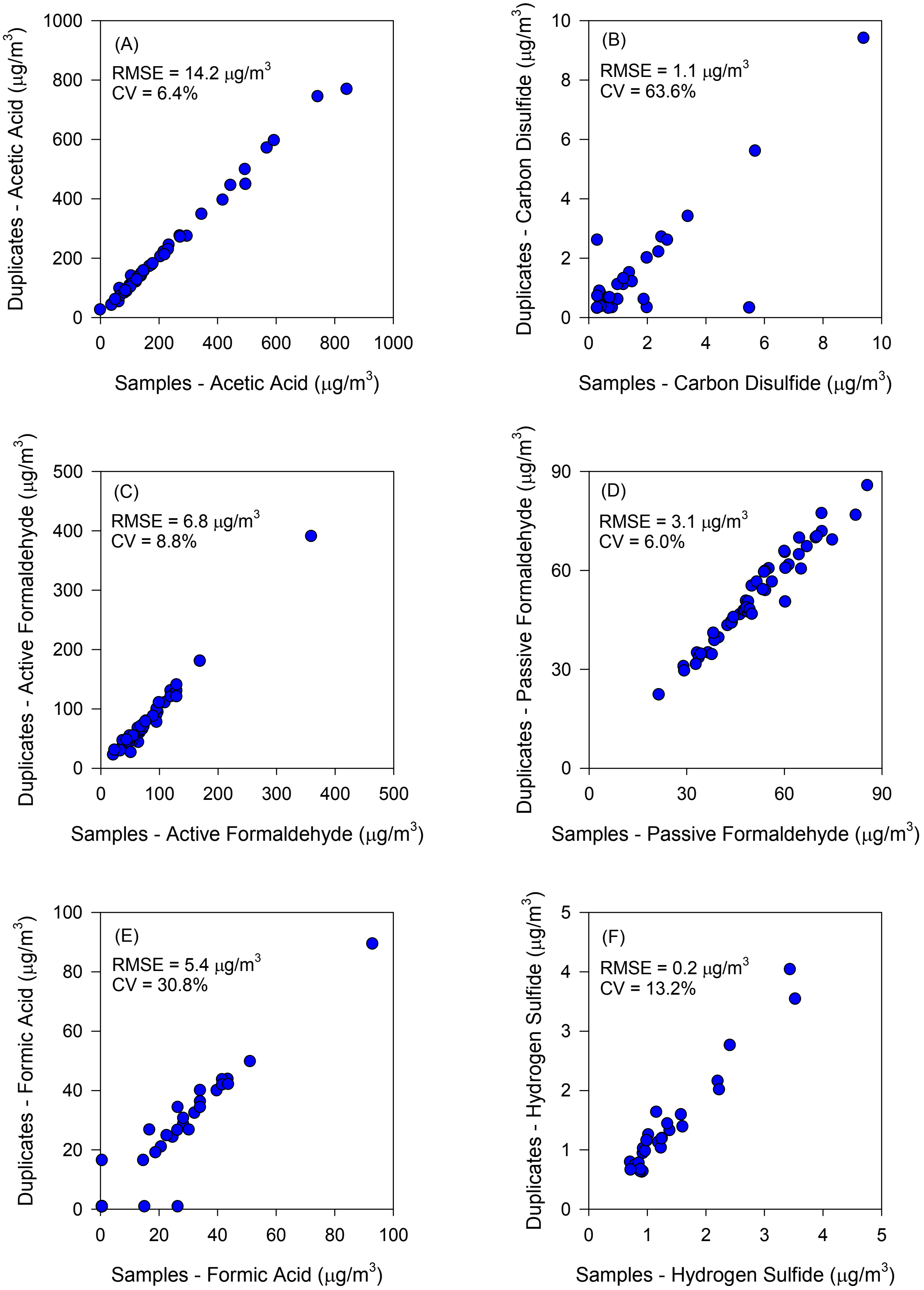


Figure 4.3 Comparison of Paired Duplicate Air Sample Measurements for Selected Compounds

The primary estimates of precision for the strontium (by XRF) and carbonate (by FTIR) measurements are shown in Table 4.15. Precision ranged from 3.4% for the carbonate measurements to 13.8% for the strontium field measurements.

Table 4.15 Primary Estimate of Measurement Precision for XRF and FTIR Measurements

Parameter	Number of Pairs	Precision (%)
Strontium (XRF Field measurements)	98	13.8
Strontium (XRF laboratory measurements)	810	12.3
Carbonate (FTIR laboratory measurements)	111	3.4

XRF	x-ray fluorescence
FTIR	Fourier transform infrared spectroscopy

Figures 4.4 and 4.5 summarize the regression analysis for strontium field measurements, strontium laboratory measurements, and carbonate laboratory measurements, all of which demonstrate a high level of precision.

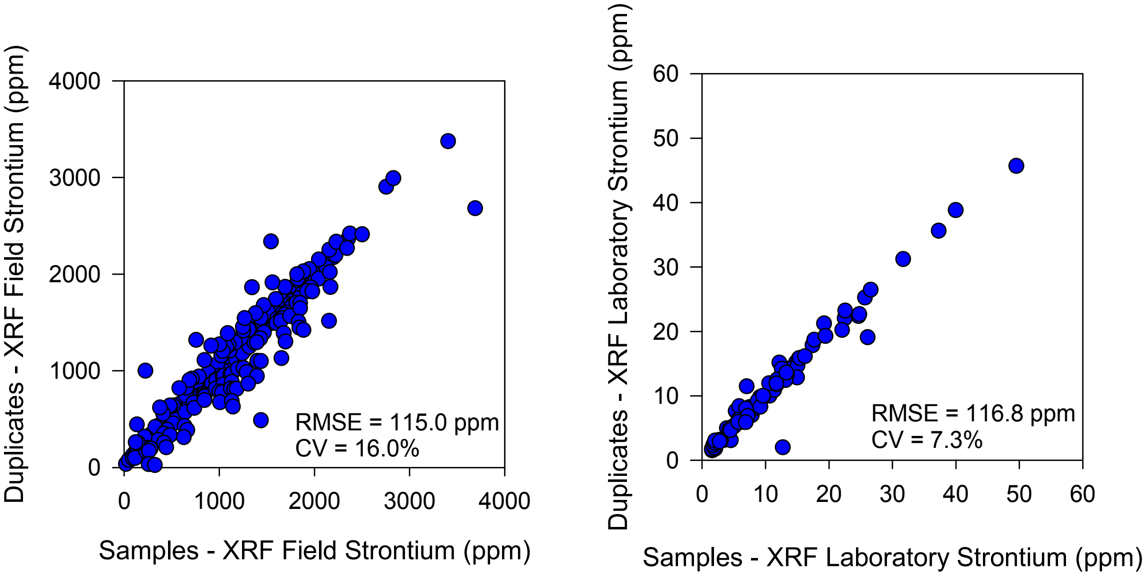


Figure 4.4 Comparison of Paired Duplicate XRF Field and Laboratory Strontium Measurements

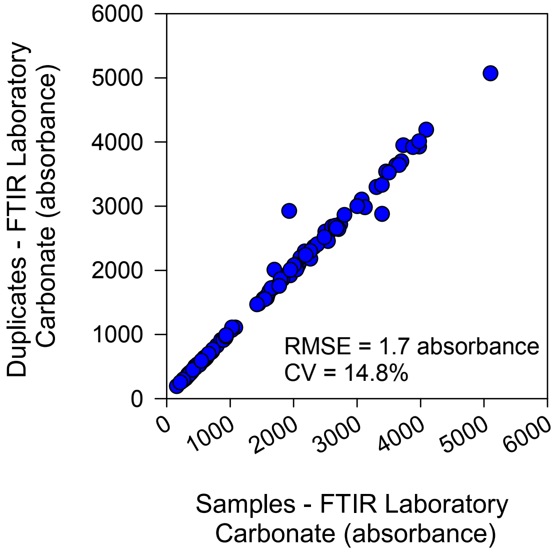


Figure 4.5 Comparison of Paired Duplicate FTIR Laboratory Carbonate Measurements

The precision of the FTIR instrument used in testing at EH&E's laboratory was also examined by evaluating the agreement between measurements repeated daily from the same sample of drywall. The CV from the repeat reference readings for carbonate indicated strong agreement as well (N=12, CV=3.3%).

The primary estimate of precision for the coupon corrosion measurements was an evaluation of the agreement between paired duplicate measurements of Cu_2S and Ag_2S. The precision estimates for the corrosion measurements are shown in Table 4.16.

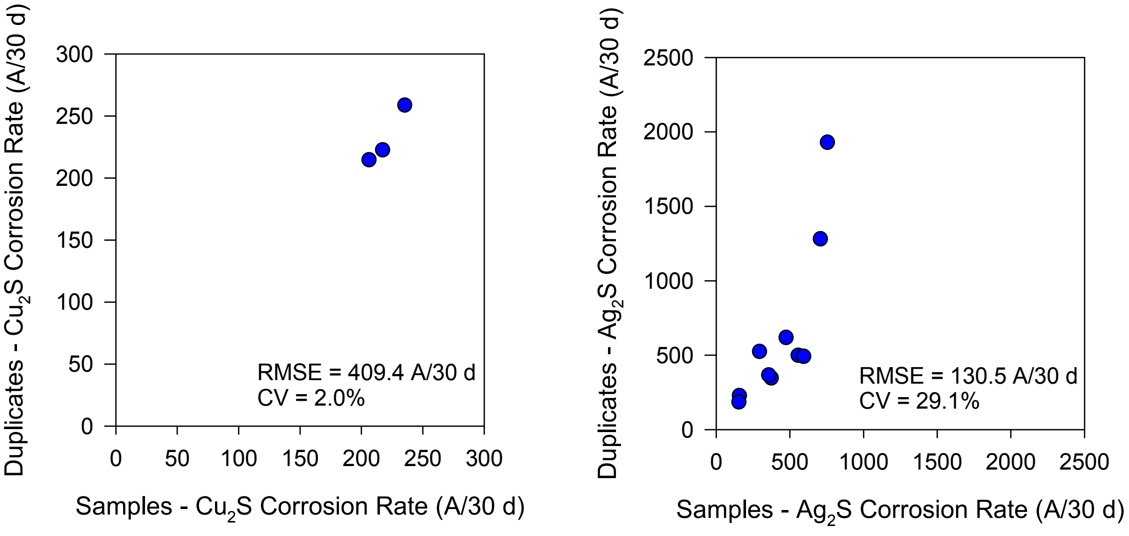


Figure 4.6 Comparison of Paired Duplicate Corrosion Rate Measurements for Copper and Silver Coupons

In addition to the calibration procedures implemented prior to, and in the field (described above), the precision and reasonableness of real-time monitoring data (temperature, relative humidity, dew point temperature, and CO_2) was evaluated utilizing several measures. For the temperature, relative humidity, and dew point temperature measurements the CV between the average values at each measurement location within a test home was used as an indicator of agreement (CV=[standard deviation/mean]∗100). Table 4.16 summarizes the mean CVs for the temperature and humidity monitoring data, all of which were less than 10%.

Table 4.16 Coefficient of Variation, Inter-home Temperatures, Relative Humidity and Dew Point Temperature Measurements

Parameter	N	Mean CV (%)
Temperature	120	1.4
Relative humidity	120	4.4
Dew point temperature	120	2.1

N	number
CV	coefficient of variation

The precision of air exchange rate measurements was evaluated using linear regression analysis between each of the coincident air exchange rate estimates within each home (between one and three locations were monitored in each home), which were based on CO_2 readings. The CVs for the air exchange rate estimates averaged 29% (range 0 – 104%). Although some houses exhibited relatively high variability in air exchange rate estimates, the error for these measurements average 7% and ranged from 2 – 30% (based on an overall RMSE of 0.016).

5.0 RESULTS

5.1 SOURCE IDENTIFICATION

5.1.1 Known Origin Sample Analysis

A preliminary laboratory study, at the EH&E facility, analyzed 34 drywall samples of known origin (also referred to as "catalog" samples) using both XRF and FTIR techniques. This analysis focused on the core of the drywall samples and excluded paint and paper associated with the drywall.

The results of the analysis of 34 samples are presented in Figure 5.1. Drywall samples imported from China are depicted in red triangles and all demonstrate elevated levels of strontium as measured by XRF and carbonate as measured by FTIR. Of note, one imported drywall sample with elevated carbonate but muted strontium concentration was determined to be a mix of synthetic and mined gypsum. All of the domestic drywall samples had low carbonate levels and the majority also had low strontium concentrations.

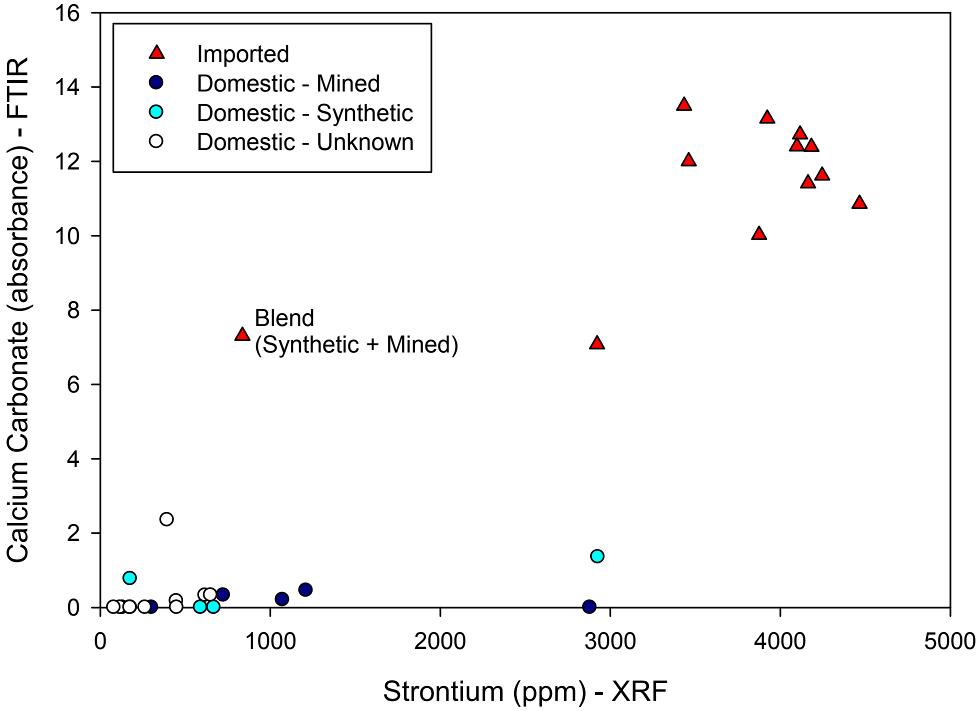


Figure 5.1 Comparison of Cored Drywall Samples of Known Origin and Analyzed in a Laboratory Setting for Strontium Concentrations (ppm) Measured by XRF and Carbonate (Absorbance) Measured Using FTIR. See Figure for Legend of Sample Type

This separation observed in the catalog data permitted the tentative discrimination of various categories of drywall based on the following criteria:

- Samples with greater than 1,200 ppm of strontium AND carbonate absorbance values greater than 5 (imported from China)
- Samples with less than 1,200 ppm of strontium and carbonate less than 5 (not imported from China)

Of note, one sample imported from China that was a blend of synthetic and mined material had high carbonate but a strontium concentration close to but below the 1,200 ppm cutoff.

5.1.2 FTIR and XRF Laboratory-Based Analysis of Core Samples Collected in the 51-home Field Study

The drywall core samples obtained from multiple locations within each home (at least one per wall) in the 51-home study were analyzed using XRF and FTIR under the same sampling protocol as the preliminary “catalog” samples described above. Results for the core samples taken from the 51 homes in the field study and analyzed in the laboratory are presented in Figure 5.2. In general, the two main groups described above, and a third group, are apparent in the data collected from the field:

- Group 1—Samples with greater than 1,200 ppm of strontium AND carbonate values greater than 5
- Group 2—Samples with less than 1,200 ppm of strontium and carbonate less than 5
- Group 3—Samples with less than 1,200 ppm of strontium and carbonate greater than 5.

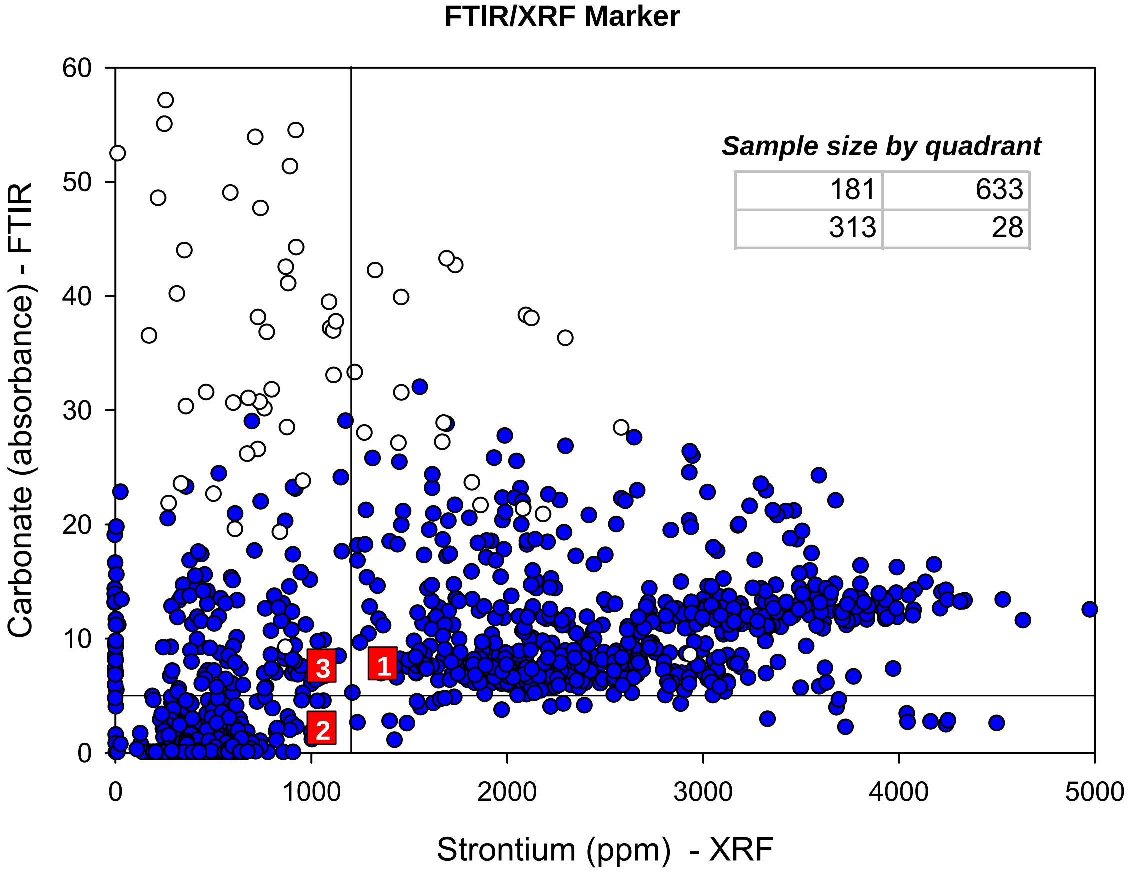


Figure 5.2 Comparison of Cored Drywall Samples Obtained in the Field and Analyzed in a Laboratory Setting for Strontium Concentrations (ppm) Measured by XRF and Carbonate (Absorbance) Measured Using FTIR. White Circles Denote Points with Elevated Carbonate and Quartz and Identified as Containing Plaster (See Text for Explanation)

Groups 1 and 2 are shown in Figure 5.2 and correspond to the cutoff points found in the ”catalog” samples presented in Figure 5.1 and appear to be useful indicators of imported and domestic drywall, respectively. An important difference between the analysis of the “catalog” samples and those collected from the 51 homes is that several samples had elevated carbonate levels (Group 3). For analyses in this report, drywall samples falling in Group 1 were defined as “FTIR/XRF Marker Present” and all others defined as “FTIR/XRF Marker Not Present.”

The field samples with elevated carbonate and lower strontium (Group 3) may be due to imported samples comprised of blended material (see Figure 5.1) or domestic samples impacted by wall coverings such as plaster. The samples with elevated carbonate were examined further and determined to also have elevated quartz (samples denoted by white circles have elevated quartz). Additional analysis was conducted on the drywall samples with the elevated quartz. It was determined that the elevated carbonate readings were due to finish plaster on the drywall being mixed with the drywall sample during the coring procedure used for sample collection (Figure 5.3). Plaster is often used on drywall to provide a smooth painting surface and commonly contains up to 50% carbonate and 1-2% of quartz.

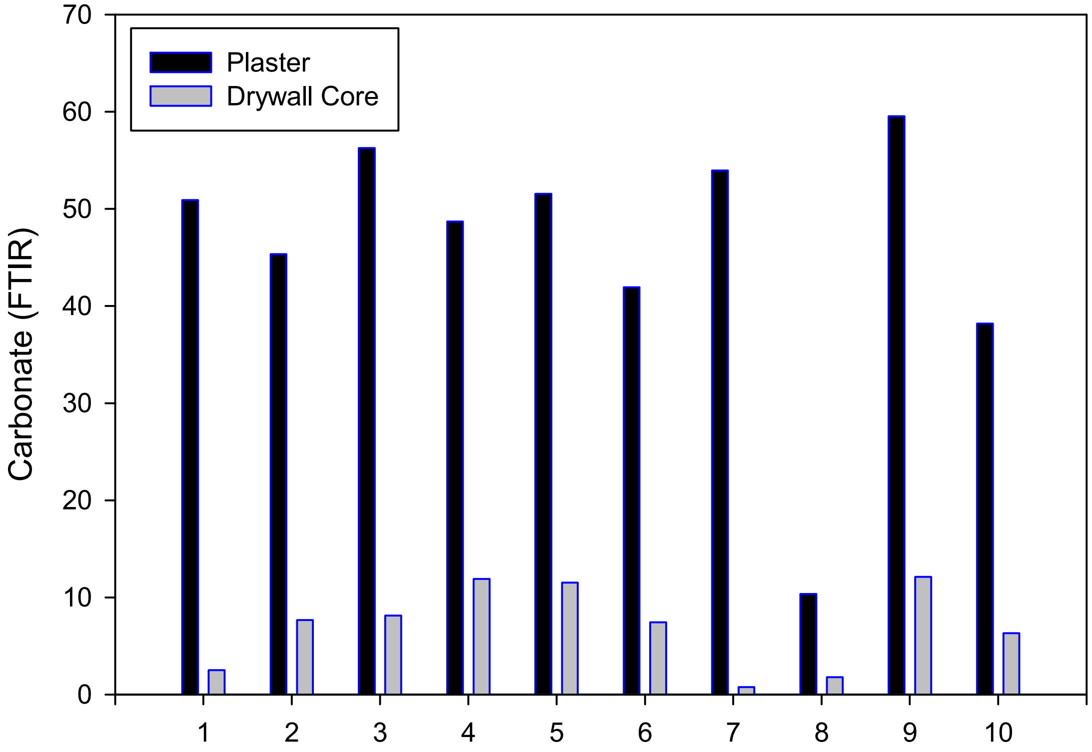


Figure 5.3 Carbonate Levels Measured Using FTIR in Matched Samples of Plaster and Drywall and Core Material Alone in Drywall

The information provided in Figure 5.3 indicates that the presence of plaster in a sample can significantly influence the results and provide a significant positive bias for the carbonate reading. This bias could result in overstating drywall carbonate results by a factor of approximately 5 to 50. In reviewing the data there are very few individual data points in which applying the correction would modify the original quadrant in which the sample would fall. The possible bias is nearly eliminated when all the samples from a home are aggregated and analyzed. The original data was used for plotting Figure 5.2 and no correction has been applied in this analysis.

5.1.3 Comparison of CPSC House Status and Status as Determined Using FTIR/XRF

Using the results of the FTIR and XRF analysis of the core samples, any sample falling in Group 1 was labeled as having the FTIR/XRF marker present. All other samples were labeled as ‘Not Present.’ To compare the objective determinant of house status (i.e., contains imported drywall or not) against the CPSC home status (i.e., complaint or non-complaint home), homes that contained greater than one sample in Group 1 were labeled as having the FTIR/XRF marker present.

A comparison of the FTIR/XRF marker against the CPSC home status is presented in Table 5.1. The two methods showed strong agreement across the 51 homes. Small differences between the two metrics were expected; three of the 41 homes self-identified to CPSC as being complaint homes were not found to have imported drywall based on the FTIR/XRF marker. The self reported CPSC ranks for these three homes are 3, 4, and 4 (Scale 0 – 7).

Table 5.1 2x2 Table Comparing CPSC Home Status and Objectively Measured Status Using FTIR/XRF

		CPSC Status		
		Complaint	**Non-complaint**	**Total**
FTIR – XRF Marker	**Present**	38	0	38
	Not Present	3	10	13
	Total	41	10	51

5.2 INTEGRATED MEASURE OF EFFECT

5.2.1 Corrosion Classification Coupons

Corrosion classification coupons containing one strip of copper and one strip of silver represent an objective integrated measure of effect. Corrosion coupons obtained from one non-complaint home (A) and three complaint homes (B-D) are depicted in Figure 5.4 and represent typical results for the non-complaint and complaint homes. Visible levels of corrosion were commonly observed on the metal coupons collected from complaint homes, while the metal coupons from non-complaint homes showed less evidence of corrosion.

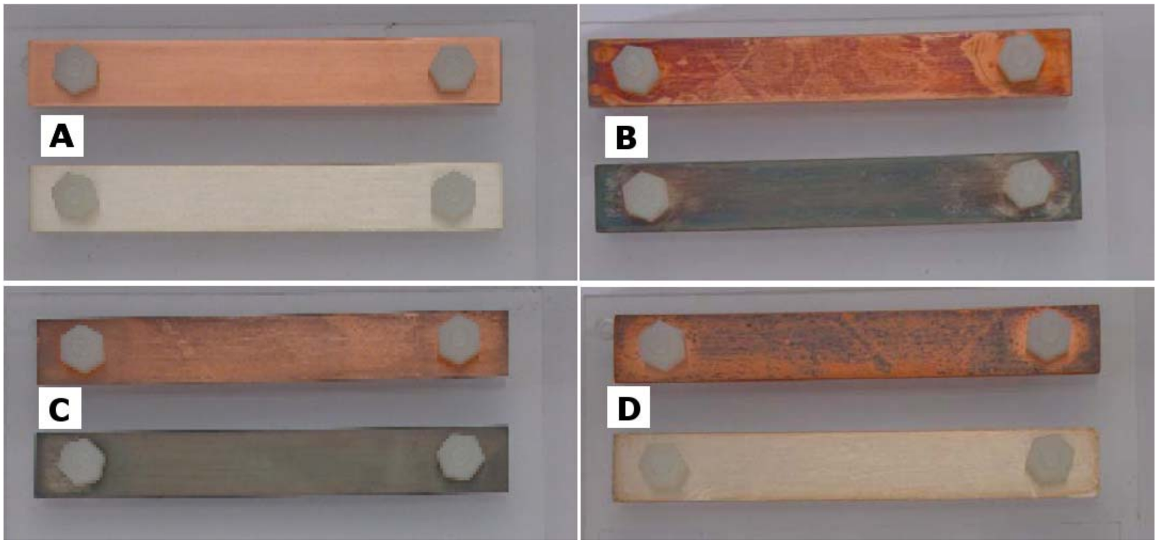


Figure 5.4 Photographs of Corrosion Coupons after Retrieval from One Non-complaint Home (A) and Three Complaint Homes (B – D)

5.2.2 Characterization of Corrosion

Corrosion rates from the silver coupons are reported as silver sulfide (Ag_2S), silver chloride (AgCl), or unknown. For copper, the rates are reported as copper sulfide (Cu_2S), copper oxide (Cu_2O), or unknown. The dominant species found in this study for most homes were silver and copper sulfides. For the silver coupons, only one sample at the air supply register showed silver chloride based corrosion products on the test strip. Similar results were found for the coupons in the rooms. For the copper coupons, the samples were dominated by Cu_2S but there was also a consistent, low-level rate of Cu_2O corrosion (Figure 5.5).

Summary statistics for corrosion rates, in angstrom per 30 days, are presented in Appendix A, Table A.3.

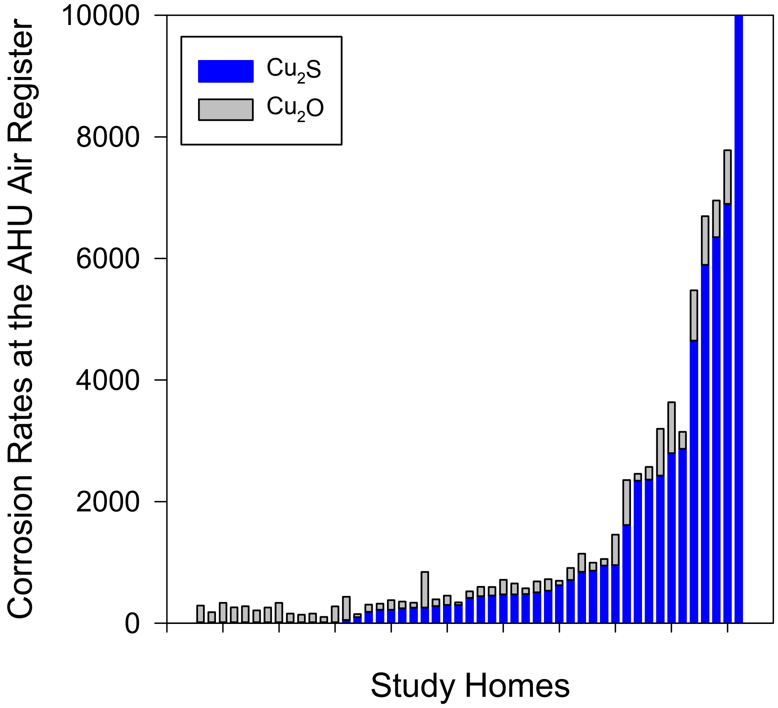


Figure 5.5 Corrosion Rates at AHU Air Register for All 51 Homes, by Corrosion Species

Corrosion species observed on the coupons were further validated using a subset of samples of co-located copper and silver coupons (n=6), which were also characterized using a scanning electron microscope (SEM) fitted with an energy dispersive spectroscopy (EDS) microprobe, and by x-ray photoelectron spectroscopy (XPS). The 6 samples (12 total coupons) were selected based on the observation of tarnish with a visual inspection. EDS analysis established that corrosion was heterogeneous on all coupons, with very similar elemental composition consisting of carbon, oxygen, sulfur, and silicone. XPS analysis confirmed the EDS findings with additional characterizations of the relative contributions which varied from coupon to coupon (Table 5.2).

Table 5.2 Major, Minor, and Trace Elemental Composition of Corrosion Coupons Analyzed by Energy Dispersive Spectroscopy

Metal	Major Elements	Minor Elements	Trace Elements
Copper	C, O, Cu	S, Si, O, Ag	S, Ag, Cl, N
Silver	C, Ag	S, O, Si, Cu	Cl, N

C	carbon
O	oxygen
Cu	copper
S	sulfur
Si	silicone
Ag	silver
N	nitrogen

Note: Variation was observed across samples. For example, sulfur was reported as a minor element in one copper sample and a trace element in another.

As a result of these findings, the analysis focuses on the sulfide based corrosion throughout the results section.

5.2.3 Comparison of Corrosion Across Rooms

Corrosion test strips were deployed at up to four unique indoor locations as well as one outdoor location. A correlation matrix comparing results from each sampling location is presented in Table 5.3. Corrosion rates on co-located copper and silver coupons were moderately to strongly correlated in indoor locations ($r=0.57 – 0.74$; $p<05$). Similar correlations were observed for the same type of metal strip across rooms in the same home ($r=0.51 – 0.78$; $p<0.01$). Outdoor corrosion was not correlated with indoor corrosion ($p>0.05$) except for a weak correlation for copper ($r=0.29-0.31$; $p=0.03-0.06$).

Table 5.3 Corrosion Correlation Matrix

		Living Room		Master Bedroom		Bedroom		AHU Air Register		Outdoors	
		Cu_2S	Ag_2S	Cu_2S	Ag_2S	Cu_2S	Ag_2S	Cu_2S	Ag_2S	Cu_2S	Ag_2S
Living Room	Cu_2S	1									
		50									
	Ag_2S	**0.62**	1								
		<0.001									
		50	50								
Master Bedroom	Cu_2S	**0.61**	**0.53**	1							
		<0.001	<0.001								
		50	50	51							
	Ag_2S	**0.51**	**0.65**	**0.71**	1						
		<0.001	<0.001	<0.001							
		50	50	51	51						
Bedroom	Cu_2S	**0.51**	**0.40**	**0.56**	**0.53**	1					
		<0.001	0.01	<0.001	<0.001						
		40	40	41	41	41					
	Ag_2S	**0.48**	**0.63**	**0.73**	**0.78**	**0.57**	1				
		0.002	<0.001	<0.001	<0.001	<0.001					
		40	40	41	41	41	41				
AHU Air Register	Cu_2S	**0.44**	**0.48**	**0.51**	**0.45**	0.30	**0.60**	1			
		0.002	<0.001	<0.001	0.001	0.05	<0.001				
		48	48	49	49	41	41	49			
	Ag_2S	**0.48**	**0.65**	**0.61**	**0.68**	**0.46**	**0.82**	**0.74**	1		
		<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001			
		48	48	49	49	41	41	49	49		
Outdoors	Cu_2S	0.18	-0.05	0.29	0.04	0.30	0.10	0.31	0.20	1	
		0.21	0.72	0.04	0.76	0.06	0.52	0.03	0.18		
		49	49	50	50	41	41	48	48	50	
	Ag_2S	0.1	0.17	0.01	-0.05	-0.04	0.01	0.08	0.01	0.04	1
		0.51	0.23	0.95	0.76	0.79	0.93	0.60	0.93	0.78	
		49	49	50	50	41	41	48	48	50	50

Cu_2S	copper sulfide
Ag_2S	silver sulfide
AHU	air handling unit

KEY
correlation coefficient (Spearman r)
p-value
n (sample size)

Note: bolded correlation coefficients are significant at $p<0.05$

The range of corrosion rates were similar in rooms and significantly higher on the corrosion strips located near the AHU air register (Figure 5.6). This may be due to a greater volume and higher velocity of air moving past them on a regular basis or variations in temperature and relative humidity during AHU cycling. This issue is discussed further in Section 6.4.2. Outdoor corrosion rates were low on the silver and copper coupons, in general. The copper coupons located outdoors also exhibited significantly more variability than the outdoor silver coupons.

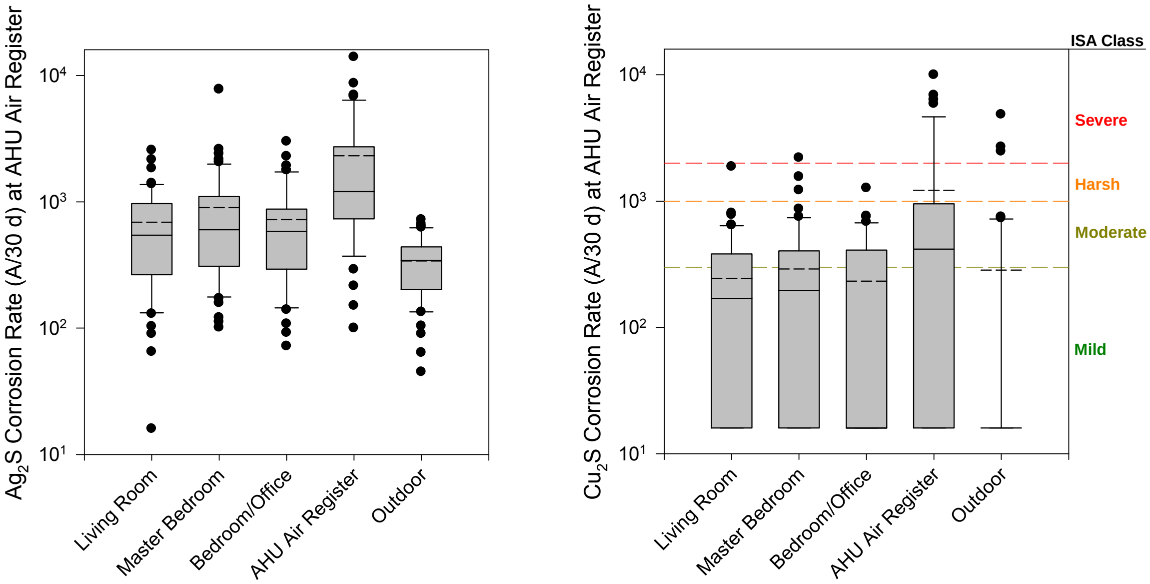


Figure 5.6 Corrosion Rates by Location within the Home and Outdoors

5.2.4 Comparison of Corrosion by House Status

Corrosion rates were compared based on the CPSC complaint or non-complaint house status (Figure 5.7). Complaint homes had significantly greater rates of corrosion on both the silver and copper coupons compared to non-complaint homes, on average ($p<0.01$). Multivariate regression modeling showed this finding remained after controlling for outdoor corrosion, indoor temperature and study region ($p<0.01$; model $R^2=0.46$ and 0.43). These findings also remained when room-specific corrosion rate results (e.g., master bedroom, living room) were used in the regression models in place of corrosion rates at the AHU air register ($p<0.05$; model $R^2=0.33$ - 0.63).

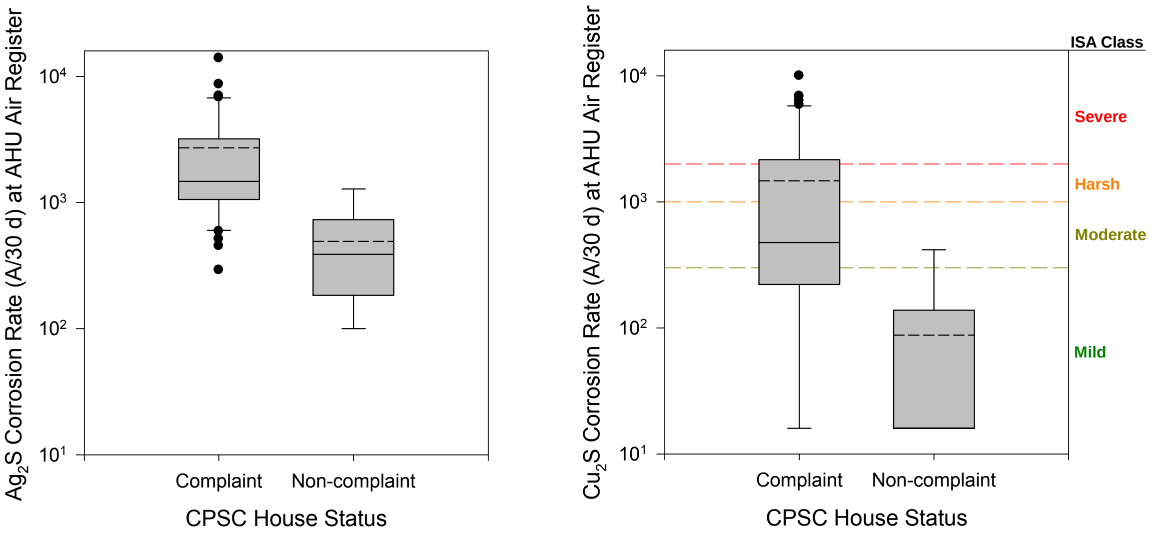


Figure 5.7 Comparison of Corrosion Film Thickness by CPSC House Status

The house status determined using the FTIR/XRF marker to assess the presence or absence of imported drywall was compared against corrosion rates in the home, similar to Figure 5.8 that used the CPSC home status by complaint. Similar to the CPSC status, homes with the FTIR/XRF marker were found to have significantly elevated rates of both silver and copper corrosion, an effect that remained after controlling for outdoor corrosion, indoor temperature and study region in multivariate models ($p<0.001$) (see Tables 5.11 and 5.12). Using the FTIR/XRF marker to classify home status explained approximately 10% more of the variability in corrosion rates compared to the CPSC homeowner's self reported home status (model $R^2=0.57$ for silver and 0.52 for copper). Models using room-specific corrosion rate results (e.g., master bedroom, living room) produced similar results ($p<0.05$; model $R^2=0.40 – 0.63$).

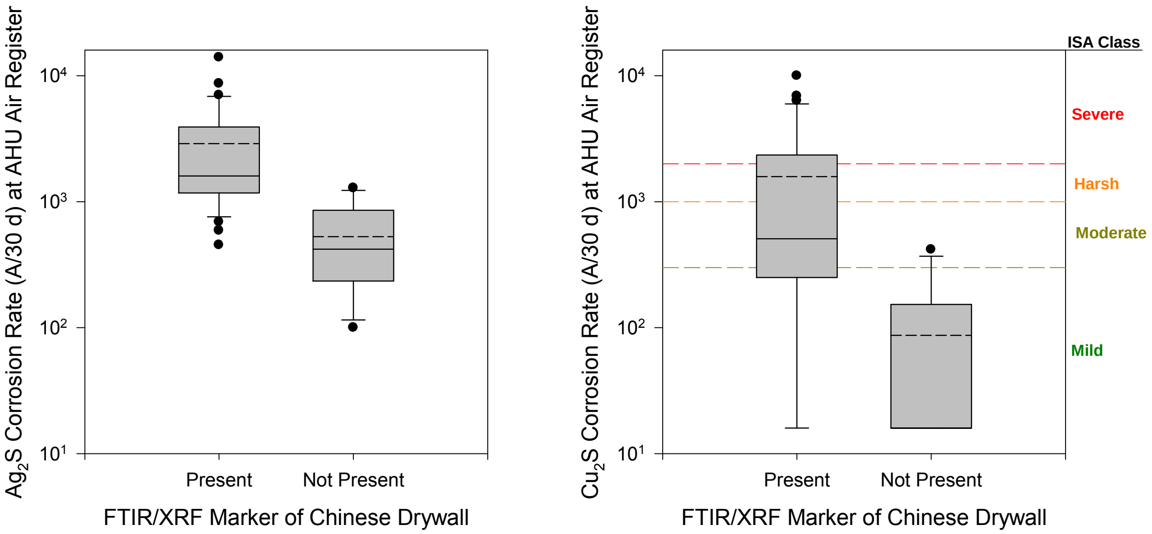
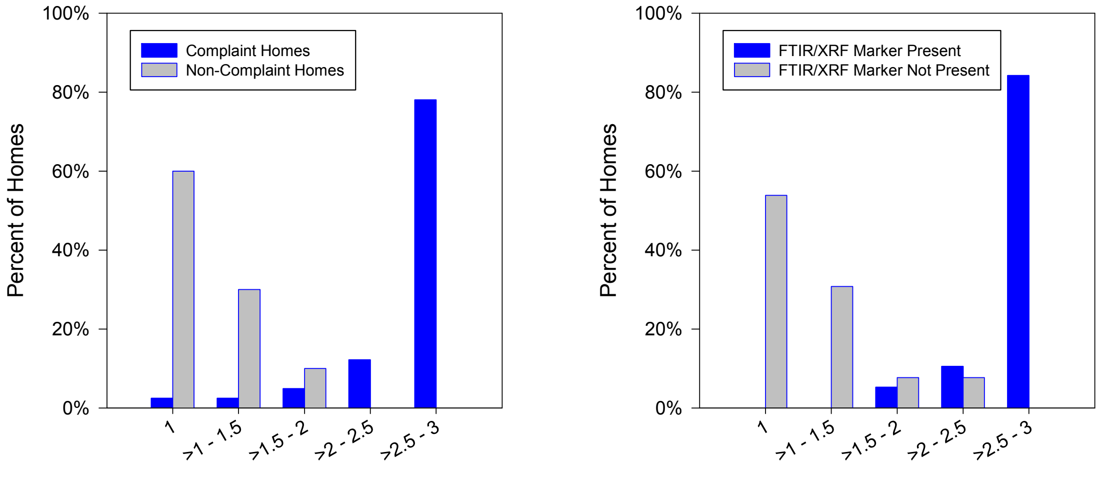


Figure 5.8 Comparison of Corrosion Film Thickness by FTIR/XRF Marker

5.2.5 Corrosion Determined by Visual Inspection

EH&E field technicians conducted inspections throughout the home and classified corrosion rates on various surfaces based on a three point scale: 1 = no visible corrosion; 2 = some visible corrosion; 3 = severe corrosion. Complete details of the corrosion scale with example photographs can be found in the Methods Section (Section 4).

Mean ground wire corrosion ratings for each home were compared based on CPSC home status (e.g., complaint or non-complaint) and FTIR/XRF marker. Complaint homes had a statistically significant greater mean ground wire corrosion rating than non-complaint homes (Figure 5.9).



Distribution of Mean Ground Wire Corrosion Rating by CPSC Status

Distribution of Mean Ground Wire Corrosion Rating by FTIR/XRF Marker

Figure 5.9 Comparison of Mean Ground Wire Corrosion Rating by CPSC Home Status

5.2.6 Comparison of Corrosion by Study Region

Corrosion rates at the AHU air register were compared across the four major regions in the field study—Florida east coast, Florida west coast, Gulf Coast, Virginia (Figure 5.10). Only for corrosion measured at the AHU air register, both silver and copper corrosion were found to be significantly higher in the Florida East region compared to Virginia ($p<0.01$), with the model accounting for a relatively small amount of variability in corrosion overall (R^2=0.15;0.20).

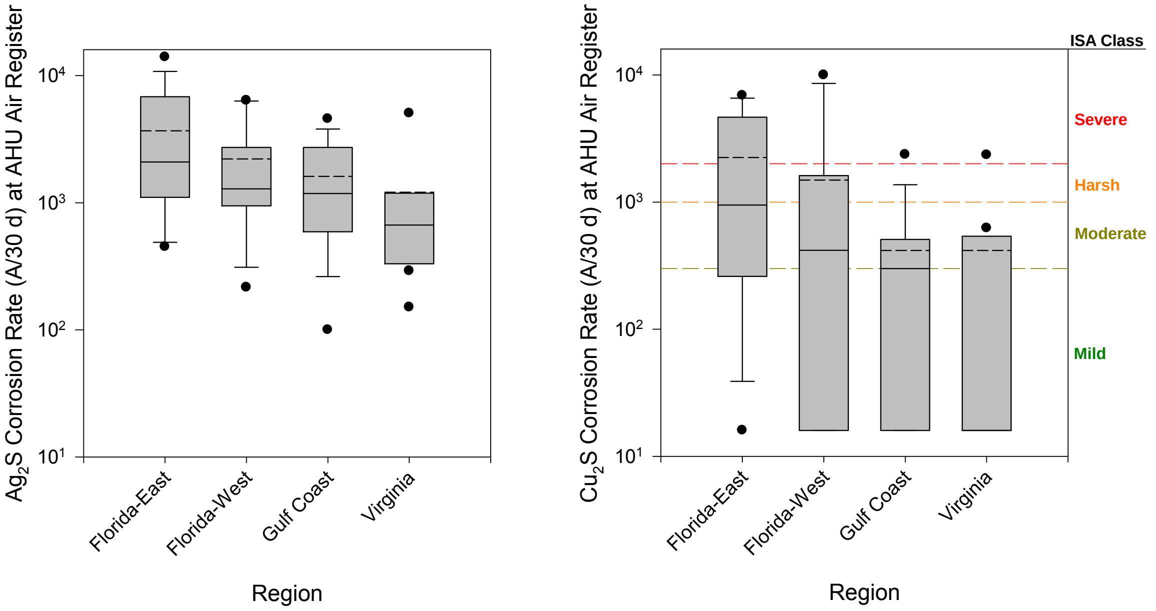


Figure 5.10 Comparison of Corrosion Film Thickness Across Study Regions

We examined potential explanatory variables to investigate the basis for the differences in corrosion rates observed across regions for the AHU air register. Contrary to the findings observed for corrosion at the AHU air register (Figure 5.10), there were no differences in room-level corrosion (e.g., bedroom, office) across the study regions. Additionally, there were no differences in the visual inspection of ground wire corrosion by region. The ground wire corrosion rating is a useful marker of long-term corrosion, although it will not be able to provide information on corrosion rate such as can be gathered through use of long-term coupons in the homes. The difference observed between coupons placed at the AHU air register and lack of a difference between 1) regions for room-level corrosion measured by corrosion coupons and 2) longer-term corrosion ascertained by visual inspection of ground wires suggest that the AHU supply air register corrosion differences by region are due to short-term environmental differences at the various AHU air registers that may not be reflective of the environment in the whole house. One plausible explanation is related to the ambient temperature during the sampling period by region; the maximum outdoor temperature during the sampling period in the Florida regions ranged from 91 – 97 (mean = 94), while the maximum outdoor temperature in Virginia ranged from 83 – 90 (mean = 84), with all homes in Virginia visited during the same 2-week period (Figure 5.11). The higher ambient air temperatures in the Florida regions would be associated with greater AHU-load, resulting in a consistently lower temperature and greater air flow and deposition velocity (V_{dep}) at the AHU air register where greater corrosion rates were observed (see Section 6.4.2 for discussion of V_{dep}).

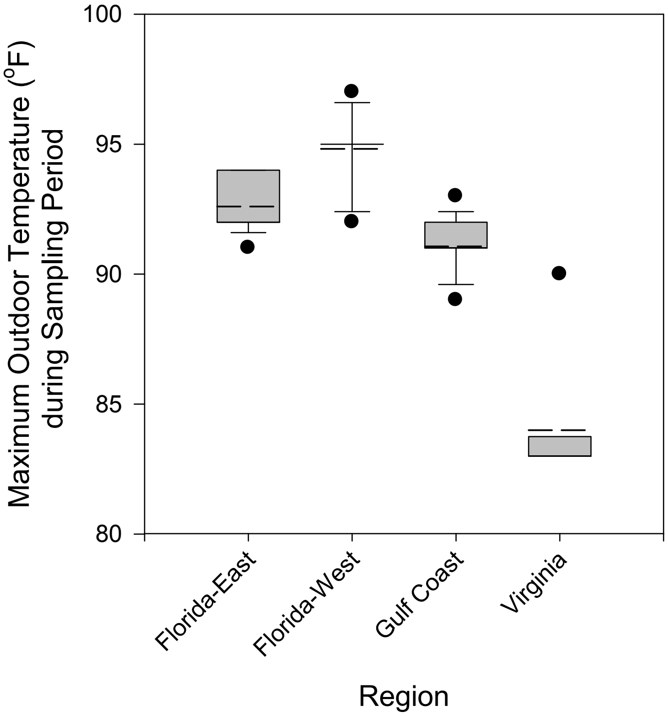


Figure 5.11 Maximum Outdoor Temperature During the Sampling Period for Each Region

5.3 AIR SAMPLING RESULTS

Air sampling results are divided by target analyte group in the following sections. For each analyte group, summary statistics for each home are presented in the Appendix tables and a comparison of house average results is made by the CPSC home status. Results for select analytes are then compared against corrosion rates.

5.3.1 Aldehydes via Active Sampling

Summary statistics for aldehyde concentrations by home are presented in Appendix A (Table A.4). Indoor concentrations of aldehydes generally exceeded outdoor concentrations by an order of magnitude.

5.3.1.1 Aldehyde Concentrations by House Status

Aldehyde concentrations ($\mu g/m^3$) in indoor air stratified by the CPSC home status are presented in Table 5.4. The mean, median and 75th percentile values show the complaint and non-complaint homes are comparable.

Table 5.4 House Average Aldehyde (Active Sampler) Concentrations ($\mu g/m^3$) in Indoor Air by House Status

Component	Status	Pct Detect	Mean	Min	p25	Median	p75	Max
Acetaldehyde	Complaint	91.3	36.9	7	24.9	32.7	48.4	138.3
	Non-complaint	97.4	30.7	8.4	17.3	28.9	43.3	52.5
Benzaldehyde	Complaint	78.3	8	2.7	5.2	7.4	9.8	21.7
	Non-complaint	78.9	7.1	3.3	4.3	6.5	9.3	14.3
Butyraldehyde	Complaint	75.2	4.8	0.7	2.9	4	5.9	18.5
	Non-complaint	78.9	4.7	1.2	2.4	4	6.2	11.7
Crotonaldehyde	Complaint	0.6	0.6	0.5	0.5	0.5	0.5	2.2
	Non-complaint	0	0.5	0.5	0.5	0.5	0.5	0.5
Dimethylbenzaldehyde	Complaint	6.8	0.7	0.5	0.5	0.5	0.5	5.7
	Non-complaint	10.5	0.6	0.5	0.5	0.5	0.5	1.3
Formaldehyde	Complaint	96.3	83.5	21.7	48.7	59.4	97.3	361.7
	Non-complaint	97.4	62.4	27.7	40.7	58.9	74.7	128.4
Isovaleraldehyde	Complaint	55.3	1.5	0.5	0.9	1.4	2.2	4
	Non-complaint	44.7	1.3	0.5	0.5	0.9	2.1	2.5
Propionaldehyde	Complaint	76.4	4.6	1	2.6	3.8	5.4	12.2
	Non-complaint	73.7	4.2	0.8	2.2	3.3	4.6	14
Valeraldehyde	Complaint	76.4	11.4	2	5.6	9.2	14.5	46
	Non-complaint	78.9	9.6	2.6	6.5	8.8	12	18.7
m,p-Tolualdehyde	Complaint	0	1	0.9	1	1	1	1.1
	Non-complaint	0	1	0.9	1	1	1	1
n-Hexaldehyde	Complaint	77	45.8	6.4	21.1	34.7	59	173.3
	Non-complaint	78.9	39.4	7.7	24.2	38.4	42.3	96.5
o-Tolualdehyde	Complaint	0	0.5	0.5	0.5	0.5	0.5	0.5
	Non-complaint	0	0.5	0.5	0.5	0.5	0.5	0.5

$\mu g/m^3$	micrograms per cubic meter
pct	percent
min	minimum
p	percentile
max	maximum

Note: sample size is 41 for complaint; 10 for non-complaint

5.3.1.2 Aldehyde Concentrations and Corrosion

Formaldehyde concentrations from the active sampling program were compared against silver and corrosion rates (Figure 5.12).

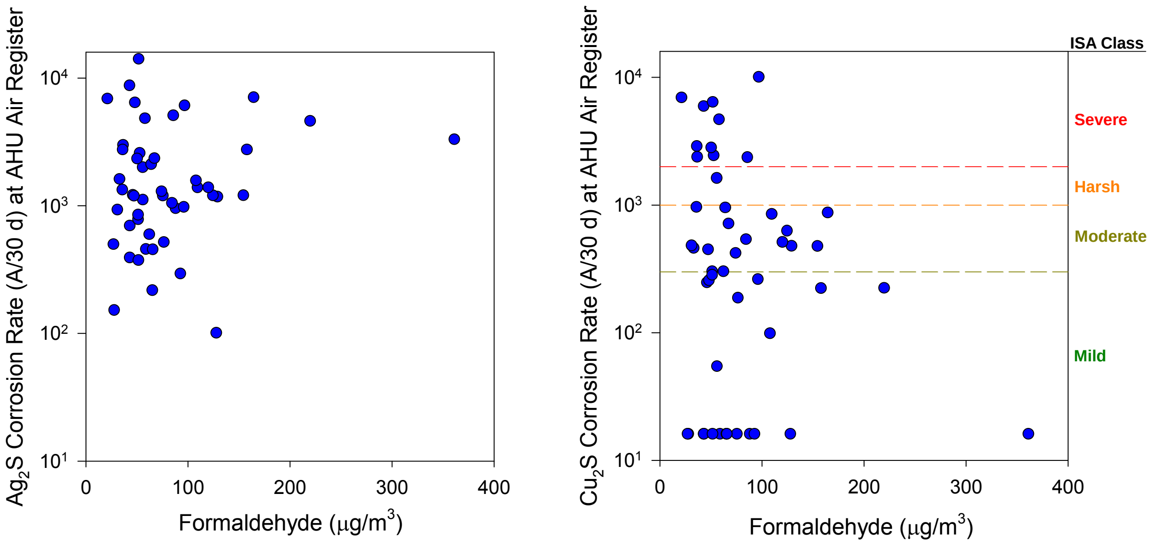


Figure 5.12 Comparison of Corrosion Film Thickness by Formaldehyde Concentration

5.3.2 Aldehydes Via Passive Sampling

Aldehyde concentrations were measured in a second set of samples using passive sampling techniques. The passive samplers were used because they provide lower detection limits due to a longer sampling period and the fact that they would be measuring the concentrations of aldehydes in the air that the passive samplers were exposed to over the two-week integration period which was also coincident with the corrosion coupon deployment. Results of the aldehyde concentrations collected on passive monitors for each home are reported in Appendix A (Table A.5).

5.3.2.1 Aldehyde Concentrations by House Status

Aldehyde concentrations measured using the passive monitors are presented by the CPSC house status in Table 5.5.

Table 5.5 House Average Aldehyde (Passive Sampler) Concentrations ($\mu g/m^3$) in Indoor Air by House Status

Component	Status	Pct Detect	Mean	Min	p25	Median	p75	Max
Acetaldehyde	Complaint	93	9.6	0.7	5.5	9.9	12.5	21.8
	Non-complaint	100	11.5	5.4	8.1	12.3	14	19.4
Acrolein	Complaint	47	3	0.8	1	2.9	4.1	8
	Non-complaint	60	3.2	0.8	2.3	3.1	4.6	5.4
Benzaldehyde	Complaint	76	2.6	1.3	1.9	2.7	3.3	4.2
	Non-complaint	75	2.3	1.3	2.1	2.4	2.6	3.4
Butanal	Complaint	94	24.5	2.7	16.3	22.1	26.2	98.2
	Non-complaint	100	29.1	9.5	20.9	31.4	33.5	56.8
Formaldehyde	Complaint	100	54.2	22.5	47.4	52.8	62.6	85.6
	Non-complaint	100	44	27.6	32.5	41.7	54.6	64.7
Isovaleraldehyde	Complaint	12	0.7	0.4	0.5	0.5	1	1.8
	Non-complaint	15	0.7	0.5	0.5	0.5	0.7	1.3
Propionaldehyde	Complaint	68	3	0.7	1.5	3.2	4	7.8
	Non-complaint	98	4.1	2.2	2.8	3.6	5.6	6.7
Valeraldehyde	Complaint	94	25.8	4.7	16.6	25	34	46.4
	Non-complaint	98	26.8	8.4	13.4	25	40.5	50
nHexaldehyde	Complaint	100	134.1	24.3	81.3	118.7	178.9	316.9
	Non-complaint	100	138.1	27.5	61.9	135.7	175.9	340.1

$\mu g/m^3$	micrograms per cubic meter
pct	percent
min	minimum
p	percentile
max	maximum

Note: sample size is 41 for complaint; 10 for non-complaint

5.3.2.2 Aldehyde Concentrations and Corrosion

Aldehydes concentrations measured using passive monitors were compared to silver and copper corrosion. Results for formaldehyde are presented in Figure 5.13.

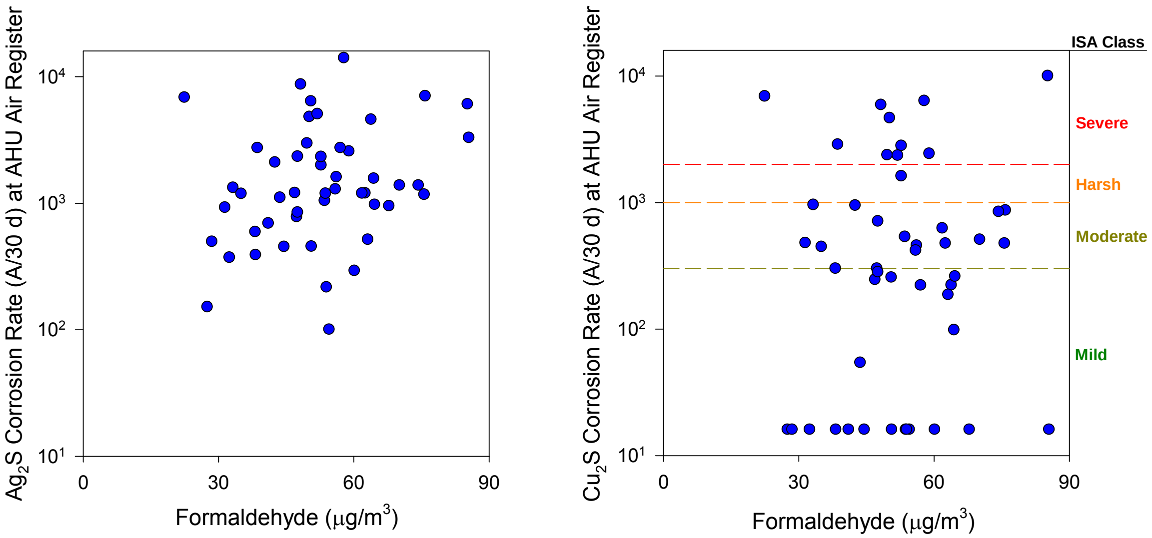


Figure 5.13 Comparison of Corrosion Rates at the AHU Air Register by House Average Formaldehyde Concentration Measured Using 2-week Passive Monitors

5.3.3 Reduced Sulfur Gases via Grab Sampling

The majority of samples collected in the homes using grab sample methods had reduced sulfur concentrations less than the reporting limit for the analytical method (see Section 4 for reporting limits). Only 9 samples were above the reporting limit for carbon disulfide (max concentration = 12 $\mu g/m^3$; reporting limit = 7.8 $\mu g/m^3$). The 9 detected samples came from 4 homes, 3 of which were located within the same neighborhood. Carbonyl sulfide was also detected in one reduced sulfur sample (concentration = 13 $\mu g/m^3$; reporting limit = 12 $\mu g/m^3$).

5.3.4 Hydrogen Sulfide, Ozone, Nitrogen Dioxide, Sulfur Dioxide, Hydrofluoric Acid (Passive Sampling)

Concentrations for analytes collected using passive monitors with low limits of detection and two-week integration periods are reported for each home (Appendix A, Table A.6).

5.3.4.1 H_2S, O_3, NO_2, SO_2, HF by House Status

House average concentrations (parts per billion [ppb]) of analytes collected over a two-week integration period are presented by the CPSC home status in Table 5.6.

Table 5.6 House Average Concentrations (ppb) of Analytes Collected Using Passive Samplers

Analyte	Status	Pct Detect	Mean	Min	p25	p50	p75	Max
Hydrogen sulfide	Complaint	65.8	0.66	0.19	0.29	0.59	0.88	2.23
	Non-complaint	37.5	0.45	0.2	0.22	0.23	0.28	2.23
Ozone	Complaint	25.9	0.36	0.3	0.33	0.34	0.36	0.92
	Non-complaint	25	0.34	0.31	0.33	0.34	0.36	0.36
Nitrogen dioxide	Complaint	97.5	2.6	0.06	0.7	1.09	3.67	12.49
	Non-complaint	100	4.42	0.89	1.77	2.15	5.03	18.67
Sulfur dioxide	Complaint	0	NA	NA	NA	NA	NA	NA
	Non-complaint	2.6	1.44	1.34	1.36	1.41	1.46	1.73
Hydrogen fluoride	Complaint	0	NA	NA	NA	NA	NA	NA
	Non-complaint	0	NA	NA	NA	NA	NA	NA

ppb	parts per billion
pct	percent
min	minimum
p	percentile
max	maximum
NA	not applicable

Note: sample size is 41 for complaint; 10 for non-complaint

5.3.4.2 H_2S, O3, NO_2, SO_2, HF and Corrosion

Hydrogen sulfide and nitrogen dioxide concentrations were compared to rates of silver and copper corrosion (Figure 5.14).

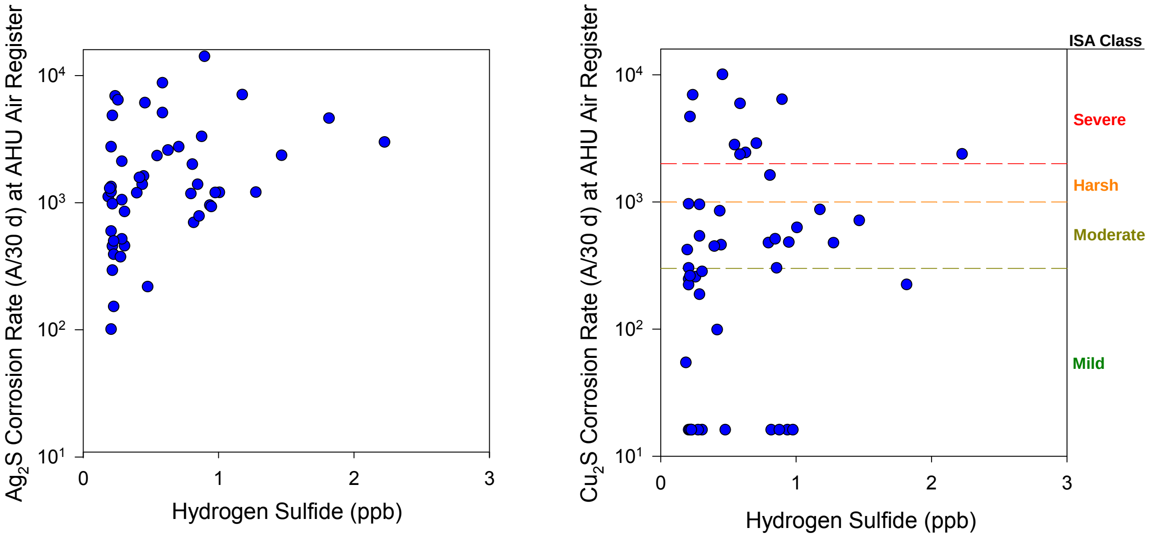


Figure 5.14a Comparison of Corrosion Rates at the AHU Air Register by House Average Hydrogen Sulfide Concentration Measured Using 2-week Passive Monitors

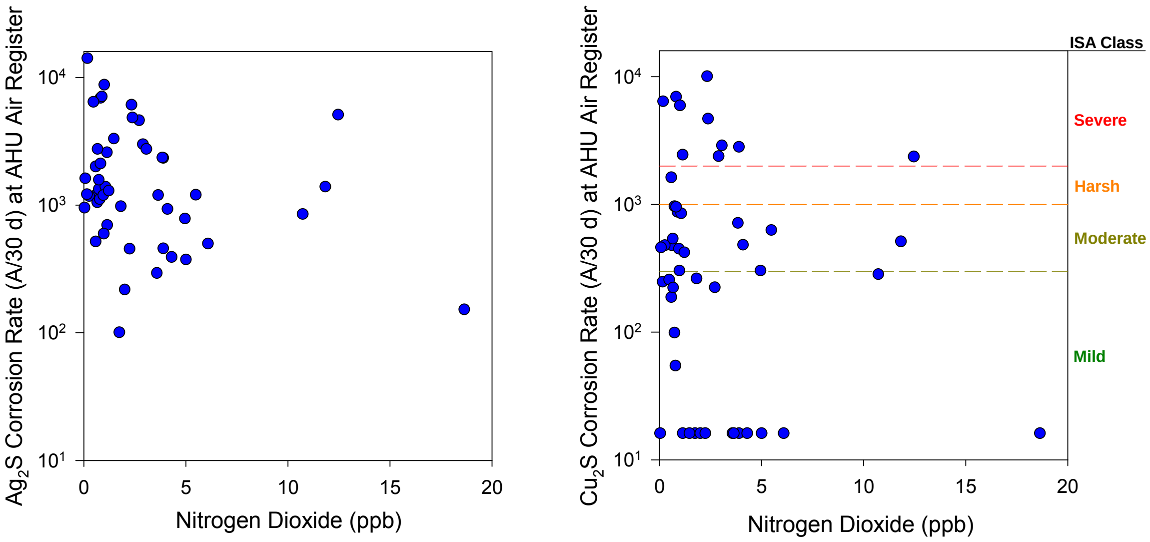


Figure 5.14b Comparison of Corrosion Rates at the AHU Air Register by House Average Nitrogen Dioxide Concentration Measured Using 2-week Passive Monitors

5.3.5 Volatile Organic Compounds

Summary statistics of VOC concentrations (µg/m^3) in indoor and outdoor air are presented in Appendix A, Table A.7.

5.3.5.1 VOCs by House Status

House average concentrations for select VOCs in indoor air stratified by the CPSC house status are presented in Table 5.7. Several VOCs show elevated concentrations in complaint homes (n=26) compared to non-complaint homes (n=5). Statistical comparisons are currently limited due to the small sample size of non-complaint homes with VOC samples.

Table 5.7 House Average VOC Concentrations ($\mu g/m^3$) in Indoor Air by House Status

Component	Status	Pct Detect	Mean	Min	p25	Median	p75	Max
1,1,2-Trichlorotrifluoroethane	Complaint	96	0.57	0.06	0.51	0.57	0.64	0.74
	Non-complaint	85	0.56	0.14	0.49	0.67	0.73	0.78
1,2,4-Trimethylbenzene	Complaint	70	6.97	0.31	2.58	5.01	9.48	28.83
	Non-complaint	65	5.44	0.62	0.93	5.05	6.42	14.17
2-Butanone (MEK)	Complaint	96	7.88	0.31	4.51	5.73	10.5	29.5
	Non-complaint	95	11.52	3.22	3.57	4.48	8.35	38
2-Propanol (Isopropyl Alcohol)	Complaint	87	66.38	0.31	7.62	13.85	92.75	355
	Non-complaint	75	11.42	5.45	6.26	9.93	11.47	24
Acetone	Complaint	95	112.17	3.05	64.75	115	155	220
	Non-complaint	85	74.75	41.5	55.9	80.67	85	110.67
Acetonitrile	Complaint	82	134.03	0.36	58.25	107.54	233.33	265
	Non-complaint	89	141.56	58	58	76.67	290	290
Acrolein	Complaint	91	5.88	0.31	4.08	5.51	6.98	14.67
	Non-complaint	95	4.38	1.62	2.77	5.5	5.87	6.13
Benzene	Complaint	95	5.88	0.06	1.38	2.92	7.85	30.83
	Non-complaint	85	4.27	0.27	0.4	2.07	4.45	14.17
Carbon Disulfide	Complaint	55	1.76	0.31	0.52	1.31	2.3	9.1
	Non-complaint	25	0.57	0.31	0.31	0.39	0.69	1.15
Carbon Tetrachloride	Complaint	95	0.61	0.06	0.48	0.57	0.67	1.23
	Non-complaint	85	0.48	0.13	0.45	0.59	0.62	0.62
Chloroform	Complaint	80	1.9	0.06	0.32	1.01	2.55	9.23
	Non-complaint	70	1.08	0.3	0.43	1.06	1.66	1.97
Chloromethane	Complaint	93	1.19	0.06	0.72	0.87	1.1	9.67
	Non-complaint	70	0.47	0.06	0.19	0.53	0.68	0.88
Ethanol	Complaint	90	1106.18	3.05	131.67	389.17	1450	5066.67
	Non-complaint	80	362.61	100.5	235.9	328.33	421.67	726.67
Ethyl Acetate	Complaint	71	10.22	0.31	1.88	4.88	9.82	58
	Non-complaint	75	7.51	2.09	3.37	6.23	6.35	19.5
Ethylbenzene	Complaint	66	6.4	0.31	1.68	5.04	7.6	24.67
	Non-complaint	60	4.47	0.59	1.09	4.47	6.27	9.95
Styrene	Complaint	71	3.53	0.31	1.81	2.98	4.28	10
	Non-complaint	65	1.85	0.52	1.28	1.47	1.68	4.28
Toluene	Complaint	91	32.77	0.31	14.17	21.03	42	124.67
	Non-complaint	70	20.91	1.62	5.45	21.67	28	47.83
Trichlorofluoromethane	Complaint	97	1.4	0.06	1.25	1.42	1.55	2.2
	Non-complaint	85	1.14	0.25	1.18	1.3	1.4	1.55
α-Pinene	Complaint	87	88.47	0.31	36.25	77.58	116.67	235
	Non-complaint	80	53.08	7.92	30.67	52.33	83.83	90.67
d-Limonene	Complaint	79	25.86	0.31	15	24.63	39.5	57
	Non-complaint	65	12.09	5.09	7.2	14.83	15.17	18.17
m,p-Xylenes	Complaint	81	20.5	0.31	6.93	14.46	24.17	82.5
	Non-complaint	65	14.46	1.92	2.92	14.63	19.5	33.33
n-Butyl Acetate	Complaint	73	4.87	0.31	1.68	3.22	5.07	26.33
	Non-complaint	65	2.7	0.54	1.81	3.05	3.17	4.95
n-Heptane	Complaint	67	4.66	0.31	1.55	3.03	5.9	25.67
	Non-complaint	50	3.05	0.31	0.61	1.08	3.38	9.85

Table 5.7 Continued

Component	Status	Pct Detect	Mean	Min	p25	Median	p75	Max
n-Hexane	Complaint	73	10.28	0.31	1.05	5.08	12.65	71.33
	Non-complaint	50	6.14	0.31	0.47	1.62	9.15	19.17
n-Octane	Complaint	71	2.25	0.31	1.25	1.6	2.23	12.67
	Non-complaint	70	1.91	0.42	0.77	1.05	2.05	5.27
o-Xylene	Complaint	67	7.34	0.31	1.43	5.23	9.09	27.83
	Non-complaint	65	4.69	0.83	1.07	4.93	5.07	11.53

$\mu g/m^3$	micrograms per cubic meter
pct	percent
min	minimum
p	percentile
max	maximum

Note: sample size is 26 for complaint; 5 for non-complaint

The results presented in Table 5.7 suggest that one reduced sulfur compound, carbon disulfide, may be slightly elevated in complaint homes compared to non-complaint homes. Boxplots comparing summary statistics for carbon disulfide by the CPSC home status and FTIR/XRF marker is presented in Figure 5.15. In statistical models (n=29), a significant difference in house average carbon disulfide concentrations was not observed by CPSC status (p=0.26) or by FTIR/XRF marker (p=0.26) after controlling for outdoor carbon disulfide concentrations and study region (see Table 5.10). Statistical inference is limited due to the small sample size.

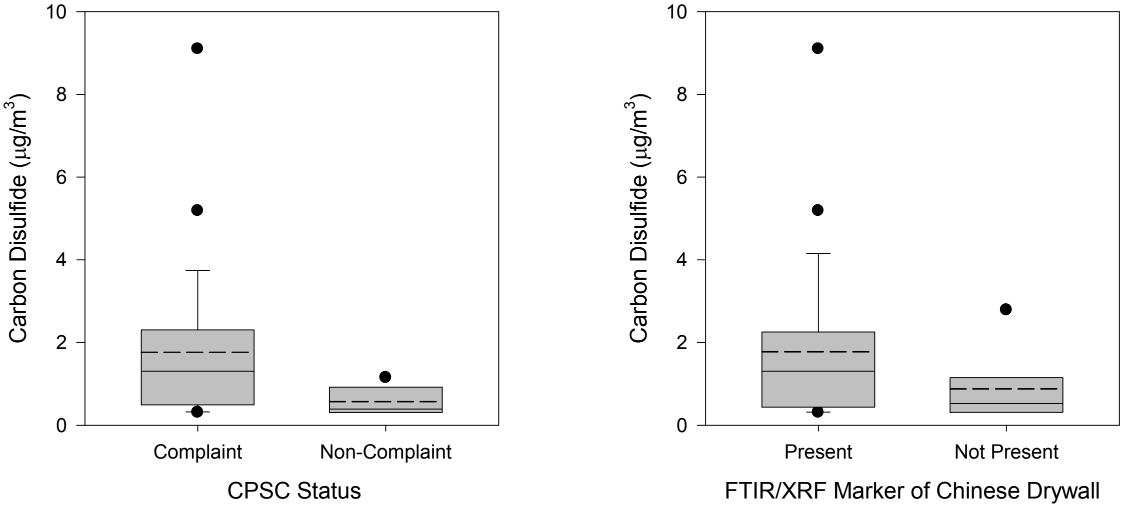


Figure 5.15 Boxplots of House Average Carbon Disulfide Concentrations by CPSC Home Status

5.3.5.2 Selected VOCs and Corrosion

Carbon disulfide concentrations were also compared against silver and copper corrosion rates in the home.

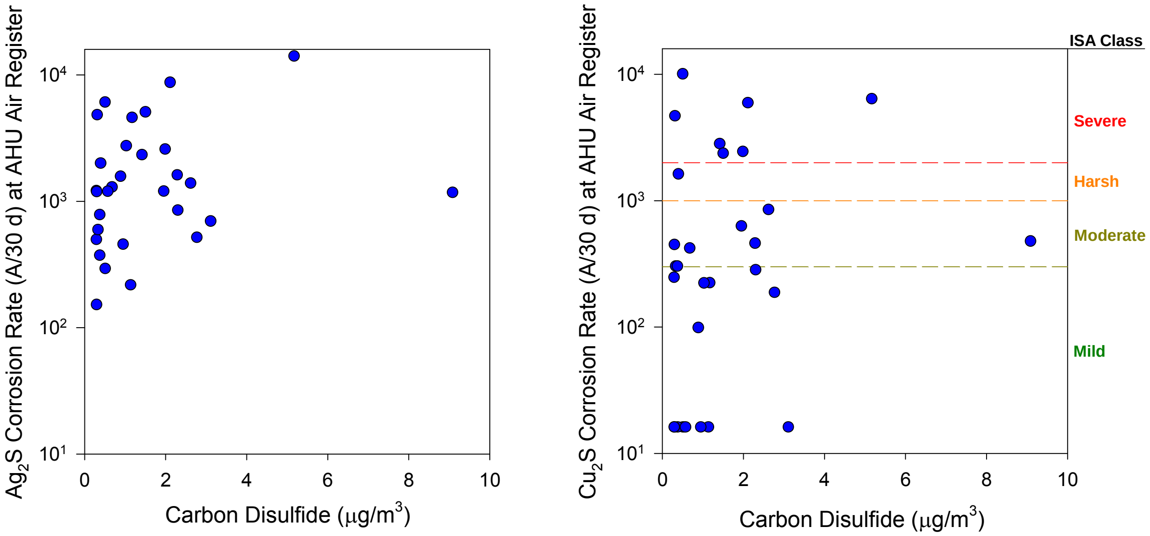


Figure 5.16 Comparison of Corrosion Film Thickness at the AHU Air Register by House Average Carbon Disulfide Concentration

5.3.6 Organic and Inorganic Acids

Only three of the acids sampled and analyzed for had values above the limit of detection. Summary statistics for the detected acids in indoor and outdoor samples are presented in Appendix A, Table A.8.

5.3.6.1 Acids by House Status

Results for the two organic acids and one inorganic acid that were found above the detection limit are presented in Table 5.8 by the CPSC house status. Concentrations of the acids appear similar in complaint and non-complaint homes, but inference is limited due to low percent detects for formic acid and hydrofluoric acid.

Table 5.8 House Average Acid Concentrations (ppb) in Indoor Air by House Status

Component	Status	Pct Detect	Mean	Min	p25	Median	p75	Max
Acetic Acid	Complaint	51	99	9	41	60	119	440
	Non-complaint	51	67	17	42	55	98	137
Formic Acid	Complaint	26	11	4	4	7	18	35
	Non-complaint	23	9	4	4	6	13	20
Hydrofluoric Acid	Complaint	8	25	16	19	20	21	94
	Non-complaint	0	NA	NA	NA	NA	NA	NA

ppb	parts per billion
pct	percent
min	minimum
p	percentile
max	maximum
NA	not applicable

Note: sample size is 41 for complaint; 10 for non-complaint

5.3.7 Home Characteristics

5.3.7.1 Air Exchange Rate

Air exchange rates, in units of air changes per hour (ACH), are presented for each home in Appendix A, Table A.9. Short-term, house average air exchange rates ranged from 0.05 – 0.8 ACH (median 0.19), indicating that the majority of these homes were tightly sealed homes with low ventilation rates.

5.3.7.1.1 Air Exchange Rate by House Status

Short-term, house average air exchange rates were compared by the CPSC house status and found to be similar between complaint and non-complaint homes, with status explaining only 6% of the variability in air exchange rate (mean air exchange rate 0.18 v. 0.24 ACH; p=0.09; R^2=0.06) (Figure 5.17). Similar findings were observed when using FTIR/XRF marker in place of the CPSC house status (p=0.26, R^2=0.03).

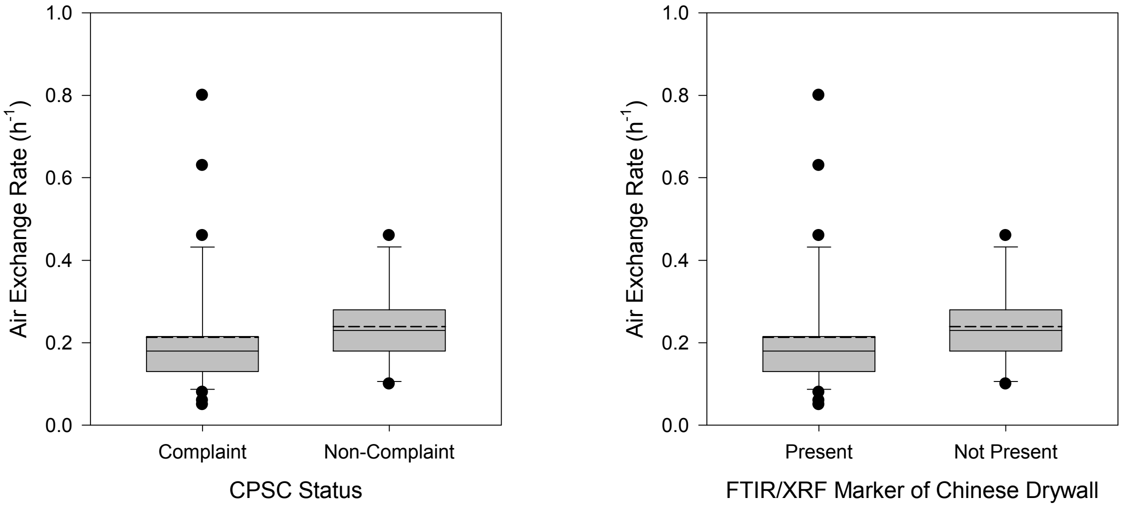


Figure 5.17 Comparison of Short-term, House Average Air Exchange Rates by CPSC House Status and FTIR/XRF Status

5.3.7.1.2 Air Exchange Rate v. Corrosion

A comparison of air exchange rates and silver and copper corrosion is presented in Figure 5.18.

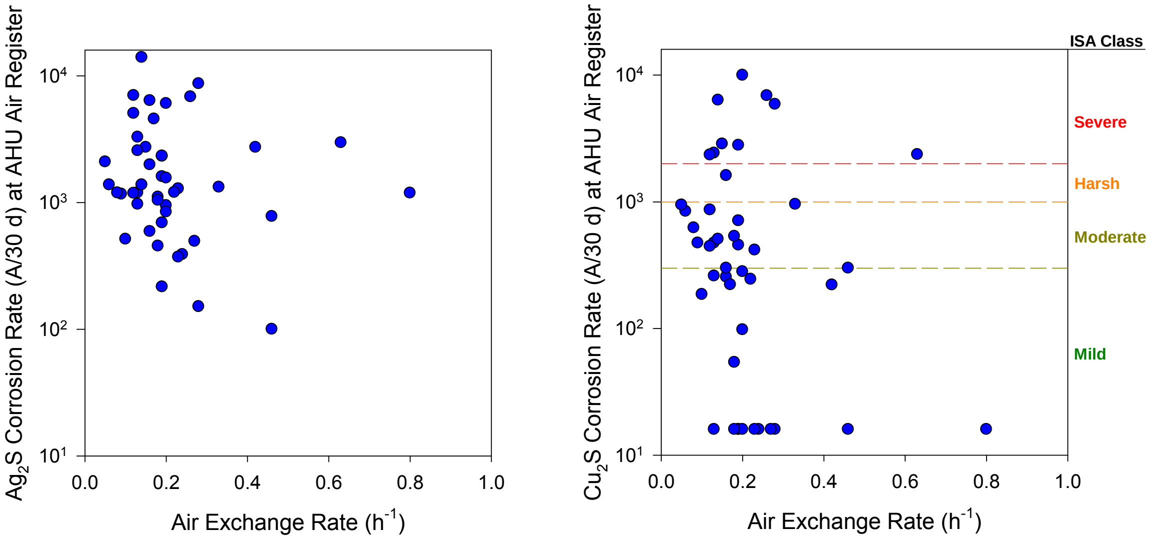


Figure 5.18 Comparison of Corrosion Film Thickness at the AHU Air Register by Air Exchange Rate

5.3.7.2 Temperature and Dew Point

Temperature and dew point values were averaged over the two-week passive sampling period. The two-week average values are reported for each home in Appendix A (Table A.10). Two-week average temperature ranged from 71 – 87 °F (median = 77 °F), and two-week average dew point ranged from 50 – 74 (median = 58) for individual homes. An examination of hourly average temperature over the two-week period showed some homes with stable temperature ranges and others with diurnal patterns, reflecting the use patterns of air handling devices to maintain stable temperature in the home. Certain unoccupied study homes may have had their AHUs off during a portion or all of the sampling periods and would account for the extreme high values in the range noted above.

5.3.7.2.1 Temperature and Dew Point by House Status

Temperature and dew point results were stratified by the CPSC house status (Figure 5.19). Complaint homes demonstrated more between-home variability for both temperature and dew point than non-complaint homes. Again, this may be due to lack of consistent AHU use in vacant homes.

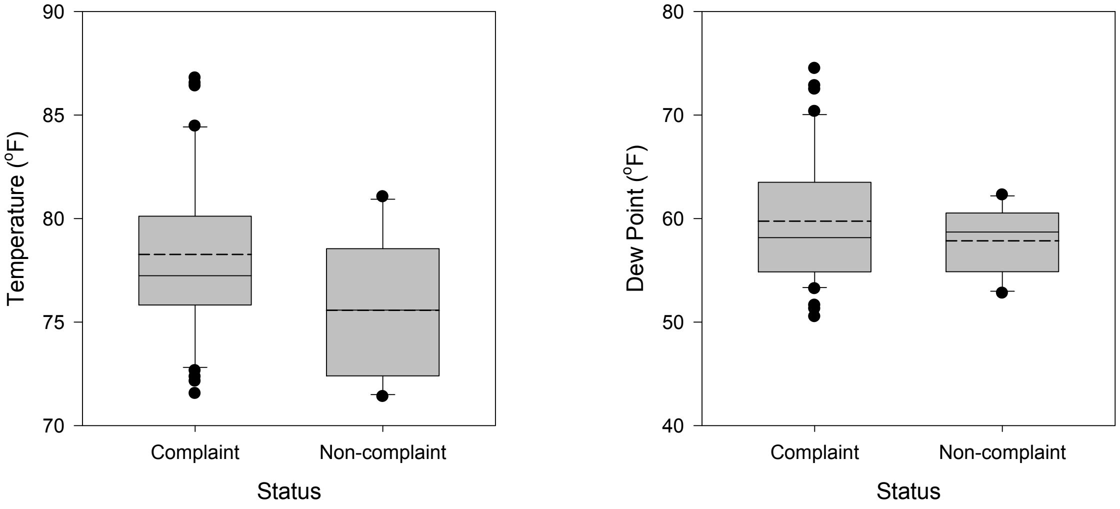


Figure 5.19 Boxplots of Indoor Temperature by CPSC Home Status

5.3.7.2.2 Temperature and Dew Point and Corrosion

Temperature and dew point were compared against silver and copper corrosion rates. A potential positive association was observed between temperature and silver corrosion rate at the AHU air register (Figure 5.20).

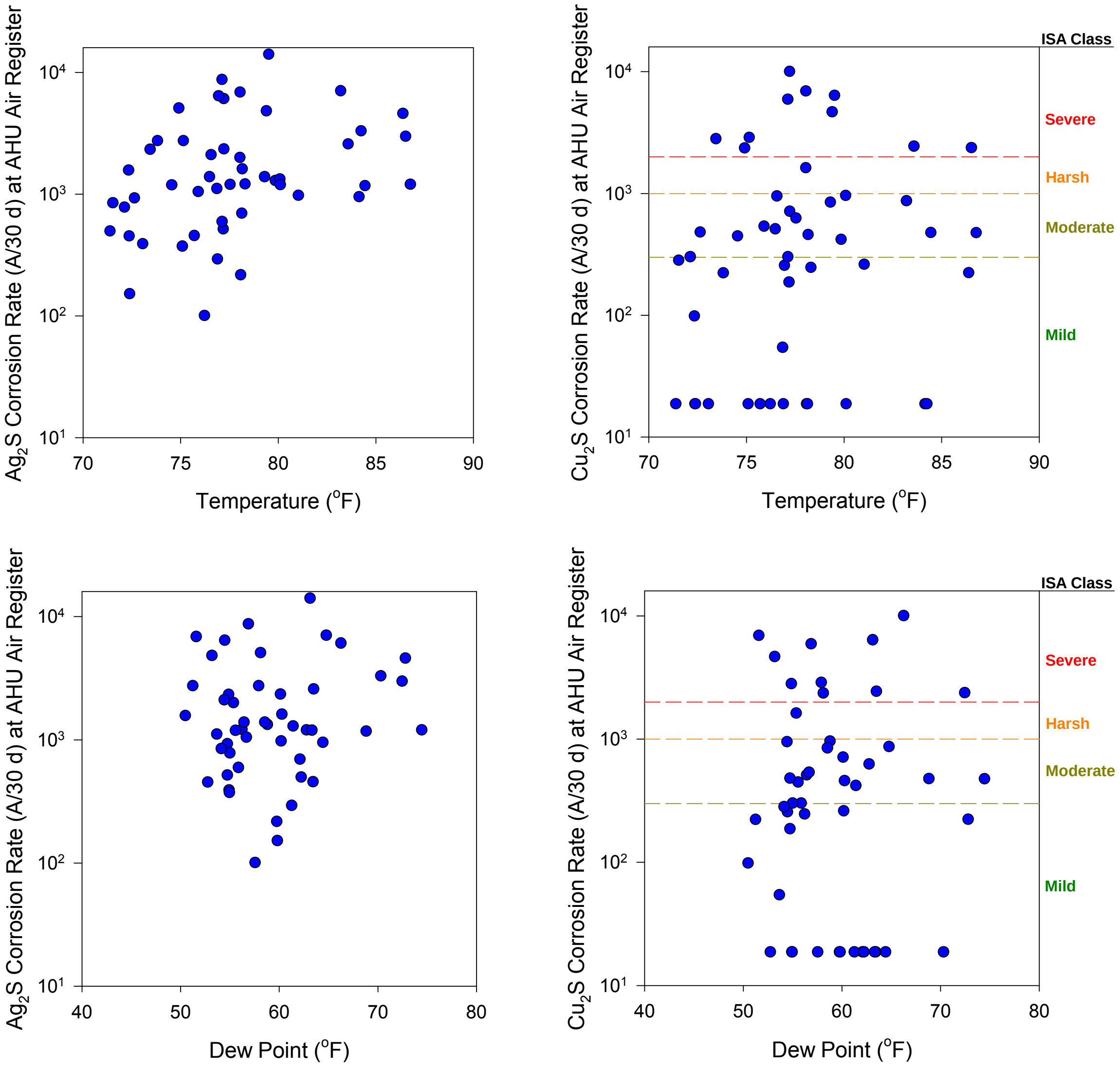


Figure 5.20 Comparison of Dry Bulb Temperature and Dew Point to Silver and Copper Corrosion Rates

5.3.8 Multivariate Modeling

Multivariate regression modeling was used to explore relationships between characteristics of drywall, constituents of indoor air, and corrosion observed for the homes in this investigation as reported in Section 5.2 while controlling for potential confounding and/or explanatory variables. The modeling aimed to address three questions:

1) Are reduced sulfur gases in indoor air associated with the presence of imported drywall (if so, what house characteristics/environmental conditions are associated with the presence of those compounds)?
2) Are corrosion rates associated with the presence of imported drywall?
3) Which compounds or house characteristics are associated with corrosion rates?

5.3.8.1 Reduced Sulfur Gases and Imported Drywall

5.3.8.1.1 Hydrogen Sulfide

A comparison of hydrogen sulfide concentration (ppb) by the CPSC home status and by FTIR/XRF marker is presented in Figure 5.21. In general, house average hydrogen sulfide concentrations in complaint homes appear to be higher than in non-complaint homes. However, there is considerable variability in the non-complaint homes driven by one home with elevated hydrogen sulfide concentrations.

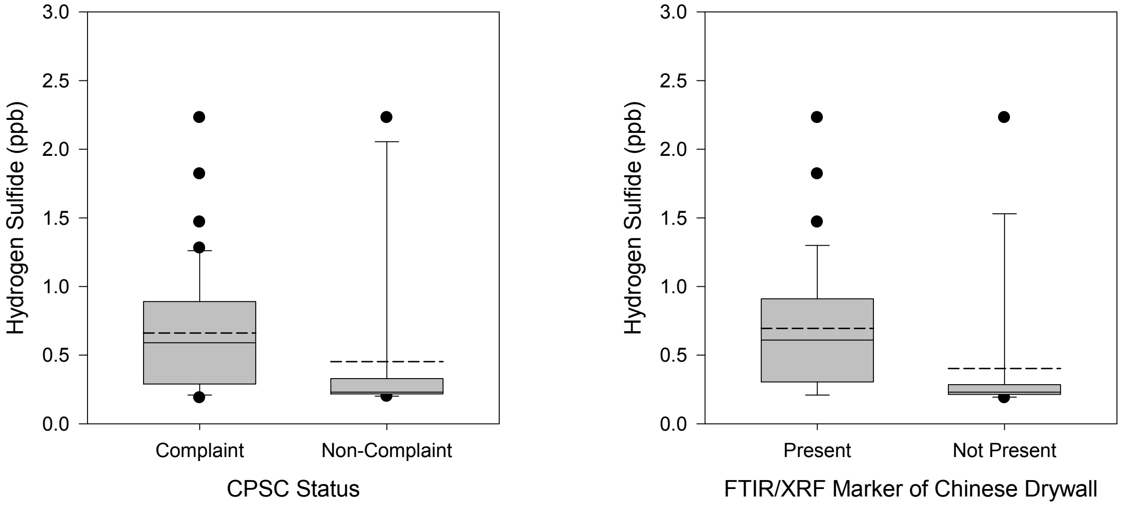


Figure 5.21 House Average Hydrogen Sulfide Concentration (ppb) by a) CPSC House Status, and b) FTIR/XRF Marker

House-average hydrogen sulfide concentrations were modeled as a function of house status while controlling for potential confounding variables. With a median concentration of 0.59 ppb, complaint homes, as determined by CPSC, had significantly ($p<0.05$) elevated concentrations of hydrogen sulfide (natural log-transformed) compared to homes with domestic drywall (median < reporting limit [0.35-0.50]) controlling for outdoor hydrogen sulfide concentrations, study region and dew point (Table 5.9). The hydrogen sulfide concentrations can be characterized as a dichotomous variable based on the presence or absence of the gas. Dew point was also a significant and positive predictor of indoor hydrogen sulfide concentrations in these homes ($p<0.01$) while outdoor hydrogen sulfide was not ($p=0.11$). (Potentially relevant variables such as air exchange rate and study region were not associated with concentrations of hydrogen sulfide in indoor air. Covariate selection was based on bivariate relationships evaluated at the $p<0.10$ level – see Methods Section for details). When the model was re-run with house status determined by FTIR/XRF, as opposed to CPSC status, status remained a significant predictor of hydrogen sulfide levels ($p<0.01$; $R^2=0.39$). Additionally, when these analyses are repeated with the one influential point removed (i.e., one non-complaint home with elevated hydrogen sulfide), the associations are further strengthened ($R^2=0.53$ [CPSC status]; 0.58 [FTIR/XRF marker]).

Table 5.9 Regression Model Results Showing Predictors of House Average Hydrogen Sulfide Concentrations (Natural log-transformed) in Indoor Air

Parameter	Estimate	Standard Error	p-value
Intercept	-4.39	0.93	<0.0001
FTIR/XRF Marker Present	0.52	0.19	0.009
FTIR/XRF Marker Not Present	–	–	–
Outdoor Hydrogen Sulfide (H_2S)	0.17	0.10	0.11
Dew Point	0.05	0.02	0.002

Model $R^2=0.39$

Dew point was a significant predictor of hydrogen sulfide concentrations in indoor air in the regression model. A scatterplot comparing hydrogen sulfide concentrations by dew point was made to further demonstrate the potential role of dew point as a modifying factor associated with the presence of hydrogen sulfide, stratifying by type of drywall as determined by FTIR/XRF marker (Figure 5.22).

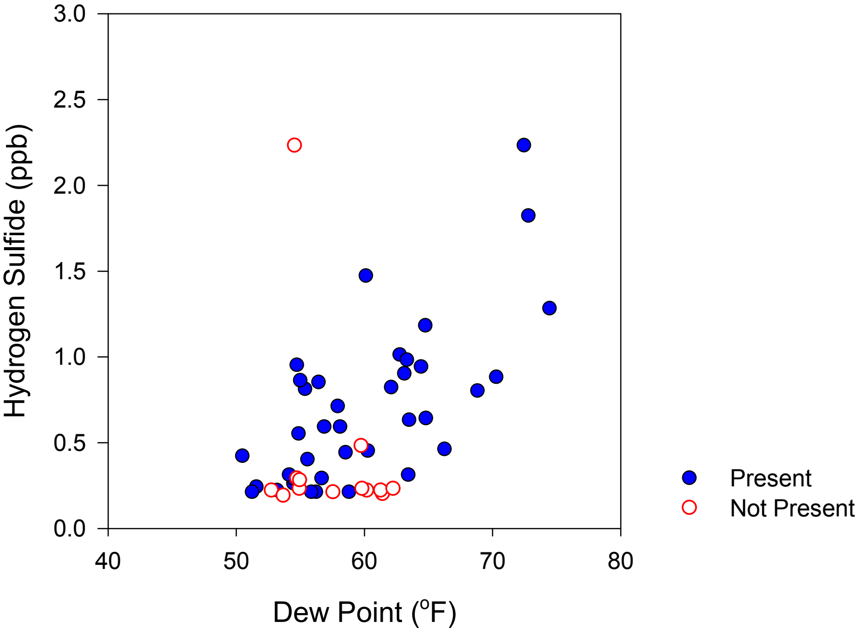


Figure 5.22 Scatterplot Comparing House Average Hydrogen Sulfide Concentration (ppb) by Dew Point, Stratified by Drywall Type as Determined by FTIR/XRF Marker

5.3.8.1.2 Carbon Disulfide

Carbon disulfide concentrations were elevated in CPSC complaint homes compared to non-complaint homes (Figure 5.15). Similar results were observed for house classification based on FTIR/XRF (Figure 5.23).

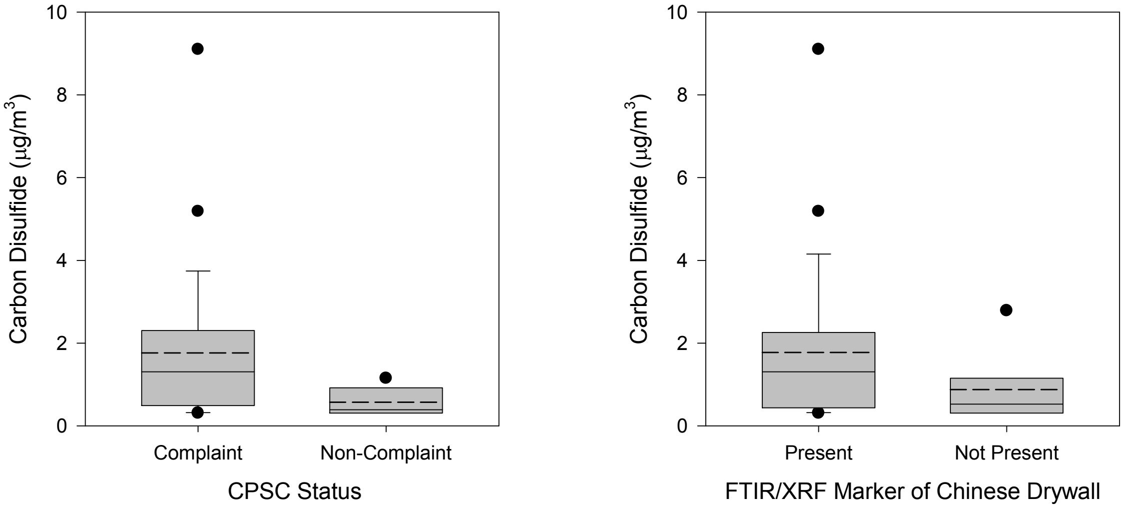


Figure 5.23 Boxplots of House Average Carbon Disulfide Concentrations by CPSC Home Status

House-average carbon sulfide concentrations were then modeled as a function of house status while controlling for potential confounding variables. Homes with imported drywall, as determined by FTIR/XRF, did not have significantly elevated concentrations of carbon disulfide (natural log-transformed) compared to homes with domestic drywall, on average, controlling for outdoor carbon sulfide concentrations and study region (p=0.29) (Table 5.10). This null finding is limited by the small sample size and resultant low power to see a difference between groups if one is present (Type II error). Similar results were obtained when CPSC status was modeled in place of the FTIR/XRF marker (p=0.25). Several parameters were significant predictors of indoor carbon disulfide concentrations on a bivariate basis (dew point p=0.08; temperature p=0.03) but could not be included in one regression model due to sample size (n=29).

Table 5.10 Regression Model Results Showing Predictors of House Average Carbon Disulfide Concentrations (Natural log-transformed) in Indoor Air

Parameter	Estimate	Standard Error	p-value
Intercept	-0.56	0.36	0.13
FTIR/XRF Marker Present	0.39	0.36	0.29
FTIR/XRF Marker (ref)	–	–	–
Region—Florida East	0.95	0.41	0.03
Region—Florida West	-0.15	0.41	0.73
Region—Gulf Coast	-0.33	0.44	0.45
Region—Virginia (ref)	–	–	–
Outdoor Carbon Disulfide (CS_2)	0.16	0.14	0.26

Model R^2=0.40

5.3.8.2 Corrosion Rates and Imported Drywall

Homes with imported drywall were found to have elevated rates of both silver and copper corrosion compared to homes with domestic drywall, as determined by FTIR/XRF (see Section 5.2.3; Figure 5.8 reproduced here as Figure 5.24).

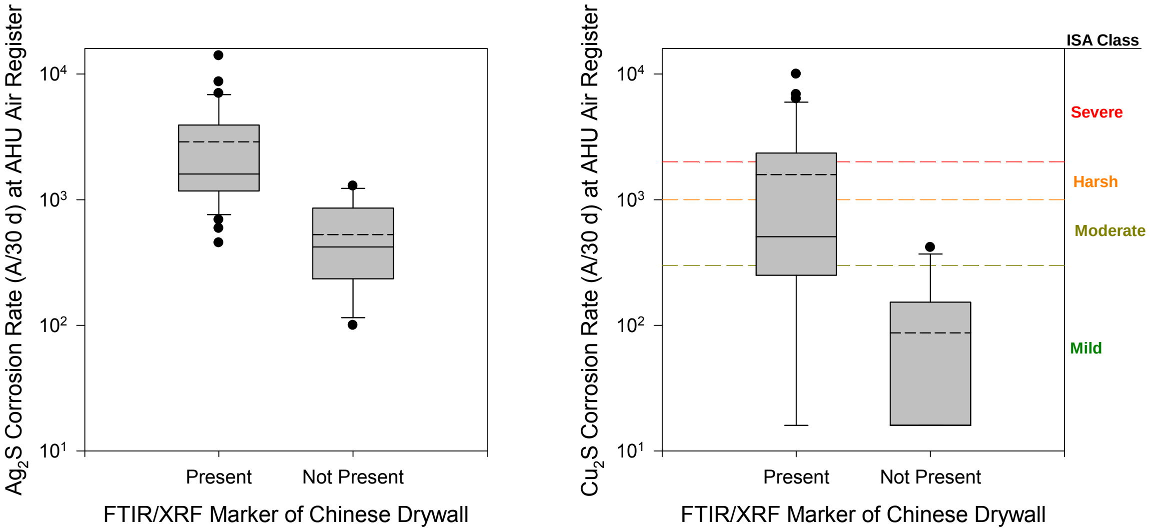


Figure 5.24 Comparison of Corrosion Film Thickness by FTIR/XRF Marker

To examine this relationship further, predictors of corrosion rates (natural log-transformed) at the AHU air register and in rooms were modeled. The findings from the bivariate analysis hold in regression models that control for corrosion rates outdoors, study region and indoor temperature (Tables 5.11 and 5.12); homes with imported drywall as determined by FTIR/XRF had elevated rates of silver and copper corrosion, on average ($p<0.001$). The variables explain 57% and 52% of the variability in silver and copper corrosion, respectively. In both models, the east coast of Florida region had significantly elevated corrosion compared to the Virginia region.

Table 5.11 Regression Model Results Showing Predictors of Silver Corrosion Rates at the AHU Air Register (Natural log-transformed) in Indoor Air

Parameter	Estimate	Standard Error	p-value
Intercept	4.00	2.27	0.09
FTIR/XRF Marker Present	1.56	0.26	<.0001
FTIR/XRF Marker (ref)	–	–	–
Region—Florida East	0.98	0.36	0.01
Region—Florida West	0.49	0.38	0.21
Region—Gulf Coast	0.20	0.34	0.55
Region—Virginia (ref)	–	–	–
Outdoor Silver Sulfide (Ag_2S)	0.001	0.001	0.23
Temperature (°F)	0.02	0.03	0.59

Model R^2=0.57

Table 5.12 Regression Model Results Showing Predictors of Copper Corrosion Rates at the AHU Air Register (Natural log-transformed) in Indoor Air

Parameter	Estimate	Standard Error	p-value
Intercept	6.27	4.54	0.18
FTIR/XRF Marker Present	2.74	0.52	<.0001
FTIR/XRF Marker (ref)	–	–	–
Region—Florida East	2.16	0.76	0.01
Region—Florida West	1.11	0.74	0.14
Region—Gulf Coast	0.53	0.57	0.43
Region—Virginia (ref)	–	–	–
Outdoor Copper Sulfide (Cu_2S)	0.0003	0.0003	0.33
Temperature (°F)	-0.05	0.06	0.42

Model R^2=0.52

Consistent results were found when room-level corrosion rates were modeled as a function of house status determined by FTIR/XRF marker and the same potential confounding variables ($p<0.01$; R^2=0.41 – 0.63). As expected based on the results of the analysis by Region in Section 5.2.6, there were no differences in room-level corrosion by study region. Additionally, using CPSC status in place of the FTIR/XRF marker produced similar results, with models using the FTIR/XRF marker explaining approximately 10% more of the variability in room-level corrosion rates.

5.3.8.3 Predictors of Corrosion Rates in Homes

In Section 5.3.8.1, reduced sulfur gases were found to be elevated in homes with the FTIR/XRF marker present compared to homes where it was not present. In Section 5.3.8.2, corrosion rates were found to be elevated in homes with imported drywall compared to domestic drywall. In this section, the direct relationship between corrosion and reduced sulfur gases and other factors is examined.

In the first set of analyses, house-average reduced sulfur concentrations were compared to corrosion rates from the AHU supply air register. House-average, indoor hydrogen sulfide concentrations were positively and significantly associated with silver and copper corrosion rates (natural log-transformed) in homes, on average ($p<0.05$) (Tables 5.13 and 5.14). As with previous models, the east coast of Florida had significantly elevated rates of corrosion compared to the Virginia study region.

Table 5.13 Regression Model Results Showing Predictors of Silver Corrosion Rates at the AHU Air Register (Natural log-transformed) in Indoor Air

Parameter	Estimate	Standard Error	p-value
Intercept	5.98	0.39	<.0001
Indoor H_2S	0.93	0.32	0.01
Indoor Formaldehyde	0.002	0.002	0.45
Region—Florida East	1.17	0.41	0.01
Region—Florida West	0.65	0.43	0.14
Region—Gulf Coast	0.14	0.42	0.75
Region—Virginia (ref)	–	–	–

Model R^2=0.32

Table 5.14 Regression Model Results Showing Predictors of Copper Corrosion Rates at the AHU Air Register (Natural log-transformed) in Indoor Air

Parameter	Estimate	Standard Error	p-value
Intercept	4.01	0.73	<.0001
Indoor H_2S	1.51	0.61	0.02
Indoor Formaldehyde	-0.01	0.005	0.11
Region—Florida East	2.61	0.78	0.002
Region—Florida West	1.26	0.83	0.13
Region—Gulf Coast	0.80	0.80	0.32
Region—Virginia (ref)	–	–	–

Model R^2=0.31

Using room-specific corrosion rates (i.e., master bedroom, living room) as the outcome variable yielded similar results. For silver, house-average hydrogen sulfide was significantly associated with room-specific corrosion rates for the living room and bedroom ($p<0.05$), with a suggestive association observed in the master bedroom ($p=0.07$). Interestingly, house average formaldehyde was significantly associated with corrosion in the master and secondary bedroom ($p<0.05$). For copper, there was suggestive evidence that house average hydrogen sulfide was associated with corrosion rates in the master and secondary bedrooms ($p<0.06$-0.08). These findings suggest that room-level analysis of the relationship between hydrogen sulfide, formaldehyde and corrosion is warranted.

The second set of analyses, therefore, focused on room-specific results and incorporated co-located room measurements of airborne compounds and corrosion rates. Linear mixed effects models were used to examine relationships between co-located measurements while accounting for within-home correlation of measurements.

Hydrogen sulfide concentrations were positively and significantly associated with room-specific silver corrosion rates in homes, controlling for outdoor hydrogen sulfide concentrations and study region (p=0.01). In this model, formaldehyde was also positively associated with silver corrosion rates (p=0.01).

Table 5.15 Linear Mixed Effects Model Fixed Effects Results for Predictors of Room-Specific Silver Corrosion Rates (Natural log-transformed)

Effect	Estimate	Standard Error	p-value
Intercept	5.42	0.28	<.0001
Indoor Hydrogen Sulfide (H_2S)	0.54	0.19	0.005
Indoor Formaldehyde	0.004	0.002	0.01
Region—Florida East	0.30	0.31	0.34
Region—Florida West	0.09	0.32	0.78
Region—Gulf Coast	0.13	0.32	0.67
Region—Virginia (ref)	–	–	–

To further examine the relationship between hydrogen sulfide and formaldehyde concentrations on silver corrosion, a multiplicative interaction term was added to the linear mixed effects model. A dichotomous variable indicating the presence or absence of hydrogen sulfide was created (LOD ~ 0.35 ppb). Suggestive evidence of interaction was observed between formaldehyde and the presence of hydrogen sulfide; the effect of formaldehyde on silver corrosion in rooms was dependent upon, and increases, in the presence of hydrogen sulfide (p=0.08) (Table 5.16).

Table 5.16 Interaction Mode—Linear Mixed Effects Model Fixed Effects Results for Predictors of Room-Specific Silver Corrosion Rates (Natural log-transformed)

Effect	Estimate	Standard Error	p-value
Intercept	5.82	0.34	<.0001
Indoor H_2S Present	0.05	0.35	0.88
Indoor H_2S (ref)	–	–	–
Indoor Formaldehyde	-0.002	0.004	0.63
Region—Florida East	0.27	0.29	0.35
Region—Florida West	0.07	0.31	0.82
Region—Gulf Coast	0.24	0.29	0.42
Region—Virginia (ref)	–	–	–
Indoor Formaldehyde*H_2S Present	0.01	0.004	0.08
Indoor Formaldehyde*H_2S (ref)	–	–	–

To aid in interpretation of the interaction model results presented in Table 5.16, a scatterplot was created comparing measured formaldehyde concentrations in the presence or absence of hydrogen sulfide (Figure 5.25). The figure suggests that for homes with hydrogen sulfide present, an increase in formaldehyde concentrations is associated with an increase in silver corrosion.

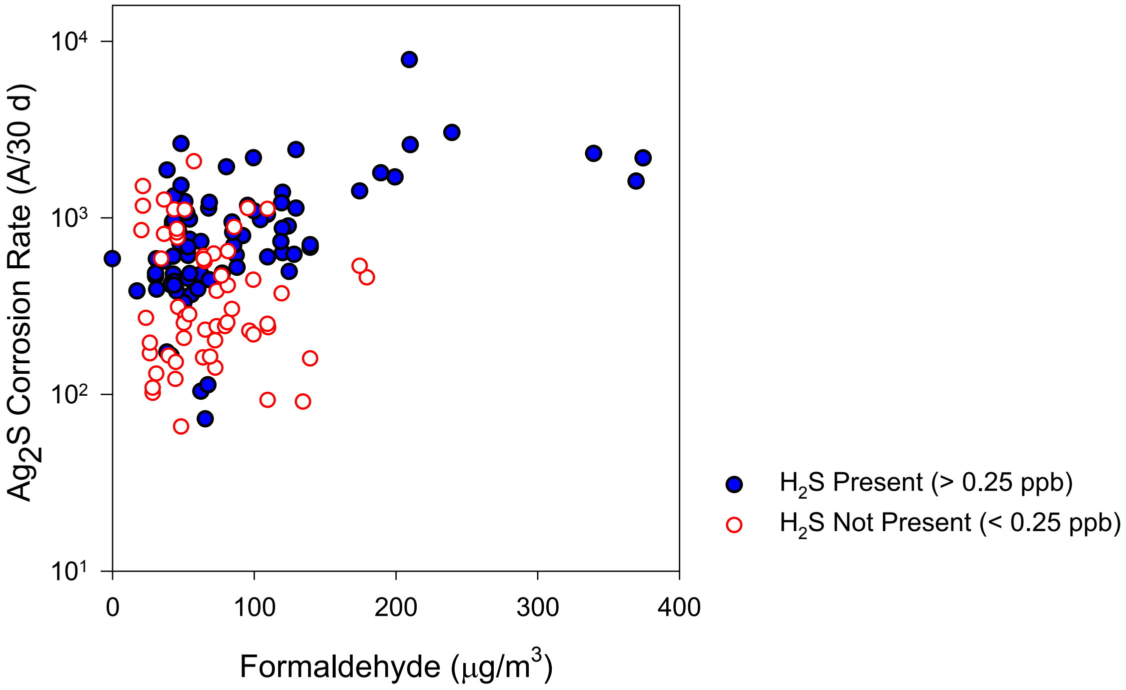


Figure 5.25 Scatterplot of Silver Corrosion Rate by Indoor Formaldehyde Concentration, Stratified by the Presence or Absence of Hydrogen Sulfide

For copper corrosion, hydrogen sulfide concentrations were positively and significantly associated with room-specific corrosion rates in homes, controlling for outdoor hydrogen sulfide concentrations and study region (p=0.04) (Table 5.17). Similar to the AHU air register corrosion model (Table 5.14), formaldehyde concentrations were not associated with room-specific copper corrosion (p=0.20).

Table 5.17 Linear Mixed Effects Model Fixed Effects Results for Predictors of Room-Specific Copper Corrosion Rates (Natural log-transformed)

Effect	Estimate	Standard Error	p-value
Intercept	3.16	0.50	<.0001
Indoor Hydrogen Sulfide (H_2S)	0.67	0.32	0.04
Indoor Formaldehyde	0.004	0.003	0.20
Region—Florida East	1.35	0.55	0.02
Region—Florida West	0.62	0.57	0.28
Region—Gulf Coast	0.22	0.56	0.69
Region—Virginia (ref)	–	–	–

All of the models presented that include formaldehyde concentrations are based on the short-term, active air sampling of formaldehyde. In addition to the active sampling, 2-week integrated formaldehyde concentrations were measured using passive monitors. The regression analyses were repeated using the 2-week formaldehyde concentrations.

Hydrogen sulfide remained a significant predictor of corrosion controlling for formaldehyde concentrations regardless of the type of formaldehyde measurement (e.g., active or passive) ($p<0.05$). However, contrary to the findings for formaldehyde concentrations measured with active sampling, 2-week formaldehyde concentrations measured passively was only a marginal predictor of silver corrosion in the mixed effects models, and not statistically associated with copper corrosion ($p=0.09$, $p=0.17$, respectively). One plausible reason for this observation is that the 2-week measurement averages through diurnal effects, while the short-term active sample captured peak formaldehyde concentration during day-time hours.

Potential contributors to formaldehyde concentrations were also explored. Indoor temperature was a significant predictor of formaldehyde concentrations in the home (Table 5.18), with increased temperatures associated with increased formaldehyde concentrations ($p<0.001$), controlling for outdoor formaldehyde concentration and study region ($R^2=0.31$). A scatterplot depicting the bivariate association between temperature and formaldehyde is presented in Figure 5.26. A consistent relationship between formaldehyde and temperature was also found when the 2-week formaldehyde measurement was used ($p<0.01$; $R^2=0.23$).

Table 5.18 Regression Model Results Showing Predictors of House Average Formaldehyde Levels (Natural log-transformed) in Indoor Air

Parameter	Estimate	Standard Error	p-value
Intercept	-1.57	1.53	0.31
Region—Florida East	-0.34	0.30	0.25
Region—Florida West	-0.45	0.30	0.15
Region—Gulf Coast	0.02	0.30	0.93
Region—Virginia (ref)	–	–	–
Indoor Temperature	0.07	0.02	<0.001
Outdoor Formaldehyde	0.05	0.05	0.28

Model R^2=0.32

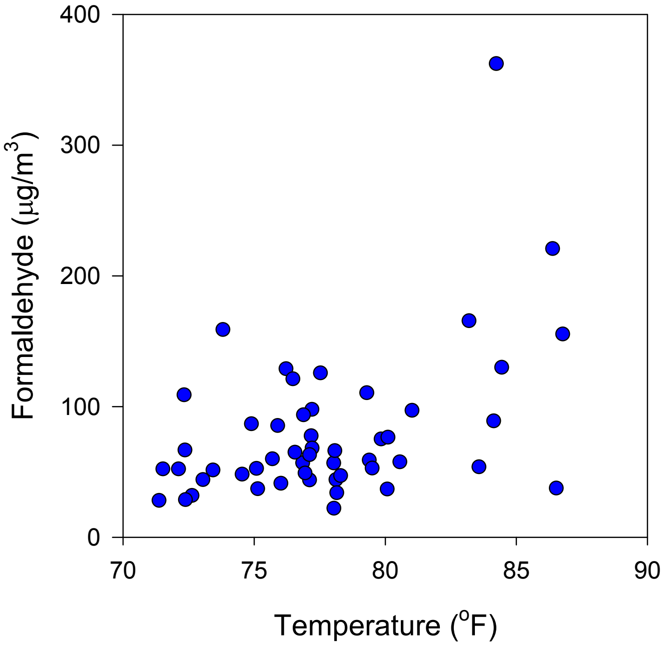


Figure 5.26 Scatterplot Comparing House Average Formaldehyde Concentrations (µg/m^3) Across Temperature Ranges (°F)

6.0 DISCUSSION

6.1 SUMMARY

An early objective of this study was to identify reliable markers of imported drywall (and techniques for measuring the marker). These measurement techniques were then used to evaluate the presence or absence of imported drywall in sample homes. The homes were selected by CPSC staff for inclusion in this study and were located in five states in the southeastern United States. CPSC classified the homes into two types, complaint and non-complaint. EH&E was blind to the classification of the homes during the site visits and data collection phase of the study. There were 41 complaint homes selected by CPSC from their existing incident reporting database and 10 non-complaint homes recruited by CPSC for a total sample size of 5 homes. The 10 non-complaint homes were located in the same neighborhoods as the complaint homes and were selected to approximate the characteristics of the complaint homes as much as possible. EH&E visited each of the 51 homes and collected data on construction/building related characteristics such as the presence of imported drywall, locations of the types drywall, dimensions of the drywall, house and room size, type of construction, geographic location, air exchange rate and the type of heating ventilation and air conditioning systems. In addition, air samples were collected for a wide range of chemical agents including reduced sulfur gases, aldehydes, volatile organic compounds, organic and inorganic acids. To assess the corrosivity of the atmosphere inside the building, corrosion coupons composed of precleaned copper and silver test strips were placed inside and outside the home. Physical parameters such as temperature and relative humidity were also measured inside and outside the home. After data collection the data were analyzed using statistical techniques that included log linear models (random and fixed effects), correlation analysis and ordinary linear regression.

The study found that the concentrations of strontium and carbonate ion (carbonate), in combination, could be used as a reliable marker of imported drywall. Portable XRF and FTIR spectrometry instruments were used to measure strontium and carbonate, respectively. The portable XRF instruments were used to make measurements in each home, and the FTIR, although portable, was used in the laboratory. These data were used to determine which study homes contained imported drywall, how much it contained and where it was located.

Imported drywall was found to be present in 92.7% of the complaint homes and not present in any of the non-complaint homes. The differences are clear but the results could be affected by a bias in the process leading to the complaint classification, e, g., if an individual knew they have imported drywall they may be more likely to file a complaint than someone that does not have imported drywall in their home.

Corrosion was found to be greater in the complaint houses than in the non-complaint houses ($p<0.01$). The corrosion effect was significant both when quantitative measures (corrosion coupons) were used as measures of corrosion as well as when the observations of corrosion on ground wires by trained technicians onsite were used. The region where the house was located was associated with corrosion rate in certain applications. Specifically, the east coast of Florida homes had the highest corrosion rates when corrosion coupons from the air handlers were compared and used as a measure of corrosion rate. When other corrosion coupons, were used, e.g., from the bedrooms or living rooms in the analysis there was no regional effect. This finding demonstrates how sensitive these measurements may be to micro environmental effects and indicates caution must be exercised in interpreting data from limited measurements to ensure unwitting bias is not introduced. Outdoor corrosion rates were not correlated with indoor corrosion rates.

Short-term, average air exchange rates were measured in each home using carbon dioxide as a tracer gas. The results of these studies indicated that the air exchange rates for complaint and non-complaint homes were similar ($p=0.09$). The tracer gas study also showed that the houses in the sample were relatively tightly sealed with a median short-term average air exchange rate of 0.19 ACH (range 0.05 – 0.8).

Several gases/vapors that were measured in this study were present at different concentrations in homes with and without imported drywall (as determined by CPSC status or the XRF/FTIR pair of markers). These gases/vapors were also investigated for their potential to contribute to corrosion or malodor. These gases/vapors include hydrogen sulfide, carbon disulfide, and potentially inorganic and organic acids.

In homes that were both non-complaint and did not have the XRF/FTIR marker of imported drywall H_2S concentration ranged from background (0.33 ppb) to levels below the minimum reported odor threshold (0.5 ppb) for samples collected with the two week passive samplers. In contrast, approximately 67% of the measurements from homes that were either complaint or had the XRF/FTIR marker of imported drywall contained two-week average concentrations of H_2S that exceeded the maximum reported background concentration level. Approximately one-half of the measured H_2S levels in complaint or imported drywall homes were greater than the minimum reported odor threshold. In multivariate analyses, hydrogen sulfide concentration was found to be positively and significantly associated with silver and copper corrosion rates (p=0.01).

Carbon disulfide concentrations differed between complaint and non-complaint homes, with median concentrations of 2.2 and 0.74 $\mu g/m^3$, respectively. The difference however, is not statistically significant (p=0.07) although this analysis is limited due to the small sample size. Carbon disulfide concentration was also not significant when evaluated as a predictor of corrosion rates in multivariate modeling while controlling for several potential confounding variables (p=0.29). Carbon disulfide concentrations were also not significantly correlated with hydrogen sulfide concentrations (p=0.22).

Organic acids were detected at a mean concentration of 11 ppb in complaint homes and 7 ppb in non-complaint homes. The differences were not statistically significant (p=0.5). Organic acid concentrations were also not significantly correlated with corrosion rates.

Concentrations of aldehydes in the indoor air of both complaint and non-complaint homes did not differ significantly but both were generally greater than levels reported in the scientific literature for residences in various areas of the United States. For example, the average concentration of formaldehyde (active sampling) in complaint and non-complaint homes was 53 $\mu g/m^3$ while mean values reported in studies of homes in large cities like New York City; Houston; Elizabeth, NJ; and Los Angeles, CA, ranged from 18 and 22 $\mu g/m^3$. Concentrations of other aldehydes in indoor air of homes in the present study were also generally two to four times greater than the corresponding levels reported for these cities. Most (78%) of the homes in the present study were constructed after 2005, thus variation in concentrations of aldehydes in indoor air compared to previous studies may be a function of age of construction and related factors such as air exchange rate. For example, Hodgson et al. (2000) evaluated air exchange rates, formaldehyde, and volatile organic compound (VOC) concentrations in new manufactured houses and site built houses. The average indoor-outdoor concentrations for these fourteen residences was 49 $\mu g/m^3$ (40 ppb) with a median of 47 $\mu g/m^3$ (38 ppb) with a range from 9 – 66 $\mu g/m^3$ (7 – 54 ppb). The average air exchange rate was 0.40 per hour with a median of 0.38 per hour. The Hodgson et al. (2000) study also demonstrated that formaldehyde is emitted by materials in a new house at fairly constant rates over the period they studied, which was nine months. The levels of formaldehyde measured in their study of newly constructed houses are quite consistent with what was measured in both the complaint and non-complaint houses in this study, even though the air exchange rates are higher in the Hodgson study (Hodgson et al. 2000).

Multivariate modeling was used to assess the significance of formaldehyde concentration as a predictor of corrosion rates. In the mixed models which compare room-specific formaldehyde concentrations and corrosion rates, formaldehyde was a significant predictor of silver corrosion rates but not copper ($p=0.01$; $p=.10$) (see additional discussion of formaldehyde and corrosion rates in Section 6.5.3).

Samples for VOCs were collected at 31 of the 51 homes using SUMMA canisters and analyzed by GC/MS. Five of the 31 homes were non-complaint, the remainder were complaint homes. Several VOCs show elevated concentrations in complaint homes compared to non-complaint homes. Statistical comparisons are currently limited due to the small sample size of non-complaint homes with VOC samples ($n=5$). VOCs were not significantly associated with corrosion rates.

6.2 SOURCE MARKERS

6.2.1 Markers of imported drywall

Laboratory-based testing of drywall samples of known origin was used to determine the utility of using real-time instruments for identifying sensitive and specific markers of imported drywall. Portable FTIR and XRF analyzers were used to quantify carbonate and strontium concentrations, respectively. A comparison of strontium and carbonate levels was previously presented in Section 5 (Figure 5.1 reproduced here as Figure 6.1).

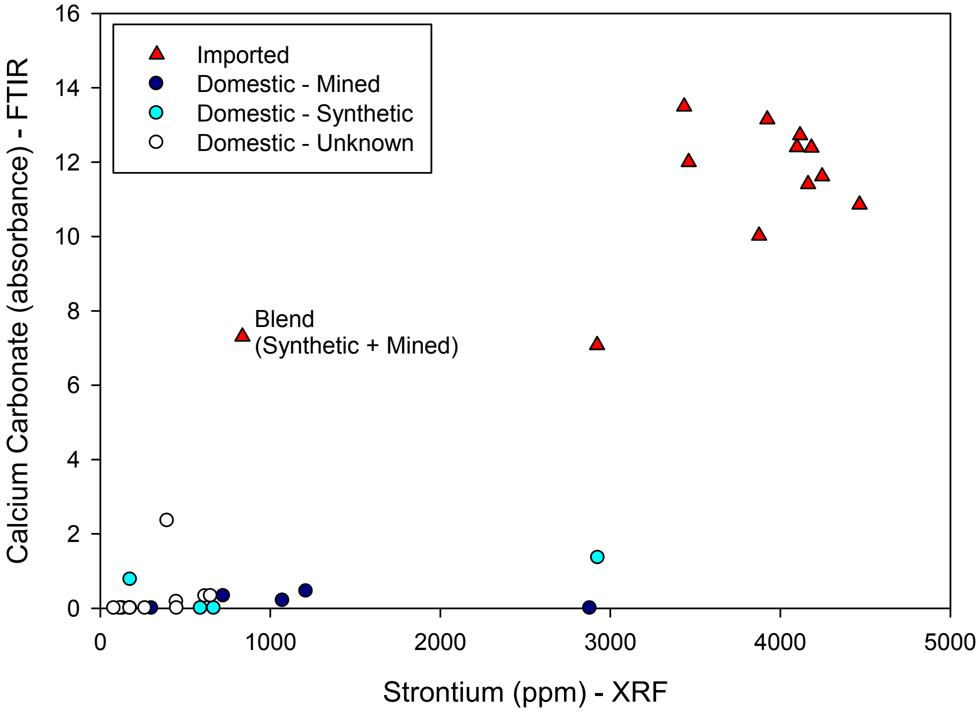


Figure 6.1 Comparison of Cored Drywall Samples of Known Origin and Analyzed in a Laboratory Setting for Strontium Concentrations (ppm) Measured by XRF and Carbonate (Absorbance) Measured using FTIR

The results demonstrate that using elevated strontium concentrations alone may be a sensitive marker of imported drywall but not perfectly specific; there were two examples of domestic samples with high strontium concentrations. The analysis of known samples also indicates that carbonate alone may be sufficient to identify imported drywall. However, results from the 51 home field study indicate that there are many instances where a sample had elevated carbonate but not elevated strontium concentrations (Figure 5.2). When carbonate levels are considered in conjunction with strontium concentrations, the results demonstrate that a good indicator of imported drywall is a sample with both elevated strontium and elevated carbonate. Using both FTIR and XRF measurements of carbonate and strontium, respectively, was therefore determined to be the most sensitive and specific marker of imported drywall.

6.2.2 Evaluation of Portable XRF as a Field Screening Tool for Source Identification

Portable XRF has been suggested as a useful tool for field identification of imported drywall, using elevated strontium concentrations as a marker. As the previously described lab analysis of core samples collected from homes demonstrates, imported drywall has elevated concentrations of strontium (greater than 1,200 ppm) compared to domestic samples. However, XRF analysis in the field can be significantly impacted by various surface materials. When drywall is measured in situ, the paint and any other of the myriad surface coatings that could be applied to walls have a muting effect on the strontium concentrations because the strontium is located at depth.

Results from a pilot study in a complaint home indicated that elevated strontium concentrations measured via XRF in situ may still be a useful indicator of imported drywall. The apparent ability of strontium concentrations to act as a differentiator is demonstrated in Figure 6.2, which shows one wall in the pilot home that appears homogeneous in texture and finish (Figure 6.2a). In Figure 6.2b, strontium concentrations from XRF are overlayed on the picture of the wall and indicate that elevated levels of strontium were detected on the lower half of the wall. The presence of imported drywall on the lower half of the wall was confirmed on another wall in the room. Therefore, in situ measurements of strontium via XRF were able to be used to identify where domestic and imported drywall were located in an otherwise uniformly painted wall. However, as discussed below there are significant limitations on using this technique as an absolute indicator.

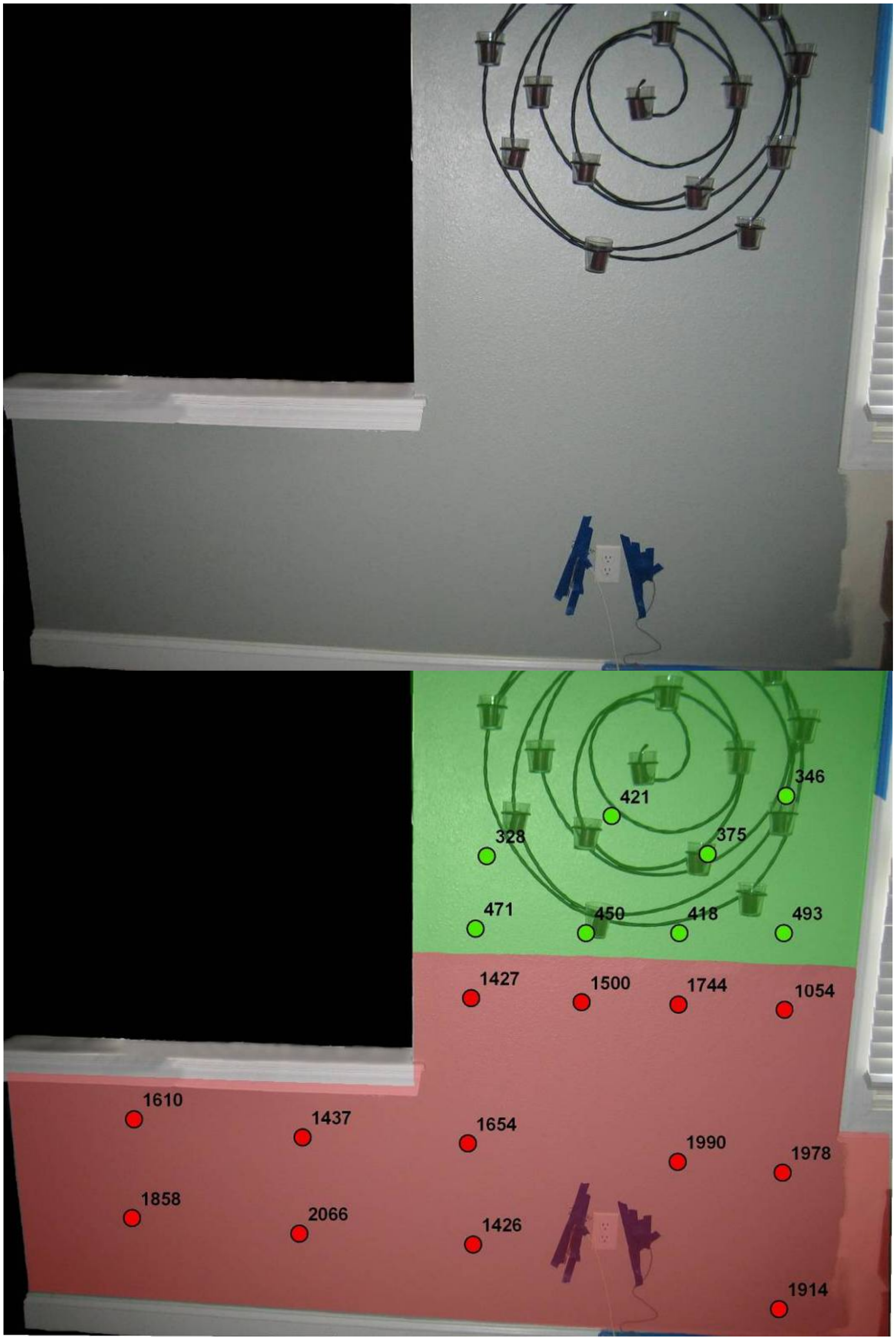


Figure 6.2 Picture of One Wall from a Complaint Home (a) and Same Wall with Strontium Concentrations Measured using XRF through Paint (b) demonstrating two Different Drywall Boards in an Otherwise Uniformly Painted Wall

During the 51 home study, at each location where a sample was cored from the wall for laboratory analysis of the core sample, a co-located measurement using XRF was taken in situ, through the paint to allow for an assessment of the utility of portable XRF as a field tool. A point by point comparison is presented in Figure 6.3. The laboratory and field-based measurements show strong agreement, in general. However, there is no clear strontium concentration measured through the paint that could be reliably used to differentiate drywall with true elevated strontium (i.e., many false negatives). The false negatives likely occur on locations in the home that have drywall with thick layers of paint and/or plaster.

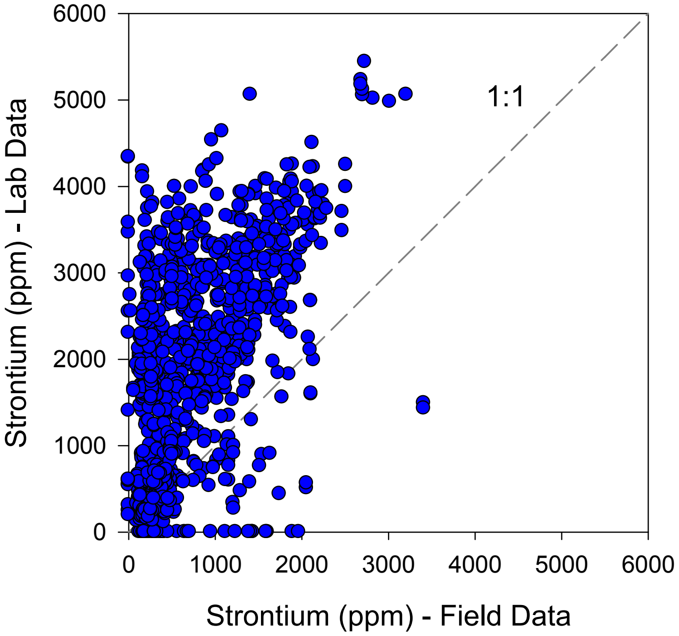


Figure 6.3 Comparison of Strontium Concentrations of Co-located Samples Measured in the Field through Paint and/or Plaster, and Samples Measured of the Drywall Core in a Controlled Laboratory Setting

To further refine the analysis presented in Figure 6.3 and reduce the misclassification due to some walls having thick coats of paint and/or plaster, we analyzed the percent of XRF in situ samples >600 ppm (half of the 1,200 ppm value used as the cut-off in controlled laboratory analysis). This marker was created as a means of attempting to obtain an overall characterization of the home in light of the evidence that some samples may have muted strontium concentration due to wall coatings.

Results comparing the percent of in situ measurements >600 ppm strontium against house status as determined by laboratory-based analysis of core samples (i.e., no paint or plaster) are presented in Figure 6.4. These results, combined with the information presented above, suggest that while in situ measurements using XRF may not be a absolute predictor of an individual drywall measurement being from imported or domestic material (due to the potential for false negatives), the house as a whole can be reasonably well characterized using the percent of XRF samples with strontium greater than 600 ppm.

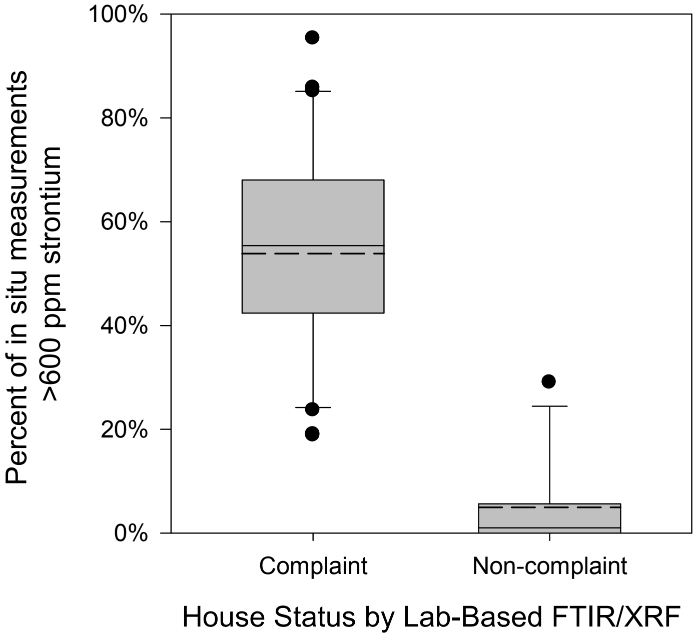


Figure 6.4 Comparison of the Percent of Situ Samples >600 ppm Strontium and Home Status Determined Using the FTIR/XRF Marker

6.3 INDOOR AIR QUALITY

6.3.1 Concentrations of Gases

The levels of several gases measured in this investigation are of note because of (i) differences observed between homes with and without imported drywall (based on CPSC status or the XRF/FTIR pair of markers), (ii) their potential to contribute to corrosion or malodor, and (iii) their absolute levels. These gases which include hydrogen sulfide, carbon disulfide, inorganic and organic acids, and formaldehyde are discussed in this section relative to levels reported in other exposure studies and related benchmarks.

A summary of concentrations reported in the literature for gases common to this investigation and relevant comparison studies is tabulated in Appendix A.

Two-week average concentrations of hydrogen sulfide in indoor air of complaint and non-complaint homes ranged from non-detect (<0.7 $\mu g/m^3$) to 3 $\mu g/m^3$. Few published studies of indoor air quality in homes report measurements of hydrogen sulfide and other reduced sulfur gases, especially with the same degree of sensitivity as the present study. For example, Inserra et al. (2002) reported that 91% of 30-min average H_2S levels inside of homes in a community impacted by point sources of H_2S were less than the method detection limit of 30 ppb (Inserra et al. 2002). All of the H_2S levels in the present study were well below 30 ppb, yet the information available from the study by Inserra et al. does not allow any further comparison to be made. Concentrations of H_2S in ambient air as a result of emissions from natural sources have been estimated to range from 0.11 to 0.33 ppb (EPA 1993 as cited in ATSDR 2006). Similarly, the World Health Organization reports that H_2S levels in outdoor air are generally less than 0.1 ppb (WHO 1981 as cited in ATSDR 2006). With a minimum reported odor threshold of 0.5 ppb (Ruth 1986 as cited in ATSDR 2006), background concentrations of H_2S in outdoor air are not expected to be detected by olfactory means (ATSDR 2006). H_2S measured in homes that were both non-complaint and did not have the XRF/FTIR marker of imported drywall were in the range of background and below the minimum reported odor threshold. In contrast, approximately 66% of the measurements from homes that were either complaint or had the XRF/FTIR marker of imported drywall contained two-week average concentrations of H_2S that exceeded the maximum reported background level of 0.33 ppb. Likewise, approximately one-half of the measured H_2S levels in complaint or imported drywall homes were greater than the minimum reported odor threshold of 0.5 ppb.

With regard to carbon disulfide and additional reduced sulfur gases other than hydrogen sulfide, a search of the published literature did not identify measurements in residential indoor air. Among these gases, only carbon disulfide was found to differ between complaint and non-complaint homes in this investigation; median concentrations of 2.2 and 0.74 $\mu g/m^3$, respectively. According to the ATSDR, most people can detect the burnt match odor characteristic of carbon disulfide at concentrations between

62 and 310 $\mu g/m^3$ (ATSDR 2004). Thus, the concentrations of carbon disulfide measured in this study are below the reported odor threshold for this substance.

Information on acid gas concentrations in homes that can be compared to results from the present study are available in a small number of published studies all of which were conducted in the northeastern United States. Formic acid, for example, was detected at a mean concentration of 11 ppb in complaint homes and 7 ppb in non-complaint homes. Reiss (Reiss et al. 1995) reported mean formic acid values of 9.8 ppb in the summer and 17.8 ppb in the winter for homes in Massachusetts, and Zhang (Zhang et al. 1994) reported a mean of 8.8 ppb in New Jersey. Concentrations of other acids measured in complaint and non-complaint homes were also similar to background levels reported in the published literature.

The indoor air levels of formaldehyde and other aldehydes were similar for complaint and non-complaint homes although generally greater than levels reported in the scientific literature for residences in various areas of the United States. For example, the average concentration of formaldehyde (active sampling) in complaint and non-complaint homes was 53 $\mu g/m^3$ while mean values reported for homes in the TEACH (New York City and Los Angeles) and RIOPA (Houston, Los Angeles, and Elizabeth, NJ) studies were 18 and 22 $\mu g/m^3$, respectively (NUATRC 2000; Weisel et al. 2004). Concentrations of other aldehydes in indoor air of homes in the present study were also generally two to four times greater than the corresponding levels reported for the TEACH and RIOPA studies. Most (78%) of the homes in the present study were constructed after 2005, thus variation in concentrations of aldehydes in indoor air compared to previous studies may be a function of age of construction and related factors such as air exchange rate. For example, Hodgson et al. (2000) evaluated air exchange rates, formaldehyde, and VOC concentrations in new manufactured houses and site built houses. The average indoor-outdoor concentrations for those fourteen residences was 49 $\mu g/m^3$ (40 ppb) with a median of 47 $\mu g/m^3$ (38 ppb) with a range from 9 – 66 $\mu g/m^3$ (7 – 54 ppb). The average air exchange rate was 0.40 per hour with a median of 0.38 per hour. The Hodgson et al. (2000) study also demonstrated that formaldehyde is emitted by materials in a new house at fairly constant rates over the period they studied, which was nine months. The levels of formaldehyde measured in their study of newly constructed houses are quite consistent with what was measured in both the complaint and non-complaint houses in this study, even though the air exchange rates are higher in the Hodgson study.

Concentrations of VOCs in the indoor air of complaint homes were nominally greater than in non-complaint homes, although a statistical test of equality of the central tendency is limited by the modest sample size in each group. Nonetheless, the concentrations of VOCs found in homes of both groups were in the range of levels reported in the published scientific literature such as the TEACH (NUATRC 2009) and RIOPA (Weisel et al. 2004), and Hodgson et al. (2000) studies. For example, toluene concentrations averaged 29.15 $\mu g/m^3$ and 10.99 $\mu g/m^3$ in complaint and non-complaint homes. In comparison, the average concentration in the TEACH and RIOPA studies were studies were 18.26 and 20.28 $\mu g/m^3$, respectively. In addition, the nominal differences between concentrations of VOCs for complaint and non-complaint homes was similar to the differences observed across homes and cities in the TEACH and RIOPA studies. For example, the average concentration of benzene in non-complaint homes was 1.06 $\mu g/m^3$ and 5.05 $\mu g/m^3$ in complaint homes. In comparison, concentrations of benzene ranged from <0.4 $\mu g/m^3$ to 39 $\mu g/m^3$ across homes in New York City and from 2.5 $\mu g/m^3$ to 5.3 $\mu g/m^3$ between average levels in Los Angeles and New York City. A larger number of observations would be required to ascertain whether any true differences in VOC concentrations exist between homes with and without imported drywall. However, the available information suggests that concentrations of VOCs in both groups of homes are similar and typical of residential buildings.

6.3.2 The Role of Air Exchange and Ventilation

Home ventilation rate, measured in air changes per hour (ACH), is an important determinant of concentrations of gases in the indoor environment. Air exchange rates in residential buildings vary considerably based on the type of construction, seasonal variability in weather, and geographic region (ASHRAE 2005).

Short-term air exchange rates were measured in each home during the sampling period. A short-term test only provides a snapshot of typical conditions in a home, yet the results can still provide useful insights if gross-level differences across homes existed. The median ventilation rate for all homes in the study was 0.19 (range 0.05 – 0.8), with no significant differences between complaint and non-complaint homes or across study region.

Typical air exchange rates for residential buildings in North America range from a seasonal average of about 0.2 ACH for tightly constructed homes to upwards of 2 ACH for loosely constructed housing (ASHRAE 2005). Additional studies have shown that an ACH of approximately 0.4 to 0.5 is a reasonable estimate of average seasonal air exchange rate for residences (ASHRAE 2005; Ek et al. 1990; Grimsrud et al. 1982; Palmiter and Brown 1989; Parker et al. 1990). This suggests that the homes in this study, both complaint and non-complaint, are on the lower end of the distribution of typical air exchange rates found in North America. The lack of variability in air exchange rates from homes in this study (i.e., most on low end of typical range) may partly explain why air exchange rate, while known to be an important variable in determining indoor gas concentrations, was not a significant predictor of gas concentrations or corrosion in the regression analyses in this study.

6.4 CORROSION

6.4.1 Corrosion Classification Coupons

Corrosion classification coupons were used as an integrated measure of effect. The levels of corrosion observed on the classification coupons represent the combined effect of all variables in the home, including both measured and unmeasured characteristics. The corrosion rates measured accounted for conditions in the home at the time of the indoor air sampling and allowed for a determination of effect to be seen even if the corrosion detected was due to a potentially un-quantifiable synergistic effect between low-level indoor air contaminants.

The corrosion classification coupons deployed in the 51 homes in this study were comprised of two metal strips—one copper and one silver. Using two different metals allows for the potential to identify and/or rule-out the presence of airborne contaminants based on differential rates of corrosion between the two metals. For example, Table 6.1 lists the material sensitivities of silver and copper to various corrosive agents.

Table 6.1 Material Sensitivities to Atmospheric Corrodants

Corrodants	Silver (Ag)	Copper (Cu)
CO_2/CO_3^{2-}	L	–
NH_3/NH_4^+	M	M
NO_2/NO_3^-	N	M
H_2S	H	H
SO_2/SO_4^{2-}	L	H
HCl/Cl^-	M	M
$RCOOH/COOH^-$	L	M
O_3	M	M

H = High sensitivity
M = Moderate sensitivity
L = Low sensitivity
N = No sensitivity

* Table reproduced from (Leygraf and Graedel 2000) Table 4.1.

From this table we can infer that if the corrosion observed in the homes was due to SO_2, then copper corrosion would be expected to be elevated compared to silver corrosion. As there was generally good agreement between copper and silver corrosion in the same homes, corrosive agents that act on silver and copper at differential rates (such as SO_2) are unlikely to be the primary cause of effect in the study homes. Similarly, the information in Table 6.1 can be used to add further evidence that hydrogen sulfide is a primary corrosive agent in this study because both silver and copper are highly sensitive to H_2S—a finding supported by field measurements which recorded high rates of corrosion for both metals observed in this study.

6.4.2 Differences in Corrosion Rates by Location in a Home

In general, co-located measurements of corrosion levels measured in rooms were moderately to highly correlated. Corrosion rates measured at the AHU supply vents was significantly greater than levels measured in the rooms. Atmospheric corrosion is dependent upon corrosive species contacting the metal surface, which is most commonly governed by the process of dry deposition where contact at the surface occurs via turbulent diffusion (Leygraf and Graedel 2000). The vertical flux (Φ) of a contaminant is dependent upon the concentration of the contaminant in air (C) and deposition velocity (V_{dep}), expressed in terms of flux units ($m^3/h/m^2$):

$$\Phi = C^*V_{dep} \qquad \text{(Equation 6.1)}$$

Measured deposition velocities are typically much greater outdoors than indoors as a result of increased air movement (Leygraf and Graedel 2000). The increased corrosion rate observed at the AHU supply vent compared to the rooms may be explained, therefore, by the increased V_{dep} in the supply duct air stream due to increased volume of air passing the corrosion coupon (i.e., increased mass-transfer rates).

6.4.3 Hydrogen Sulfide and Formaldehyde

The results of the multivariate modeling (Section 5.3.8.3) indicate that both indoor formaldehyde and hydrogen sulfide concentrations were associated with silver and copper corrosion. Formaldehyde and its related acid (formic acid), can cause corrosion on copper and silver, with silver having a lower sensitivity to formic acid (Table 6.1) (Leygraf and Graedel 2000).

Reduced sulfur gases in air, even at low concentrations, are able to initiate corrosion and disrupt the protective cuprous oxide layer that forms on copper thereby enabling other corrosive agents (i.e., formaldehyde, formic acid) to more readily act on the metal. While silver does not form an oxide layer in typical temperature ranges (Campbell and Thomas 1939; Graedel et al. 1985), synergistic effects have been seen between hydrogen sulfide and other airborne corrosive agents (Leygraf and Graedel 2000).

The results from the field study support this hypothesis. The multivariate modeling results suggest that for silver corrosion there was an interactive effect between hydrogen sulfide and formaldehyde; the level of silver corrosion associated with formaldehyde was dependent upon the presence of hydrogen sulfide. This same interactive effect would be expected to be seen for copper but was not. One possible explanation relates to the mass increase rates for silver and copper. Copper and silver both have fast mass increase rates, but, in an experimental study, silver was shown to have a mass increase rate an order of magnitude faster than copper, showing mass responses within several minutes after hydrogen sulfide was introduced (Forslund et al. 1997).

Further support of a multi-component model of corrosion can be found in the literature. A study of corrosion rates of copper by sulfurous gases determined a copper corrosion rate of 29 Angstrom per ppb of hydrogen sulfide per 30 days (0.04 Ǻ ppb $30d^{-1}$) (Graedel et al. 1983). Using the 75th percentile of hydrogen sulfide concentration in homes with imported drywall (0.79 ppb), the estimated rate of corrosion due to hydrogen sulfide would be 23 Ǻ per 30 days. In this study, the average rate of copper corrosion in homes with imported drywall was ~350 Ǻ $30d^{-1}$ in room air and 1400 Ǻ $30d^{-1}$ at the AHU air register, values that are 1 to 2 orders of magnitude greater than predicted based on hydrogen sulfide alone. Accounting for corrosion rates associated with another reduced sulfur, carbon disulfide, does not alter this finding; adding the 75th percentile air concentration for carbon disulfide (3.13 ppb) and the copper corrosion rates reported by Graedel et al (Graedel et al. 1983) does not significantly increase the copper corrosion rate (<0.1%). Therefore, the copper corrosion observed in homes may not be solely attributable to the concentration of reduced sulfur gases observed in this study. Additional work would be necessary to confirm this observation.

6.5 HEALTH CONSIDERATIONS

This assessment of indoor environmental quality in homes provides new information that is relevant to understanding the potential for human health effects to occur in association with the imported drywall that is under investigation by CPSC and its federal and state partners. The principal contrasts in exposure conditions between homes with and without imported drywall that were observed in this field study were: (1) levels of hydrogen sulfide and possibly carbon disulfide and selected hydrocarbons in indoor air; (2) rates of silver and copper corrosion; and (3) malodor. Factors such as formaldehyde concentrations and air exchange rate that were approximately equal between complaint and non-complaint homes but notable because of their magnitude and potential to influence health symptoms are considered in this discussion as well.

Hydrogen sulfide is a flammable, colorless gas with a characteristic odor of rotten eggs that may cause irritation to the eyes, nose, or throat at low concentrations and can be poisonous at elevated concentrations (ATSDR 2006). Health-based benchmarks for hydrogen sulfide exposures in non-occupational settings have been recommended by ATSDR and EPA. The ATSDR minimum risk level (ATSDR 2008) of 20 ppb for inhalation exposure to hydrogen sulfide over an intermediate duration (more than 14 days and less than a year) is based on the prevalence of damage to olfactory neurons observed in mice exposed to 10, 30 and 80 part per million of hydrogen sulfide for 6 hours per day, 7 days per week for 10 weeks reported by Brenneman et al. (Brenneman et al. 2000). ATSDR also recommends a minimum reporting limit (MRL) of 70 ppb for acute exposure (duration of one to 14 days) based on suggestive evidence of bronchial obstruction among asthmatics exposed to 2 ppm hydrogen sulfide for 30 minutes reported by Jappinen et al. (Jappinen et al. 1990). The EPA inhalation reference concentration (RfC) for hydrogen sulfide of 2×10^{-3} milligrams per cubic meter (1.4 ppb) was also derived from the Brenneman (2000) study of mice. Most of the two-week average concentrations of hydrogen sulfide measured in complaint homes included in this study were below these health-based benchmarks.

Concentrations of carbon disulfide and hydrocarbons measured in whole air samples collected with SUMMA canisters were nominally about 1.5 to 2 times greater in complaint homes than in non-complaint homes. As discussed in Section 6.2, the strength of conclusions about systematic differences in VOCs levels between complaint and non-complaint homes are constrained by the number of non-complaint homes (5) from which these types of samples were obtained. The MRL for carbon disulfide of 300 ppb (936 $\mu g/m^3$) recommended by ATSDR is based upon reports of reduced motor nerve conduction velocity in humans after prolonged occupational exposure to the chemical (ATSDR 1996). The EPA derived the RfC for carbon disulfide of 700 $\mu g/m^3$ from an observational study of workers in the viscose rayon industry (EPA 2002). With a maximum house-wide average concentration of 9.1 $\mu g/m^3$, the levels of carbon disulfide in complaint and non-complaint homes were well below the ATSDR and EPA health-based benchmarks. Similar conclusions can be reached for hydrocarbons that were also assessed through the SUMMA canister sampling and analysis. For instance, the median concentration of n-hexane in complaint homes was 4.13 $\mu g/m^3$ compared to 0.95 $\mu g/m^3$ in non-complaint homes, levels that are more than 500 times below the MRL of 2,117 $\mu g/m^3$ and 150 times below RfC of 700 $\mu g/m^3$. Moreover, the target organs and health endpoints from which MRLs and RfCs are derived typically differ across VOCs and differ from the symptoms reported by occupants of complaint homes such as respiratory irritation, headache, and eye irritation. Thus while effects of concurrent exposure to multiple VOCs are possible, the variety of health endpoints that form the basis of health-based benchmarks complicates an assessment of risk associated with cumulative exposure. Additional analysis would be needed to evaluate the potential for cumulative effects of these gases further.

As described in Section 5.2.3, corrosion of silver and copper coupons was accelerated in complaint homes compared to non-complaint homes. The levels of hydrogen sulfide found in complaint homes may not be sufficient cause for the rate of corrosion observed in these buildings (see Section 5.3). The accelerated corrosion could be the product of synergistic effects of hydrogen sulfide with formic or acetic acid or other species that are ubiquitous in indoor environments, perhaps potentiated by dew points in the vicinity of ambient indoor temperatures as described in Section 5.3.8.1. The mixtures of corrosive species found in the air of these homes have not been studied in relation to health based considerations based upon a literature search completed by EH&E. Nevertheless, the acid gases found in these homes including hydrogen sulfide, nitrogen dioxide, acetic acid, and formic acid, are well known to be irritating to the eyes and respiratory tract (Klaassen et al. 1986; Lewis 2000) although typically at higher concentrations in air than were observed in this investigation. Hence, a close examination of the acid gas and health literature may be valuable for further evaluation of the health implications of the corrosion observed in these homes.

Malodor perceived in indoor air is another distinct difference that was observed between the complaint and non-complaint homes included in this study. Hydrogen sulfide has a low odor threshold, was enriched in indoor air of complaint homes, and therefore could be responsible for contributing to the malodors in complaint homes (see Section 6.2).

Symptoms of eye, nose, and throat irritation are often cited by occupants of polluted indoor environments (Cometto-Muñiz 2001; Molhave 2001). Studies conducted by Fanger (Fanger 201), and Molhave (Molhave et al. 1986) have shown that emissions associated with building materials, furnishings, and equipment contribute to the pollution and sensory load of the indoor environment. Liu et al. (Liu et al. 2007) found that people who had been exposed to moderate to strong odors from home renovations were approximately four times more likely to experience discomfort than those who had been exposed to emissions that generated “weak” odors. A paper by (Schiffman and Williams 2005) cites three mechanisms by which odors may produce health symptoms. Although their paper focuses primarily on the impact of ambient odors on community health, it does provide a useful construct by which to consider the possible impact of malodors on occupants of homes containing suspect Chinese drywall. Schiffman and Williams (2005) describe these mechanisms as:

- Mechanism One: Irritation, rather than the odor, causes the health symptoms.
- Mechanism Two: Health symptoms occur at odorant concentrations that are not irritant.
- Mechanism Three: A co-pollutant in an odorous mixture is responsible for the reported health symptoms.

The first mechanism proposed details a direct association between symptoms and the compounds producing the malodors. In this case irritation, rather than the odor, is the cause of the health symptoms. The associated odor is not the cause, but rather serves as an exposure marker. Of interest is the fact that this mechanism is not dependent upon only one chemical being above its odorant threshold; irritation may be induced by a number of chemicals that each individually may be below the concentrations that cause irritation, but taken in aggregate may exceed the irritant threshold (Cometto-Muñiz et al. 1999; Cometto-Muñiz et al. 1997).

In the second mechanism it is postulated that health symptoms can occur from odors, even when the odorant is below the irritant threshold. Schiffman and Williams (2005) acknowledge that the mechanism responsible for health complaints in the absence of irritation is not well understood, however they cite several community-based studies in which low levels of hydrogen sulfide were associated with health complaints (Haahtela et al. 1992; Jaakkola et al. 1991; Jaakkola et al. 1990).

The third mechanism acknowledges that the odorant is not the only source of pollutant or irritant that is in the indoor environment. Other co-pollutants may originate from the source of the odorant material, from other sources within the residence such as VOCs and formaldehyde from wood products or NO_2 associated with gas stoves (Andersson et al. 1997; Hodgson et al. 2000), or be transported from outdoors such as ozone or vehicular pollutants . In this case the odorant may focus occupants' attention on the indoor air and the irritant symptoms, but may only be a minor contributor to the health concerns that are really attributable to other materials present in the indoor environment.

One additional effect of malodor is that occupants are aware of the status of a building with respect to construction with imported drywall. Knowledge of the drywall status of a building could bias beliefs about relationships between health symptoms and occupancy of that space. This type of bias is commonly described as dependent error in the vernacular of epidemiology (Rothman et al. 2008). Under this scenario, symptoms such as upper respiratory irritation experienced by occupants of complaint homes could be incorrectly ascribed to construction with imported drywall, as opposed to other factors. At least one well known respiratory irritant, formaldehyde, was found at elevated concentrations in the indoor air of both complaint and non-complaint homes. Yet, homes without the malodor do not have a history of health complaints with CPSC. The low air exchange rate in complaint and non-complaint homes could also be a factor in dependent error because of the potential for other common respiratory irritants to accumulate within these residences. Further research would be needed to evaluate the role of odor in reported health effects in greater detail.

6.6 COMPARISON TO CHAMBER STUDIES

Results of chamber studies of imported drywall reported to date are generally consistent with the observations made during the field investigation with some notable exceptions. Accelerated corrosion of copper evidenced by visual inspection and SEM/EDS was reported when clean copper tubing was stored with imported drywall (Unified Engineering Inc. 2009). Similarly, the rate of corrosion measured on both copper and silver test coupons during the field investigation was substantially and significantly greater in homes with imported drywall than in homes with domestic drywall (see Section 5.2.3). The type of corrosion observed in the chamber studies also agrees with the results of the field investigation. Specifically, analysis of corrosion material in the chamber studies and the field investigation indicate production of Cu_2S (and Ag_2S in the field study coupons) rather than sulfates, chlorides or other common forms of copper corrosion. These results are consistent with sulfidation via H_2S and carbonyl sulfide although only the former species was found at elevated levels in indoor air of homes with imported drywall (Graedel et al. 1983), whereas chamber studies have identified both

H_2S and carbonyl sulfide in headspace analysis (CAS 2009; EPA 2009; Unified Engineering Inc. 2009).

In contrast to the agreement note here, some corrosive species reported to be released from imported drywall tested in chamber studies were not observed at elevated concentrations during the field investigation. For instance, carbonyl sulfide has been observed in some chamber tests (Unified Engineering Inc. 2009) but was not found in homes of this field investigation. The absence of carbonyl sulfide in samples obtained from homes could be explained by several reasons. First, carbonyl sulfide may have been present at concentrations below the method detection limit of the grab sampling procedure (see Table 4.2). Second, some species present in chamber studies may not be produced in the field because of differences in environmental conditions between the lab and actual homes. The chamber studies are typically performed at elevated temperatures (e.g., 37 °C, 98 °F), while the average indoor temperature of homes included in the present study was 25.5 °C (78 °F). Third, species evolved from imported drywall could be rapidly scavenged by sinks inside of homes that are not present in the chamber studies. For example, hydrogen sulfide and carbonyl sulfide are known to rapidly react with copper (Graedel et al. 1985), which could result in limited direct evidence of their presence within homes. Measurements of sulfur dioxide made during exploratory experiments conducted in EH&E's laboratory also support this explanation. As shown in Figure 6.5, sulfur dioxide was measured at elevated concentrations in the air of a sealed and heated glass container that held imported drywall and water. Yet, no notable differences in sulfur dioxide concentrations compared to the control conditions were observed when a piece of clean copper tubing was also present inside the jar, although the copper tubing rapidly showed evidence of corrosion, thereby supporting the scavenging of the reactive gases from the air. Additional investigation is required to ascertain the reasons that fully explain differences between the field investigation and chambers studies that have been reported to date.

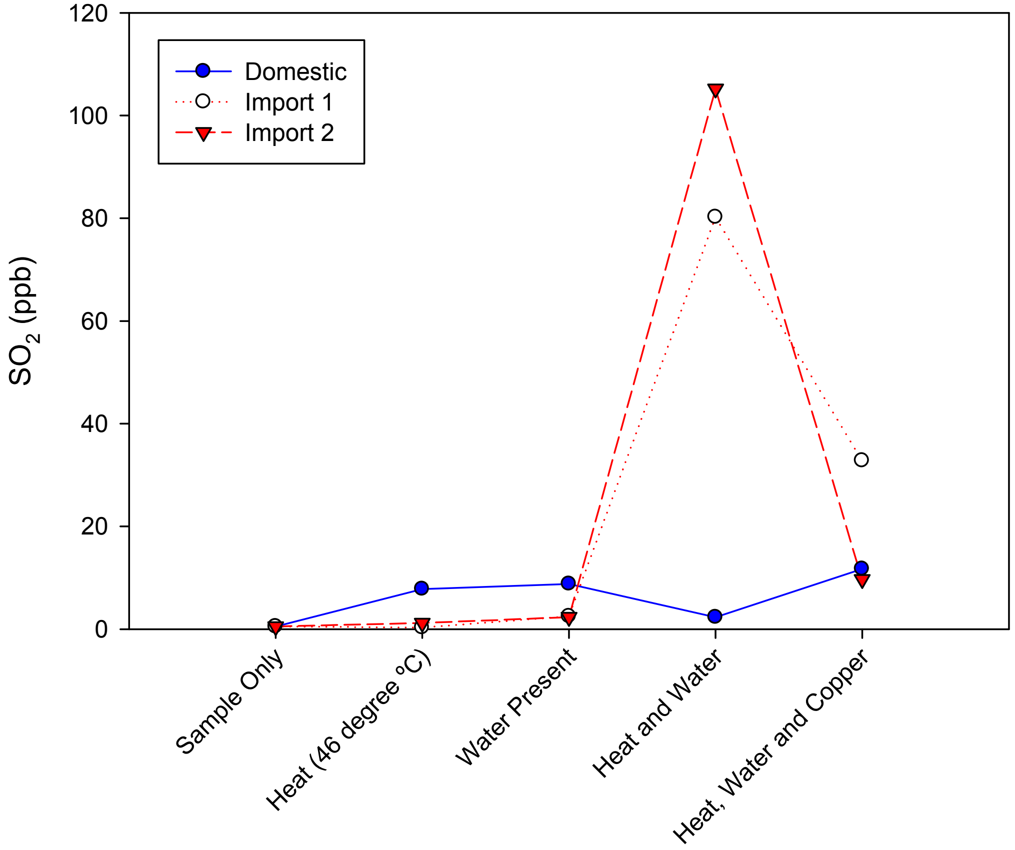


Figure 6.5 Sulfur Dioxide (SO_2) Concentrations inside Small-volume Chamber Studies Comparing Two Imported and One Domestic Drywall Sample Under Varying Environmental Conditions.

6.7 LIMITATIONS

This study was designed to characterize the air quality in homes that had health and/or corrosion complaints suspected to be associated with certain types of drywall. This "suspect" drywall is believed to originate and be imported from the People's Republic of China. However, at this time there is insufficient evidence to support or refute the assertion that all Chinese-origin or imported drywall exhibits the health or corrosive characteristics reported in complaint homes.

The intent of this sampling and analysis program was to elucidate the relationships between suspect drywall and environmental conditions existing in the home that could be characterized by use of objective measurements such as the rate of corrosion on metal surfaces. A variety of sampling and inspectional techniques were utilized in this study. This study was designed as an in situ investigation in which the house was characterized in the “lived in” condition. (Certain exceptions to this “lived in” characterization, where the houses were unoccupied during the testing, are discussed in the body of the report.) So as to not possibly miss an important interaction effect, no attempt was made to restrict occupant activities, manipulate the mechanical systems or remove materials from the residence prior to, or during, sampling. Thirteen of the 51 homes in this study were unoccupied during the sampling (12 complaint homes). Unoccupied homes represent a different environment than occupied homes and thus could potentially be an important factor when looking for associations between sources, the environment and effects. To examine the potential for occupancy status to impact the study findings, we compared several key parameters (hydrogen sulfide, formaldehyde, air exchange rate, dew point, temperature) by occupancy status and found that only temperature was significantly different across the two groups (similar results were observed when the analysis was restricted to comparing occupied status within complaint homes only). Additionally, consistent results were observed in all regression models when they were re-run controlling for occupancy status.

Formaldehyde was observed to be a predictor of silver corrosion but this study cannot rule out the possibility that formaldehyde is a surrogate for some other agent. For example, formaldehyde is corrosive to some metals, although its related acid (formic acid) is known to be more corrosive. Similarly, formaldehyde concentrations were positively associated with indoor air temperature. Therefore, the effect of formaldehyde on corrosion could be a true effect, or formaldehyde could be a marker for formic acid, temperature or some other variable.

The indoor environment of the complaint homes is complex, dynamic and in many ways challenging to characterize due to the low concentrations of the contaminants present and the highly reactive nature of many of the species of interest. It is also probable that there are important interactions between the materials emitted from the suspect drywall and airborne compounds present in the indoor environment that may be associated with other sources, as well as specific home characteristics, that could cause, or be a significant contributor to, the complaints reported.

7.0 CONCLUSIONS

The objective of the in-home investigation was to characterize the indoor environment in representative complaint homes in detail, obtain air samples and other objective measurements that could be used for future risk assessments and examine homes for evidence of health stressors that could plausibly be related to drywall based on complaints and scientific information compiled by CPSC and EH&E. The following associations were observed based on the results of the 51-home study:

- Study homes with imported drywall had elevated rates of objectively quantified corrosion

  CPSC complaint homes were found to have elevated rates of corrosion as measured objectively by metal coupon and visual inspection, compared to non-complaint homes. This finding remained when house status was determined using an objective marker of imported drywall (FTIR/XRF).

- Imported drywall found in these homes was associated with increased levels of hydrogen sulfide in indoor air

  Homes with imported drywall had significantly greater hydrogen sulfide concentrations compared to homes with domestic drywall.

- Hydrogen sulfide concentrations in air were associated with higher dew points for complaint homes

  A positive association was observed between elevated dew points and hydrogen sulfide concentrations for homes with imported drywall. Hydrogen sulfide was present where the dew point reached typical room temperatures and condensation of water vapor would be expected.

- Hydrogen sulfide and formaldehyde concentrations in indoor air were associated with corrosion rates

  Hydrogen sulfide was associated with corrosion rates in these study homes. For silver, a potential interactive effect was seen with formaldehyde; the effect of formaldehyde on corrosion rates was dependent upon the presence of hydrogen *sulfide. Formaldehyde may be associated itself or may be a marker of some other factor associated with corrosion (e.g., formic acid).*

- Objective markers of imported drywall can be quantified using portable FTIR and XRF analyzers

  FTIR and XRF analyzers provide an additional metric for characterizing homes with imported drywall that can be used in conjunction with objectively measured estimates of corrosion rates and malodor.

- Air exchange rates in the study homes were all on the low-end of typical air exchange rates in homes

  Both complaint and non-complaint homes were newly constructed homes with air exchange rates consistent with the low end of the distribution for North American housing stock (i.e., tightly constructed homes). These low air exchange rates may play an important role in the effect of gases and indoor environmental conditions on corrosion and possible exposures to indoor contaminants.

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APPENDIX A

SUMMARY DATA TABLES

SUMMARY DATA TABLES

Table A.1 Summary of Analytical Laboratory Quality Assurance Flags

Sample Group	Total Number of Measurements*	Laboratory Quality Assurance Flags**				Laboratory Flags (%)
		Receiving	Laboratory Blank	Laboratory Duplicate	Laboratory Spike (Standard)	
Acids (inorganic)	1,758	0	0	0	0	0
Acids (organic)	1,180	0	0	0	0	0
Active aldehydes	3,552	0	0	0	0	0
Reduced sulfur	5,080	460	0	0	0	9.1
H_2S passive	307	58	0	2	0	19.5
HF passive	302	58	0	0	0	19.2
NO_2 passive	302	162	0	0	0	53.6
O_3 passive	303	58	0	4	0	20.5
SO_2 passive	302	0	0	0	0	0
Passive aldehydes	2,754	522	0	0	34	20.2
VOCs	11,749	0	0	0	8	0.1
Totals	**27,589**	**1,318**	**0**	**6**	**42**	**5.0**

H_2S	hydrogen sulfide
HF	hydrogen fluoride
NO_2	nitrogen dioxide
O_3	ozone
SO_2	sulfur dioxide
VOC	volatile organic compound

* Data points considered in the analysis, including samples, duplicates, field blanks, and shipping blanks

** Number of measurements with one or more laboratory quality assurance flags divided by the total number of measurements.

Table A.2 Summary of Precision Estimates for Air Samples, Corrosion, and Drywall Measurements

Compound	Sample Group	Sample Matrix	N*	Precision Estimate (%)**
Hydrofluoric acid	Acids (inorganic)	Air	5	4.4
Acetic acid	Acids (organic)	Air	47	5.9
Formic acid	Acids (organic)	Air	23	8.5
2,5-Dimethylbenzaldehyde	Active aldehyde	Air	1	10
Acetaldehyde	Active aldehyde	Air	48	5.7
Benzaldehyde	Active aldehyde	Air	48	14.4
Butyraldehyde	Active aldehyde	Air	46	13.7
Formaldehyde	Active aldehyde	Air	48	10
Isovaleraldehyde	Active aldehyde	Air	32	9.2
n-Hexaldehyde	Active aldehyde	Air	48	8.7
Propionaldehyde	Active aldehyde	Air	45	10
Valeraldehyde	Active aldehyde	Air	48	9.9
Hydrogen sulfide (H_2S)	H_2S Passive	Air	28	12.5
Nitrogen dioxide (NO_2)	NO_2 Passive	Air	48	18.5
Ozone (O_3)	O_3 Passive	Air	1	6.7
Acetaldehyde	Passive aldehyde	Air	47	9.2
Acrolein	Passive aldehyde	Air	32	5.9
Benzaldehyde	Passive aldehyde	Air	51	8
Butanal (*)	Passive aldehyde	Air	48	5.9
Formaldehyde	Passive aldehyde	Air	51	3.9
Hexanal	Passive aldehyde	Air	51	3.5
Pentanal	Passive aldehyde	Air	6	17.3
Propanal	Passive aldehyde	Air	51	7.4
Carbon disulfide	Reduced sulfur	Air	38	7.2
1,1,1-Trichloroethane	VOC	Air	3	8.8
1,1,2-Trichlorotrifluoroethane	VOC	Air	2	3.7
1,1-Dichloroethene	VOC	Air	26	5.6
1,2,4-Trimethylbenzene	VOC	Air	1	1.7
1,2-Dichlorobenzene	VOC	Air	26	6
1,2-Dichloroethane	VOC	Air	1	4.9
1,2-Dichloropropane	VOC	Air	24	27
1,3,5-Trimethylbenzene	VOC	Air	2	13.9
1,3-Butadiene	VOC	Air	20	6.2
1,4-Dichlorobenzene	VOC	Air	6	11.8
1,4-Dioxane	VOC	Air	13	10.9
2-Butanone (MEK)	VOC	Air	1	5.1
2-Hexanone	VOC	Air	27	23.6
2-Propanol (isopropyl alcohol)	VOC	Air	18	18.4
4-Ethyltoluene	VOC	Air	28	33.9
4-Methyl-2-pentanone	VOC	Air	20	6.9
Acetone	VOC	Air	20	10.1
Acetonitrile	VOC	Air	27	19
Acrolein	VOC	Air	7	16.3
Acrylonitrile	VOC	Air	28	24.4
α-Pinene	VOC	Air	1	0
Benzene	VOC	Air	28	33.9
Benzyl Chloride	VOC	Air	28	33.1
Bromodichloromethane	VOC	Air	1	5.2
Bromoform	VOC	Air	11	5.8

Table A.2 Continued

Compound	Sample Group	Sample Matrix	N*	Precision Estimate (%)**
Bromomethane	VOC	Air	2	3.7
Carbon Disulfide	VOC	Air	6	7.7
Carbon Tetrachloride	VOC	Air	14	6.1
Chloroform	VOC	Air	27	7
Chloromethane	VOC	Air	27	17.5
cis-1,3-Dichloropropene	VOC	Air	26	26.4
Cumene	VOC	Air	3	0.6
Cyclohexane	VOC	Air	6	4.1
Dibromochloromethane	VOC	Air	19	14.1
Dichlorodifluoromethane (CFC 12)	VOC	Air	5	8
d-Limonene	VOC	Air	27	14.3
Ethanol	VOC	Air	28	35.9
Ethyl acetate	VOC	Air	28	33.9
Ethylbenzene	VOC	Air	25	24.9
m,p-Xylenes	VOC	Air	24	6.9
Methyl methacrylate	VOC	Air	28	33
Methyl tert-Butyl Ether	VOC	Air	1	0
Methylene chloride	VOC	Air	2	5.3
Naphthalene	VOC	Air	6	2.4
n-Butyl acetate	VOC	Air	20	27.3
n-Heptane	VOC	Air	25	13.8
n-Hexane	VOC	Air	25	25
n-Nonane	VOC	Air	24	5.8
n-Octane	VOC	Air	24	24.9
n-Propylbenzene	VOC	Air	24	16.2
o-Xylene	VOC	Air	17	5.6
Propene	VOC	Air	25	6.9
Styrene	VOC	Air	22	28
Tetrachloroethene	VOC	Air	26	6.2
Tetrahydrofuran (THF)	VOC	Air	15	12.1
Toluene	VOC	Air	17	16.5
trans-1,2-Dichloroethene	VOC	Air	28	32.7
trans-1,3-Dichloropropene	VOC	Air	2	7.8
Trichloroethene	VOC	Air	3	0
Trichlorofluoromethane	VOC	Air	8	15.8
Vinyl acetate	VOC	Air	27	8.5
Vinyl chloride	VOC	Air	2	23.4
Copper sulfide	Corrosion	Corrosion	1	3.6
Silver silfide	Corrosion	Corrosion	10	28.1
Carbonate	Drywall (FTIR Lab)	Drywall	98	13.8
Strontium	Drywall (XRF Field)	Drywall	810	12.3
Strontium	Drywall (XRF Lab)	Drywall	111	3.4

VOC volatile organic compound

* number of primary sample and duplicate pairs above the reporting limit.
** root mean square of the scaled relative differences between pairs of duplicate samples

Table A.3 Summary Statistics for Corrosion Rates (Angstrom/30 days) in Indoor and Outdoor Air, by House

				Cu_2S		Ag_2S	
No.	**State**	**Status**	**n**	**Indoor Ave (Max)**	**OA**	**Indoor Ave (Max)**	**OA**
1	FL	Complaint	2	331.5 (445.0)	16.0	932.0 (1102.0)	601.0
2	FL	Non-complaint	2	16.0 (16.0)	16.0	290.5 (381.0)	253.0
3	FL	Complaint	2	255.5 (304.0)	16.0	531.0 (581.0)	401.0
4	FL	Complaint	2	16.0 (16.0)	16.0	555.5 (748.0)	140.0
5	FL	Non-complaint	3	16.0 (16.0)	16.0	95.7 (112.0)	246.0
6	FL	Complaint	2	16.0 (16.0)	16.0	512.0 (563.0)	321.0
7	FL	Complaint	3	591.0 (752.0)	16.0	1082.0 (1684.0)	64.0
8	FL	Non-complaint	2	16.0 (16.0)	16.0	168.0 (172.0)	182.0
9	FL	Complaint	3	260.7 (750.0)	16.0	446.3 (475.0)	203.0
10	FL	Complaint	2	273.5 (531.0)	462.0	514.0 (727.0)	216.0
11	FL	Complaint	3	627.3 (1221.0)	16.0	908.3 (1162.0)	464.0
12	FL	Complaint	2	332.0 (377.0)	16.0	1658.0 (2602.0)	186.0
13	FL	Complaint	3	529.0 (577.0)	16.0	775.3 (935.0)	187.0
14	FL	Complaint	3	337.3 (400.0)	2687.0	878.7 (1253.0)	371.0
15	FL	Complaint	2	268.5 (301.0)	0.0	463.0 (599.0)	0.0
16	FL	Complaint	3	446.3 (531.0)	16.0	914.0 (1112.0)	45.0
17	FL	Non-complaint	2	52.0 (88.0)	556.0	195.0 (230.0)	251.0
18	FL	Complaint	3	16.0 (16.0)	602.0	171.3 (309.0)	253.0
19	FL	Complaint	3	669.7 (866.0)	462.0	1061.0 (2066.0)	281.0
20	FL	Complaint	3	478.3 (512.0)	734.0	815.3 (1223.0)	200.0
21	FL	Complaint	3	924.7 (1561.0)	750.0	1054.3 (1317.0)	345.0
22	FL	Non-complaint	3	16.0 (16.0)	2473.0	291.3 (410.0)	518.0
23	FL	Complaint	3	1231.3 (2204.0)	4845.0	1165.3 (1497.0)	643.0
24	FL	Complaint	3	130.7 (191.0)	16.0	593.7 (745.0)	262.0
25	FL	Complaint	3	16.0 (16.0)	16.0	327.7 (441.0)	401.0
26	FL	Complaint	3	262.0 (346.0)	16.0	679.7 (727.0)	496.0
27	FL	Complaint	3	321.3 (762.0)	16.0	1180.0 (1511.0)	626.0
28	FL	Complaint	3	243.0 (294.0)	16.0	1434.0 (1777.0)	468.0
29	LA	Complaint	3	207.0 (589.0)	16.0	956.7 (1381.0)	367.0
30	LA	Complaint	3	363.3 (506.0)	16.0	751.0 (962.0)	401.0
31	LA	Complaint	3	126.0 (346.0)	16.0	996.3 (1209.0)	345.0
32	LA	Complaint	3	243.3 (416.0)	16.0	2014.3 (2288.0)	338.0
33	LA	Non-complaint	3	16.0 (16.0)	16.0	145.3 (164.0)	432.0
34	LA	Complaint	3	216.3 (334.0)	16.0	483.3 (579.0)	253.0
35	LA	Non-complaint	3	16.0 (16.0)	16.0	269.7 (285.0)	401.0
36	LA	Complaint	3	1225.0 (1873.0)	16.0	4446.3 (7767.0)	413.0
37	LA	Complaint	3	16.0 (16.0)	16.0	435.0 (478.0)	722.0
38	LA	Complaint	3	331.7 (779.0)	16.0	943.7 (1844.0)	641.0
39	MS	Complaint	3	87.7 (231.0)	16.0	735.7 (877.0)	367.0
40	MS	Complaint	3	122.0 (203.0)	16.0	1213.3 (2165.0)	134.0
41	VA	Complaint	3	16.0 (16.0)	16.0	315.3 (412.0)	432.0
42	VA	Non-complaint	3	16.0 (16.0)	16.0	166.3 (268.0)	352.0
43	VA	Complaint	3	239.3 (686.0)	16.0	1366.3 (2405.0)	235.0
44	VA	Complaint	3	16.0 (16.0)	16.0	208.7 (248.0)	669.0
45	VA	Complaint	3	349.7 (462.0)	16.0	671.3 (820.0)	518.0
46	VA	Non-complaint	3	16.0 (16.0)	16.0	157.0 (194.0)	345.0
47	VA	Complaint	3	90.3 (239.0)	16.0	1157.0 (1924.0)	200.0
48	VA	Complaint	3	156.0 (241.0)	16.0	615.0 (857.0)	496.0
49	AL	Complaint	3	76.0 (196.0)	16.0	451.0 (529.0)	90.0
50	AL	Complaint	2	106.0 (196.0)	16.0	403.5 (601.0)	104.0
51	AL	Non-complaint	3	16.0 (16.0)	16.0	113.3 (158.0)	156.0

$\mu g/m^3$	micrograms per cubic meter	ave	average	OA	outdoor air
n	number of samples	max	maximum		

States: FL = Florida, LA = Louisiana, MS = Mississippi, VA = Virginia, AL = Alabama

Table A.4 Summary Statistics for Aldehyde Concentrations ($\mu g/m^3$) in Indoor and Outdoor Air, by House

No.	State	Status	n	Acetaldehyde Indoor Ave (Max)	Acetaldehyde OA	Benzaldehyde Indoor Ave (Max)	Benzaldehyde OA	Butyraldehyde Indoor Ave (Max)	Butyraldehyde OA	Crotonaldehyde Indoor Ave (Max)	Crotonaldehyde OA
1	FL	Complaint	3	25.7 (26.7)	1.6	5.2 (5.5)	0.5	5.3 (5.5)	0.5	0.5 (0.5)	0.5
2	FL	Non-complaint	3	40.7 (42.0)	1.1	7.5 (7.7)	0.5	6.2 (6.5)	0.5	0.5 (0.5)	0.5
3	FL	Complaint	3	14.7 (29.8)	0.6	3.7 (8.0)	0.6	3.6 (7.6)	0.6	0.5 (0.5)	0.6
4	FL	Complaint	3	54.9 (59.6)	1.9	4.5 (4.7)	0.7	2.7 (3.0)	0.7	0.5 (0.5)	0.7
5	FL	Non-complaint	3	22.2 (24.0)	1.8	6.2 (7.0)	0.7	4.1 (4.4)	0.7	0.5 (0.5)	0.7
6	FL	Complaint	3	29.2 (30.0)	1.5	2.7 (3.2)	0.5	4.7 (5.0)	0.5	0.5 (0.5)	0.5
7	FL	Complaint	3	31.1 (33.0)	1.4	17.0 (19.0)	1.3	4.0 (4.4)	0.5	0.5 (0.6)	0.5
8	FL	Non-complaint	3	24.5 (25.5)	1.6	4.3 (4.4)	0.6	1.6 (1.8)	0.6	0.5 (0.5)	0.6
9	FL	Complaint	3	30.0 (31.0)	1.6	4.9 (5.0)	0.5	6.0 (6.4)	0.5	0.5 (0.5)	0.5
10	FL	Complaint	3	50.8 (53.0)	1.6	3.9 (4.5)	0.5	3.4 (3.7)	0.5	0.5 (0.5)	0.5
11	FL	Complaint	3	14.3 (15.0)	1.4	6.4 (6.6)	0.5	1.7 (1.7)	0.5	0.5 (0.5)	0.5
12	FL	Complaint	3	31.1 (31.2)	44.4	6.9 (7.2)	0.5	6.2 (6.5)	0.5	0.5 (0.5)	0.5
13	FL	Complaint	3	43.0 (44.0)	0.5	9.8 (10.0)	0.5	6.1 (6.3)	0.5	0.5 (0.5)	0.5
14	FL	Complaint	3	24.0 (24.0)	0.5	3.4 (3.8)	0.5	2.7 (4.0)	0.5	0.5 (0.5)	0.5
15	FL	Complaint	3	18.2 (20.0)	1.8	4.9 (5.3)	0.5	2.6 (4.3)	0.5	2.2 (5.7)	0.5
16	FL	Complaint	3	138.3 (140.0)	1.7	10.9 (12.0)	0.5	4.8 (5.0)	0.5	0.5 (0.5)	0.5
17	FL	Non-complaint	3	50.2 (52.0)	1.7	6.9 (7.1)	0.5	8.5 (8.7)	0.5	0.5 (0.5)	0.5
18	FL	Complaint	3	52.5 (54.1)	1.9	11.4 (13.0)	0.5	8.4 (9.7)	0.5	0.5 (0.5)	0.5
19	FL	Complaint	3	26.3 (27.0)	1.3	4.9 (5.2)	0.5	4.3 (5.2)	0.5	0.5 (0.5)	0.5
20	FL	Complaint	3	28.1 (29.9)	1.4	9.0 (10.0)	0.5	6.5 (6.8)	0.5	0.5 (0.5)	0.5
21	FL	Complaint	3	50.5 (54.0)	0.5	5.7 (6.2)	0.5	4.4 (6.2)	0.5	0.5 (0.5)	0.5
22	FL	Non-complaint	3	52.5 (54.3)	1.2	9.3 (10.0)	0.5	11.7 (12.1)	0.5	0.5 (0.5)	0.5
23	FL	Complaint	3	44.7 (46.0)	1.1	8.1 (8.7)	0.5	10.3 (11.0)	0.5	0.8 (1.0)	1.0
24	FL	Complaint	3	28.7 (30.0)	0.5	4.3 (4.7)	0.5	3.4 (3.5)	0.5	0.5 (0.5)	0.5
25	FL	Complaint	3	34.0 (37.0)	0.5	6.4 (7.1)	0.5	5.1 (5.4)	0.5	0.5 (0.5)	0.5
26	FL	Complaint	3	24.9 (26.0)	0.5	12.1 (12.4)	0.5	7.3 (9.0)	0.5	0.5 (0.5)	0.5
27	FL	Complaint	3	52.7 (59.0)	0.5	5.3 (6.2)	0.5	5.0 (5.8)	0.5	0.5 (0.5)	0.5
28	FL	Complaint	3	57.2 (59.0)	0.5	10.5 (11.5)	0.5	18.5 (19.5)	0.5	0.5 (0.6)	0.5
29	LA	Complaint	3	48.4 (51.2)	0.5	8.7 (8.8)	0.5	3.2 (3.3)	0.5	1.0 (1.0)	1.0
30	LA	Complaint	3	26.3 (28.0)	0.6	12.0 (13.0)	0.6	2.9 (3.0)	0.6	1.0 (1.0)	1.2
31	LA	Complaint	3	63.9 (66.0)	1.2	7.5 (8.4)	0.5	5.9 (6.3)	0.5	0.6 (1.0)	0.5
32	LA	Complaint	3	55.2 (56.0)	0.5	21.7 (23.0)	0.5	10.6 (11.0)	0.5	0.5 (0.5)	0.5
33	LA	Non-complaint	3	43.3 (48.7)	1.1	10.3 (11.1)	0.5	5.1 (5.8)	0.5	0.5 (0.5)	0.5
34	LA	Complaint	3	23.7 (24.0)	1.6	5.9 (6.3)	0.5	2.5 (2.9)	0.5	0.5 (0.5)	0.5
35	LA	Non-complaint	3	33.4 (37.0)	1.8	4.8 (4.9)	0.5	3.9 (4.3)	0.5	0.5 (0.5)	0.5
36	LA	Complaint	3	33.4 (37.0)	2.8	9.8 (11.0)	0.4	4.0 (4.4)	0.4	0.5 (0.5)	0.4
37	LA	Complaint	3	17.7 (19.0)	1.5	7.0 (7.9)	0.5	1.8 (2.0)	0.5	0.5 (0.5)	0.5
38	LA	Complaint	3	7.0 (8.8)	1.3	5.2 (5.3)	3.1	0.7 (1.2)	0.5	0.5 (0.5)	0.5
39	MS	Complaint	3	18.7 (23.0)	0.5	7.4 (8.3)	0.5	2.1 (2.3)	0.5	0.5 (0.6)	0.5
40	MS	Complaint	3	33.3 (35.0)	1.3	5.6 (6.0)	0.6	2.9 (5.9)	0.6	0.5 (0.5)	0.6
41	VA	Complaint	3	18.1 (31.8)	NA	8.4 (11.9)	NA	3.3 (5.8)	NA	0.5 (0.5)	NA
42	VA	Non-complaint	3	8.4 (10.0)	NA	3.3 (3.5)	NA	1.2 (1.4)	NA	0.5 (0.5)	NA
43	VA	Complaint	3	33.5 (34.0)	1.3	16.8 (17.5)	0.5	6.3 (6.5)	0.5	0.5 (0.5)	0.5
44	VA	Complaint	3	40.8 (44.0)	1.2	9.0 (9.3)	0.5	5.2 (5.7)	0.5	0.5 (0.5)	0.5
45	VA	Complaint	3	19.0 (23.1)	0.5	8.8 (11.1)	0.5	2.9 (3.7)	0.5	0.5 (0.5)	0.5
46	VA	Non-complaint	3	17.3 (19.0)	0.6	4.3 (6.4)	0.6	2.8 (2.9)	0.6	0.5 (0.5)	0.6
47	VA	Complaint	3	32.7 (33.1)	NA	10.7 (12.0)	NA	5.5 (5.8)	NA	0.5 (0.5)	NA
48	VA	Complaint	3	63.0 (79.0)	NA	7.5 (8.9)	NA	3.2 (3.5)	NA	0.5 (0.5)	NA
49	AL	Complaint	3	39.0 (41.0)	1.4	8.1 (8.8)	1.5	3.6 (3.9)	0.5	0.5 (0.5)	0.5
50	AL	Complaint	3	35.3 (38.0)	NA	6.6 (7.1)	NA	3.4 (3.6)	NA	0.5 (0.6)	NA
51	AL	Non-complaint	3	14.7 (15.0)	NA	14.3 (17.0)	NA	2.4 (2.6)	NA	0.5 (0.5)	NA

$\mu g/m^3$ micrograms per cubic meter ave average OA outdoor
n number of samples max maximum

States: FL = Florida, LA = Louisiana, MS = Mississippi, VA = Virginia, AL = Alabama

Table A.4 Summary Statistics for Aldehyde Concentrations ($\mu g/m^3$) in Indoor and Outdoor Air, by House

				2,5-Dimethylbenzaldehyde		Formaldehyde		n-Hexaldehyde		Isovaleraldehyde	
No.	**State**	**Status**	**n**	**Indoor Ave (Max)**	**OA**	**Indoor Ave (Max)**	**OA**	**Indoor Ave (Max)**	**OA**	**Indoor Ave (Max)**	**OA**
1	FL	Complaint	3	0.5 (0.5)	0.5	46.6 (49.3)	4.5	31.8 (32.8)	0.5	1.2 (1.2)	0.5
2	FL	Non-complaint	3	1.3 (1.7)	0.5	74.7 (77.0)	3.2	24.2 (25.0)	0.5	2.4 (2.5)	0.5
3	FL	Complaint	3	0.7 (1.2)	0.6	33.5 (78.1)	2.5	17.6 (40.3)	0.6	0.9 (1.6)	0.6
4	FL	Complaint	3	0.5 (0.5)	0.7	57.1 (60.0)	3.4	21.6 (24.0)	0.7	1.3 (1.4)	0.7
5	FL	Non-complaint	3	0.5 (0.5)	0.7	65.7 (68.0)	6.2	41.5 (46.0)	0.7	0.9 (1.3)	0.7
6	FL	Complaint	3	0.5 (0.5)	0.5	36.7 (42.0)	5.3	14.5 (17.0)	0.5	1.5 (1.5)	0.5
7	FL	Complaint	3	0.5 (0.6)	0.5	154.9 (200.0)	5.0	58.5 (64.0)	0.5	0.9 (1.2)	0.5
8	FL	Non-complaint	3	0.8 (1.3)	0.6	40.7 (42.0)	2.9	7.7 (9.0)	0.6	0.5 (0.5)	0.6
9	FL	Complaint	3	0.5 (0.5)	0.5	43.5 (44.0)	4.1	61.3 (66.0)	0.5	1.7 (1.8)	0.5
10	FL	Complaint	3	0.5 (0.5)	3.4	56.2 (63.0)	1.5	13.7 (15.0)	0.5	0.6 (1.0)	0.5
11	FL	Complaint	3	0.5 (0.5)	0.5	97.3 (100.0)	5.3	24.0 (25.0)	0.5	0.5 (0.5)	0.5
12	FL	Complaint	3	0.5 (0.5)	0.5	48.7 (49.0)	0.5	21.1 (23.0)	0.5	2.2 (2.3)	0.5
13	FL	Complaint	3	0.5 (0.5)	0.5	88.5 (92.5)	0.5	50.2 (53.5)	0.5	2.0 (2.3)	0.5
14	FL	Complaint	3	5.7 (7.0)	7.5	36.3 (37.0)	0.5	6.4 (7.4)	0.5	0.5 (0.5)	0.5
15	FL	Complaint	3	0.5 (0.6)	0.5	50.8 (58.0)	5.6	16.4 (18.0)	0.5	0.5 (0.6)	0.5
16	FL	Complaint	3	0.8 (1.3)	0.5	110.0 (110.0)	3.7	26.5 (28.5)	0.5	2.8 (3.4)	0.5
17	FL	Non-complaint	3	0.5 (0.5)	0.5	66.2 (68.0)	5.1	96.5 (99.0)	0.5	2.5 (2.7)	0.5
18	FL	Complaint	3	0.5 (0.5)	0.5	56.4 (73.2)	6.5	21.0 (24.1)	0.5	1.5 (1.6)	0.5
19	FL	Complaint	3	0.5 (0.5)	3.4	58.5 (66.0)	1.4	14.3 (15.0)	0.5	1.4 (1.7)	0.5
20	FL	Complaint	3	0.5 (0.5)	0.5	53.3 (60.8)	6.0	23.4 (25.9)	0.5	0.5 (0.5)	0.5
21	FL	Complaint	3	0.5 (0.5)	3.1	43.3 (44.0)	1.1	31.0 (35.0)	0.5	1.4 (1.5)	0.5
22	FL	Non-complaint	3	0.5 (0.5)	0.5	96.5 (110.5)	5.9	42.3 (44.8)	0.5	2.1 (2.1)	0.5
23	FL	Complaint	3	0.8 (1.0)	1.0	21.7 (22.0)	2.0	44.2 (48.0)	0.5	1.5 (1.7)	0.5
24	FL	Complaint	3	0.5 (0.5)	0.5	64.5 (65.5)	3.4	20.8 (22.0)	0.5	1.1 (1.1)	0.5
25	FL	Complaint	4	0.5 (0.5)	0.5	77.0 (84.8)	3.1	60.2 (67.0)	0.5	2.2 (2.4)	0.5
26	FL	Complaint	3	0.5 (0.5)	0.5	129.4 (140.0)	2.3	77.8 (85.0)	0.5	2.2 (2.4)	0.5
27	FL	Complaint	3	0.5 (0.5)	0.5	52.3 (55.0)	3.2	59.0 (63.0)	0.5	2.0 (2.2)	0.5
28	FL	Complaint	3	1.1 (1.1)	1.0	165.0 (190.0)	0.5	107.7 (120.0)	0.5	4.0 (4.2)	0.5
29	LA	Complaint	3	1.0 (1.0)	0.5	120.5 (120.6)	2.7	38.2 (41.2)	0.5	1.7 (1.9)	0.5
30	LA	Complaint	3	0.5 (0.5)	0.6	47.7 (52.9)	0.6	49.0 (54.0)	0.6	0.7 (1.1)	0.6
31	LA	Complaint	3	0.5 (0.5)	0.5	67.7 (69.0)	3.5	90.5 (96.5)	0.5	2.5 (2.7)	0.5
32	LA	Complaint	3	0.5 (0.5)	0.5	361.7 (375.0)	1.8	173.3 (180.0)	0.5	2.5 (5.2)	0.5
33	LA	Non-complaint	3	0.5 (0.5)	0.5	43.5 (45.2)	1.8	63.5 (70.0)	0.5	0.9 (1.8)	0.5
34	LA	Complaint	3	1.0 (1.3)	0.5	31.5 (31.8)	4.5	27.7 (30.0)	0.5	1.1 (1.1)	0.5
35	LA	Non-complaint	3	0.5 (0.5)	0.5	52.0 (53.0)	4.9	41.2 (45.0)	0.5	1.8 (2.0)	0.5
36	LA	Complaint	3	0.5 (0.5)	0.4	220.3 (240.0)	5.2	101.8 (110.0)	1.0	3.3 (3.7)	0.4
37	LA	Complaint	3	0.5 (0.5)	0.5	51.7 (55.1)	3.7	13.7 (15.0)	0.5	0.9 (1.1)	0.5
38	LA	Complaint	3	0.5 (0.5)	0.5	37.0 (54.0)	3.7	7.8 (12.0)	0.5	0.5 (0.5)	0.5
39	MS	Complaint	3	0.9 (1.1)	1.0	84.8 (86.5)	3.7	30.5 (33.0)	0.5	0.7 (1.0)	0.5
40	MS	Complaint	3	0.5 (0.5)	0.6	108.4 (120.1)	4.4	27.2 (30.0)	0.6	0.7 (1.1)	0.6
41	VA	Complaint	3	0.5 (0.5)	NA	59.4 (81.6)	NA	34.7 (62.7)	NA	1.1 (2.4)	NA
42	VA	Non-complaint	3	0.5 (0.5)	NA	28.3 (31.5)	NA	16.1 (20.0)	NA	0.5 (0.5)	NA
43	VA	Complaint	3	0.5 (0.5)	0.5	125.1 (130.0)	2.8	130.1 (139.9)	0.5	3.4 (3.8)	0.5
44	VA	Complaint	3	0.5 (0.5)	0.5	93.2 (110.0)	2.2	68.3 (73.0)	0.5	2.7 (3.0)	0.5
45	VA	Complaint	3	0.5 (0.5)	0.5	76.0 (88.5)	1.9	36.3 (51.2)	0.5	0.5 (0.5)	0.5
46	VA	Non-complaint	3	0.5 (0.5)	0.6	27.7 (29.0)	0.6	35.6 (39.0)	0.6	0.9 (1.1)	0.6
47	VA	Complaint	3	0.5 (0.5)	NA	86.2 (100.4)	NA	91.4 (95.4)	NA	1.1 (2.3)	NA
48	VA	Complaint	3	0.5 (0.5)	NA	51.7 (65.0)	NA	43.7 (50.0)	NA	1.1 (1.4)	NA
49	AL	Complaint	3	0.5 (0.5)	0.5	158.3 (180.0)	4.3	47.8 (52.0)	0.5	2.4 (2.6)	0.5
50	AL	Complaint	3	0.5 (0.6)	NA	62.7 (72.0)	NA	43.3 (46.0)	NA	1.5 (1.8)	NA
51	AL	Non-complaint	3	0.5 (0.5)	NA	128.4 (140.1)	NA	25.5 (27.0)	NA	0.5 (0.5)	NA

$\mu g/m^3$ micrograms per cubic meter ave average OA outdoor air
n number of samples max maximum

States: FL = Florida, LA = Louisiana, MS = Mississippi, VA = Virginia, AL = Alabama

Table A.4 Summary Statistics for Aldehyde Concentrations ($\mu g/m^3$) in Indoor and Outdoor Air, by House

				Propionaldehyde		m,p-Tolualdehyde		o-Tolualdehyde		Valeraldehyde	
No.	State	Status	n	Indoor Ave (Max)	OA	Indoor Ave (Max)	OA	Indoor Ave (Max)	OA	Indoor Ave (Max)	OA
1	FL	Complaint	3	3.2 (3.4)	0.5	1.0 (1.1)	1.0	0.5 (0.5)	0.5	8.6 (8.9)	0.5
2	FL	Non-complaint	3	3.3 (3.4)	0.5	1.0 (1.0)	1.1	0.5 (0.5)	0.5	7.8 (8.2)	0.5
3	FL	Complaint	3	2.2 (4.6)	0.6	1.0 (1.0)	1.1	0.5 (0.5)	0.6	5.5 (11.9)	0.6
4	FL	Complaint	3	3.1 (3.5)	0.7	0.9 (1.0)	1.4	0.5 (0.5)	0.7	5.7 (6.2)	0.7
5	FL	Non-complaint	3	3.7 (4.0)	0.7	0.9 (1.0)	1.5	0.5 (0.5)	0.7	11.0 (11.0)	0.7
6	FL	Complaint	3	3.8 (3.9)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	4.0 (4.4)	0.5
7	FL	Complaint	3	7.7 (8.3)	17.0	1.0 (1.1)	1.0	0.5 (0.6)	0.5	16.3 (17.0)	0.5
8	FL	Non-complaint	3	2.2 (2.5)	0.6	1.0 (1.1)	1.1	0.5 (0.5)	0.6	2.6 (3.1)	0.6
9	FL	Complaint	3	4.8 (5.4)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	15.2 (16.0)	0.5
10	FL	Complaint	3	2.0 (2.3)	0.5	0.9 (1.0)	1.0	0.5 (0.5)	0.5	3.9 (4.8)	0.5
11	FL	Complaint	3	3.0 (3.1)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	6.1 (6.8)	0.5
12	FL	Complaint	3	4.3 (4.6)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	5.6 (5.8)	0.5
13	FL	Complaint	3	5.0 (5.1)	0.5	0.9 (1.0)	1.1	0.5 (0.5)	0.5	14.2 (14.5)	0.5
14	FL	Complaint	3	2.1 (2.2)	0.5	0.9 (1.0)	1.0	0.5 (0.5)	0.5	2.8 (3.6)	0.5
15	FL	Complaint	3	2.3 (2.5)	0.5	1.1 (1.2)	1.0	0.5 (0.6)	0.5	4.0 (4.4)	0.5
16	FL	Complaint	3	8.1 (8.2)	0.5	1.0 (1.0)	0.9	0.5 (0.5)	0.5	10.3 (12.0)	0.5
17	FL	Non-complaint	3	4.6 (4.8)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	18.7 (19.0)	0.5
18	FL	Complaint	3	5.2 (5.6)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	7.8 (8.4)	0.5
19	FL	Complaint	3	2.6 (2.8)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	4.2 (4.4)	0.5
20	FL	Complaint	3	3.6 (3.9)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	6.6 (6.9)	0.5
21	FL	Complaint	3	3.1 (3.2)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	7.8 (8.0)	0.5
22	FL	Non-complaint	3	14.0 (15.1)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	12.0 (13.1)	0.5
23	FL	Complaint	3	5.7 (6.1)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	14.5 (15.5)	0.5
24	FL	Complaint	3	3.4 (3.4)	0.5	1.0 (1.0)	1.1	0.5 (0.5)	0.5	5.3 (5.5)	0.5
25	FL	Complaint	4	5.3 (5.5)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	13.2 (15.0)	0.5
26	FL	Complaint	3	5.4 (5.7)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	17.4 (19.0)	0.5
27	FL	Complaint	3	5.0 (5.6)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	13.3 (14.0)	0.5
28	FL	Complaint	3	10.4 (11.0)	0.5	1.1 (1.1)	1.0	0.5 (0.6)	0.5	28.5 (31.0)	0.5
29	LA	Complaint	3	12.1 (27.1)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	8.9 (8.9)	0.5
30	LA	Complaint	3	4.8 (5.1)	0.6	1.0 (1.0)	1.2	0.5 (0.5)	0.6	11.2 (12.0)	0.6
31	LA	Complaint	3	10.2 (10.9)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	22.5 (23.0)	0.5
32	LA	Complaint	3	12.2 (12.5)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	46.0 (49.0)	0.5
33	LA	Non-complaint	3	6.1 (6.9)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	16.7 (17.1)	0.5
34	LA	Complaint	3	1.9 (2.6)	0.5	0.9 (1.0)	1.0	0.5 (0.5)	0.5	7.8 (8.2)	0.5
35	LA	Non-complaint	3	3.2 (3.4)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	9.2 (10.0)	0.5
36	LA	Complaint	3	5.2 (5.6)	0.4	1.0 (1.0)	0.9	0.5 (0.5)	0.4	19.4 (21.0)	0.4
37	LA	Complaint	3	2.1 (2.4)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	4.0 (4.3)	0.5
38	LA	Complaint	3	1.0 (1.5)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	2.0 (2.9)	0.5
39	MS	Complaint	3	2.3 (2.4)	0.5	1.0 (1.1)	1.0	0.5 (0.6)	0.5	7.1 (7.8)	0.5
40	MS	Complaint	3	2.6 (2.8)	0.6	0.9 (1.0)	1.1	0.5 (0.5)	0.6	5.6 (5.7)	0.6
41	VA	Complaint	3	2.6 (5.2)	NA	1.0 (1.0)	NA	0.5 (0.5)	NA	9.6 (16.9)	NA
42	VA	Non-complaint	3	0.8 (1.5)	NA	1.0 (1.1)	NA	0.5 (0.5)	NA	3.3 (4.1)	NA
43	VA	Complaint	3	6.4 (7.0)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	26.2 (27.0)	0.5
44	VA	Complaint	3	6.1 (6.6)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	17.2 (18.5)	0.5
45	VA	Complaint	3	2.5 (3.4)	0.5	1.0 (1.0)	1.0	0.5 (0.5)	0.5	9.2 (12.1)	0.5
46	VA	Non-complaint	3	1.8 (1.9)	0.6	1.0 (1.0)	1.1	0.5 (0.5)	0.6	8.4 (9.1)	0.6
47	VA	Complaint	3	5.7 (6.2)	NA	1.0 (1.0)	NA	0.5 (0.5)	NA	19.8 (21.1)	NA
48	VA	Complaint	3	3.1 (3.4)	NA	1.0 (1.0)	NA	0.5 (0.5)	NA	10.3 (11.0)	NA
49	AL	Complaint	3	4.4 (4.6)	0.5	0.9 (1.0)	1.0	0.5 (0.5)	0.5	11.2 (12.0)	0.5
50	AL	Complaint	3	2.8 (2.9)	NA	1.0 (1.1)	NA	0.5 (0.6)	NA	9.9 (10.5)	NA
51	AL	Non-complaint	3	2.5 (3.0)	NA	1.0 (1.0)	NA	0.5 (0.5)	NA	6.5 (6.7)	NA

$\mu g/m^3$	micrograms per cubic meter	ave	average	OA	outdoor air
n	number of samples	max	maximum		

States: FL = Florida, LA = Louisiana, MS = Mississippi, VA = Virginia, AL = Alabama

Table A.5 Summary Statistics for Aldehyde (Passive) Concentrations (μg/m^3) in Indoor and Outdoor Air, by House

No.	State	Status	n	Acetaldehyde		Acrolein		Benzaldehyde	
				Indoor Ave (Max)	OA	Indoor Ave (Max)	OA	Indoor Ave (Max)	OA
1	FL	Complaint	3	12.5 (12.7)	0.8	4.5 (4.8)	0.2	2.5 (2.7)	0.1
2	FL	Non-complaint	3	12.9 (15.4)	0.9	3.7 (4.4)	0.2	2.4 (2.9)	0.1
3	FL	Complaint	3	10.7 (11.3)	0.7	5.9 (6.0)	0.2	2.7 (2.8)	0.1
4	FL	Complaint	3	13.4 (15.2)	1.1	0.8 (0.9)	0.2	1.7 (1.8)	0.1
5	FL	Non-complaint	3	10.5 (11.6)	0.8	0.8 (0.8)	0.2	2.2 (2.5)	0.1
6	FL	Complaint	3	15.5 (15.5)	1.4	0.8 (0.8)	0.2	1.5 (1.5)	0.1
7	FL	Complaint	3	2.1 (3.6)	NA	5.4 (7.9)	NA	3.8 (4.7)	NA
8	FL	Non-complaint	3	14.4 (15.0)	1.1	0.8 (0.8)	0.2	2.6 (2.8)	0.1
9	FL	Complaint	3	11.4 (11.9)	1.1	0.8 (0.8)	0.2	2.0 (2.2)	0.1
10	FL	Complaint	3	21.8 (23.3)	1.3	0.9 (1.0)	0.2	1.9 (2.7)	0.1
11	FL	Complaint	3	4.4 (4.8)	0.7	1.9 (1.9)	0.2	2.6 (2.9)	0.1
12	FL	Complaint	3	20.8 (21.0)	1.0	1.0 (1.0)	0.2	3.0 (3.4)	0.1
13	FL	Complaint	3	11.1 (13.0)	0.8	2.2 (2.2)	0.2	3.3 (3.5)	0.1
14	FL	Complaint	3	10.4 (10.9)	0.8	0.8 (0.8)	0.2	1.4 (1.4)	0.1
15	FL	Complaint	3	9.1 (9.1)	0.8	1.6 (3.5)	0.2	1.8 (2.0)	0.1
16	FL	Complaint	3	10.0 (10.4)	1.2	1.1 (1.2)	0.2	2.7 (2.9)	0.1
17	FL	Non-complaint	3	13.1 (14.4)	1.0	4.6 (4.7)	0.2	2.7 (2.9)	0.1
18	FL	Complaint	3	15.5 (18.1)	NA	1.8 (4.0)	NA	4.2 (4.4)	NA
19	FL	Complaint	3	8.3 (8.3)	0.9	0.9 (1.0)	0.2	1.9 (2.0)	0.1
20	FL	Complaint	3	8.2 (10.7)	0.7	3.5 (3.6)	0.2	3.0 (3.4)	0.1
21	FL	Complaint	3	19.3 (19.4)	1.2	1.0 (1.0)	0.2	2.7 (2.8)	0.1
22	FL	Non-complaint	3	5.9 (8.3)	1.5	2.6 (2.7)	0.2	2.6 (2.8)	0.1
23	FL	Complaint	3	20.2 (20.6)	1.0	1.1 (1.1)	0.2	4.2 (4.3)	0.1
24	FL	Complaint	3	10.6 (11.3)	0.7	2.3 (2.3)	0.2	1.3 (1.3)	0.1
25	FL	Complaint	3	7.2 (8.5)	1.0	2.7 (2.8)	0.2	3.5 (3.6)	0.1
26	FL	Complaint	3	3.8 (4.2)	0.9	4.1 (4.5)	0.2	2.8 (2.8)	0.1
27	FL	Complaint	3	12.3 (13.5)	0.8	5.8 (6.0)	0.2	2.5 (2.7)	0.1
28	FL	Complaint	3	4.0 (4.7)	0.9	3.7 (3.8)	0.2	3.3 (3.8)	0.1
29	LA	Complaint	3	4.2 (4.6)	1.0	3.6 (3.7)	0.2	2.7 (2.8)	0.1
30	LA	Complaint	2	12.5 (12.5)	0.7	7.2 (7.3)	0.2	3.7 (3.7)	0.1
31	LA	Complaint	3	14.1 (15.3)	1.7	6.4 (6.7)	0.2	2.5 (2.7)	0.1
32	LA	Complaint	3	0.9 (0.9)	0.8	3.0 (3.1)	0.2	1.4 (1.5)	0.1
33	LA	Non-complaint	3	19.4 (22.2)	1.1	5.4 (5.8)	0.2	3.4 (3.7)	0.1
34	LA	Complaint	3	11.2 (11.9)	1.0	0.9 (0.9)	0.5	2.0 (2.1)	0.1
35	LA	Non-complaint	3	14.0 (15.0)	0.8	5.4 (6.0)	0.2	2.3 (2.5)	0.1
36	LA	Complaint	3	0.7 (0.7)	0.9	2.9 (3.3)	0.2	1.4 (1.8)	0.1
37	LA	Complaint	3	9.9 (10.7)	0.8	8.0 (8.8)	0.4	2.2 (2.5)	0.1
38	LA	Complaint	3	0.7 (0.7)	0.8	4.7 (4.9)	0.2	1.8 (1.9)	0.1
39	MS	Complaint	3	5.7 (8.3)	0.8	3.8 (4.5)	0.2	2.2 (2.5)	0.1
40	MS	Complaint	3	4.5 (5.7)	0.9	2.9 (3.0)	0.2	1.5 (1.6)	0.1
41	VA	Complaint	3	11.0 (11.5)	0.8	2.9 (3.2)	0.2	4.0 (4.2)	0.1
42	VA	Non-complaint	3	8.1 (9.0)	0.8	2.6 (2.9)	0.2	1.3 (1.7)	0.1
43	VA	Complaint	3	2.9 (3.7)	0.7	4.1 (4.3)	0.2	3.8 (3.9)	0.1
44	VA	Complaint	3	6.6 (11.1)	1.0	3.1 (3.6)	0.2	3.1 (3.5)	0.1
45	VA	Complaint	3	6.8 (7.1)	1.0	3.0 (3.6)	0.2	3.3 (3.9)	0.1
46	VA	Non-complaint	3	11.7 (12.1)	0.8	2.3 (2.6)	0.2	2.1 (2.1)	0.1
47	VA	Complaint	3	6.7 (8.2)	0.7	4.8 (5.1)	0.2	3.4 (3.5)	0.1
48	VA	Complaint	3	17.8 (22.4)	0.8	1.0 (1.0)	0.2	3.6 (3.7)	0.1
49	AL	Complaint	3	5.5 (7.7)	0.7	3.5 (4.2)	0.2	2.1 (2.3)	0.1
50	AL	Complaint	3	8.8 (9.5)	1.0	NA	0.2	2.8 (3.1)	0.1
51	AL	Non-complaint	3	5.4 (5.9)	0.8	4.1 (4.2)	0.2	1.7 (1.9)	0.1

μg/m^3	micrograms per cubic meter	ave	average	OA	outdoor air
n	number of samples	max	maximum		

States: FL = Florida, LA = Louisiana, MS = Mississippi, VA = Virginia, AL = Alabama

Table A.5 Summary Statistics for Aldehyde (Passive) Concentrations ($\mu g/m^3$) in Indoor and Outdoor Air, by House

No.	State	Status	n	Formaldehyde		n-Hexaldehyde		Isovaleraldehyd	
				Indoor Ave (Max)	OA	Indoor Ave (Max)	OA	Indoor Ave (Max)	OA
1	FL	Complaint	3	47.0 (48.6)	1.9	152.8 (157.4)	1.2	0.7 (1.2)	0.1
2	FL	Non-complaint	3	56.0 (65.2)	2.1	83.7 (96.5)	1.0	0.7 (1.0)	0.1
3	FL	Complaint	3	56.2 (57.9)	1.9	114.5 (116.3)	1.1	1.0 (1.3)	0.1
4	FL	Complaint	3	47.7 (47.7)	2.6	70.8 (78.7)	1.6	0.4 (0.5)	0.1
5	FL	Non-complaint	3	54.0 (56.4)	2.7	143.0 (152.5)	1.9	0.5 (0.5)	0.1
6	FL	Complaint	3	38.7 (39.7)	2.8	57.5 (58.5)	2.0	0.4 (0.4)	0.1
7	FL	Complaint	3	62.6 (65.8)	NA	167.1 (193.8)	NA	1.0 (1.0)	NA
8	FL	Non-complaint	3	38.7 (39.7)	2.6	27.5 (27.7)	1.3	1.3 (1.5)	0.1
9	FL	Complaint	3	41.1 (41.9)	4.1	137.4 (144.3)	2.0	0.4 (0.4)	0.1
10	FL	Complaint	3	52.8 (55.0)	3.3	56.4 (60.5)	2.1	0.5 (0.5)	0.1
11	FL	Complaint	3	85.3 (92.2)	2.2	88.7 (98.6)	1.0	1.0 (1.0)	0.1
12	FL	Complaint	3	50.6 (52.3)	2.6	94.1 (94.7)	1.2	0.5 (0.5)	0.1
13	FL	Complaint	3	67.9 (69.8)	1.9	138.1 (139.2)	1.1	1.2 (1.2)	0.1
14	FL	Complaint	3	33.3 (35.4)	1.7	24.8 (25.7)	0.8	0.4 (0.4)	0.1
15	FL	Complaint	3	52.8 (57.7)	2.0	67.0 (71.4)	0.9	0.4 (0.5)	0.1
16	FL	Complaint	3	74.4 (77.1)	2.3	81.3 (84.9)	1.2	0.6 (0.7)	0.1
17	FL	Non-complaint	3	44.6 (46.8)	1.9	340.1 (349.4)	2.5	0.5 (0.5)	0.1
18	FL	Complaint	3	43.7 (56.6)	NA	67.9 (72.6)	NA	0.4 (0.5)	NA
19	FL	Complaint	3	50.2 (56.9)	1.9	51.2 (53.7)	1.3	0.5 (0.5)	0.1
20	FL	Complaint	3	59.0 (65.8)	1.6	127.1 (136.3)	1.1	0.5 (0.5)	0.1
21	FL	Complaint	3	48.3 (49.5)	2.3	113.4 (118.0)	1.7	0.5 (0.5)	0.1
22	FL	Non-complaint	3	64.7 (70.1)	2.1	128.4 (133.4)	1.7	0.5 (0.5)	0.1
23	FL	Complaint	3	22.5 (23.3)	2.1	162.6 (166.9)	1.5	0.6 (0.6)	0.1
24	FL	Complaint	3	42.6 (44.1)	2.1	67.2 (68.5)	1.1	0.5 (0.5)	0.1
25	FL	Complaint	3	63.2 (66.7)	2.4	215.8 (220.0)	2.2	1.1 (1.3)	0.1
26	FL	Complaint	3	75.7 (79.4)	1.9	288.5 (290.5)	1.7	0.5 (0.5)	0.1
27	FL	Complaint	3	57.9 (59.8)	1.9	288.0 (298.9)	1.7	0.9 (1.6)	0.1
28	FL	Complaint	3	75.9 (80.7)	2.1	316.9 (316.9)	2.0	1.7 (2.6)	0.1
29	LA	Complaint	3	70.2 (70.2)	2.5	118.7 (124.7)	2.4	1.0 (1.2)	0.1
30	LA	Complaint	2	35.1 (36.5)	1.5	178.9 (183.8)	1.1	0.5 (0.5)	0.1
31	LA	Complaint	3	47.6 (49.1)	4.0	246.7 (256.6)	6.5	0.5 (0.5)	0.1
32	LA	Complaint	3	85.6 (85.6)	2.3	129.0 (132.5)	1.6	0.7 (0.7)	0.1
33	LA	Non-complaint	3	38.3 (44.2)	2.3	175.9 (189.8)	1.6	0.5 (0.5)	0.1
34	LA	Complaint	3	31.5 (32.2)	2.2	110.4 (113.6)	1.1	0.5 (0.5)	0.1
35	LA	Non-complaint	3	32.5 (36.1)	2.0	225.8 (233.1)	1.2	0.5 (0.5)	0.1
36	LA	Complaint	3	63.9 (67.2)	1.7	146.1 (156.1)	1.2	1.0 (1.2)	0.1
37	LA	Complaint	3	47.4 (50.4)	1.9	42.5 (44.4)	0.8	0.5 (0.5)	0.1
38	LA	Complaint	3	49.7 (54.4)	1.7	24.3 (27.2)	0.9	0.5 (0.5)	0.1
39	MS	Complaint	3	53.6 (62.9)	1.8	88.0 (96.8)	0.9	0.5 (0.5)	0.1
40	MS	Complaint	3	64.5 (65.3)	1.7	94.9 (102.3)	1.0	0.5 (0.5)	0.1
41	VA	Complaint	3	50.7 (54.1)	1.5	183.4 (249.9)	0.9	0.8 (1.4)	0.1
42	VA	Non-complaint	3	27.6 (29.4)	1.6	61.9 (74.9)	0.8	0.5 (0.5)	0.1
43	VA	Complaint	3	61.9 (67.1)	1.5	283.9 (283.9)	1.1	1.8 (2.1)	0.1
44	VA	Complaint	3	60.2 (70.1)	1.9	195.4 (207.7)	1.1	0.8 (1.2)	0.1
45	VA	Complaint	3	53.8 (62.9)	2.1	102.3 (132.4)	0.9	0.5 (0.5)	0.1
46	VA	Non-complaint	3	28.6 (32.2)	1.5	146.7 (157.6)	0.9	1.1 (1.6)	0.1
47	VA	Complaint	3	52.0 (56.4)	1.7	203.3 (217.0)	0.9	1.2 (1.9)	0.1
48	VA	Complaint	3	47.6 (51.1)	1.8	186.2 (191.2)	0.8	1.0 (1.8)	0.1
49	AL	Complaint	3	57.1 (60.4)	1.7	85.4 (85.8)	0.9	0.5 (0.5)	0.1
50	AL	Complaint	3	38.2 (44.1)	1.7	129.8 (145.5)	1.2	0.5 (0.5)	0.1
51	AL	Non-complaint	3	54.6 (60.5)	1.7	47.6 (51.3)	0.9	0.5 (0.5)	0.1

$\mu g/m^3$	micrograms per cubic meter	ave	average	OA	outdoor air
n	number of samples	max	maximum		

States: FL = Florida, LA = Louisiana, MS = Mississippi, VA = Virginia, AL = Alabama

Table A.5 Summary Statistics for Aldehyde (Passive) Concentrations ($\mu g/m^3$) in Indoor and Outdoor Air, by House

				Butanal		Propionaldehyde		Valeraldehyde	
No.	State	Status	n	Indoor Ave (Max)	OA	Indoor Ave (Max)	OA	Indoor Ave (Max)	OA
1	FL	Complaint	3	28.1 (29.9)	2.0	4.3 (4.5)	0.2	29.7 (31.9)	0.7
2	FL	Non-complaint	3	23.3 (28.9)	1.8	2.7 (3.4)	0.3	16.6 (18.4)	0.6
3	FL	Complaint	3	26.1 (27.2)	1.9	3.4 (3.7)	0.2	24.9 (25.8)	0.6
4	FL	Complaint	3	25.0 (30.1)	2.1	3.4 (4.1)	0.5	14.5 (17.5)	0.6
5	FL	Non-complaint	3	31.5 (35.1)	1.5	3.6 (3.9)	0.3	26.7 (28.4)	0.5
6	FL	Complaint	3	22.0 (22.8)	2.0	5.4 (5.4)	0.6	11.4 (11.9)	0.6
7	FL	Complaint	3	10.8 (16.1)	NA	1.5 (1.5)	NA	19.4 (24.1)	NA
8	FL	Non-complaint	3	39.2 (41.7)	2.2	4.5 (4.8)	0.5	8.4 (8.6)	0.6
9	FL	Complaint	3	28.1 (29.1)	2.5	3.6 (3.8)	0.5	25.0 (25.9)	0.8
10	FL	Complaint	3	20.4 (21.8)	2.1	3.3 (3.3)	0.5	15.5 (15.9)	0.7
11	FL	Complaint	3	5.8 (5.8)	1.8	1.6 (1.6)	0.2	11.8 (12.8)	0.5
12	FL	Complaint	3	56.5 (57.4)	2.2	6.7 (6.8)	0.5	27.3 (30.4)	0.6
13	FL	Complaint	3	44.3 (48.2)	1.8	1.8 (1.8)	0.2	27.4 (29.9)	0.7
14	FL	Complaint	3	22.1 (23.1)	2.4	0.7 (0.7)	0.4	9.3 (10.0)	0.5
15	FL	Complaint	3	18.5 (19.9)	1.9	1.4 (3.1)	0.4	17.1 (19.4)	0.5
16	FL	Complaint	3	29.0 (30.5)	3.4	0.9 (1.0)	0.6	22.2 (22.2)	0.6
17	FL	Non-complaint	3	31.3 (32.9)	2.9	5.6 (6.1)	0.4	50.0 (52.2)	0.7
18	FL	Complaint	3	35.4 (42.0)	NA	6.1 (7.2)	NA	26.8 (28.5)	NA
19	FL	Complaint	3	17.1 (17.6)	2.1	3.2 (3.3)	0.4	14.7 (14.9)	0.8
20	FL	Complaint	3	23.6 (25.5)	1.8	3.7 (4.5)	0.2	31.8 (33.4)	0.6
21	FL	Complaint	3	98.2 (104.0)	4.1	4.1 (4.3)	0.5	28.2 (30.3)	1.2
22	FL	Non-complaint	3	32.4 (35.4)	2.7	2.9 (3.8)	0.5	23.4 (23.7)	0.8
23	FL	Complaint	3	63.0 (63.0)	3.5	7.8 (7.9)	0.4	46.4 (47.1)	0.9
24	FL	Complaint	3	26.2 (27.2)	1.4	3.3 (3.5)	0.2	14.6 (15.3)	0.2
25	FL	Complaint	3	23.7 (24.0)	2.1	3.7 (3.9)	0.4	32.9 (34.8)	0.7
26	FL	Complaint	3	18.9 (19.2)	2.0	1.5 (2.1)	0.4	39.8 (43.2)	0.7
27	FL	Complaint	3	37.1 (37.4)	2.0	4.0 (4.3)	0.2	41.8 (43.8)	0.7
28	FL	Complaint	3	24.3 (27.5)	1.9	1.7 (2.2)	0.4	45.1 (46.5)	0.9
29	LA	Complaint	3	14.7 (15.5)	2.4	1.5 (2.0)	0.6	22.0 (23.7)	0.9
30	LA	Complaint	2	25.9 (26.2)	1.2	4.3 (4.5)	0.2	42.2 (43.6)	0.2
31	LA	Complaint	3	24.8 (25.0)	2.6	5.6 (5.6)	0.5	45.5 (49.4)	1.8
32	LA	Complaint	3	4.8 (7.2)	1.5	1.0 (1.0)	0.2	17.3 (17.9)	0.8
33	LA	Non-complaint	3	33.5 (36.9)	2.2	6.7 (7.4)	0.4	43.5 (49.4)	0.7
34	LA	Complaint	3	20.7 (21.8)	1.9	3.3 (3.5)	0.5	27.4 (29.6)	0.5
35	LA	Non-complaint	3	56.8 (58.3)	1.9	6.5 (6.8)	0.3	40.5 (43.0)	0.6
36	LA	Complaint	3	6.6 (7.2)	1.8	0.8 (0.8)	0.2	15.6 (18.3)	0.5
37	LA	Complaint	3	13.0 (14.1)	1.4	3.1 (3.2)	0.4	13.3 (13.8)	0.6
38	LA	Complaint	3	2.7 (2.7)	1.6	0.8 (0.8)	0.2	4.7 (5.3)	0.2
39	MS	Complaint	3	23.8 (25.6)	1.4	3.2 (4.2)	0.5	16.7 (17.3)	0.2
40	MS	Complaint	3	10.2 (10.9)	2.0	1.1 (1.7)	0.4	16.6 (18.4)	0.5
41	VA	Complaint	3	28.4 (33.1)	1.7	4.1 (4.5)	0.5	44.3 (53.5)	0.2
42	VA	Non-complaint	3	12.7 (14.2)	1.4	2.8 (3.0)	0.3	13.4 (14.6)	0.2
43	VA	Complaint	3	15.1 (18.3)	1.6	0.8 (0.8)	0.2	37.2 (37.8)	0.2
44	VA	Complaint	3	22.0 (29.1)	2.3	2.4 (4.2)	0.4	34.0 (40.6)	0.2
45	VA	Complaint	3	16.3 (18.7)	2.1	2.5 (2.7)	0.4	23.1 (28.1)	0.5
46	VA	Non-complaint	3	20.9 (22.9)	1.4	3.5 (3.6)	0.2	32.7 (34.7)	0.5
47	VA	Complaint	3	17.9 (19.8)	1.5	2.2 (2.5)	0.2	34.1 (35.7)	0.5
48	VA	Complaint	3	25.8 (27.4)	1.6	4.2 (4.8)	0.2	40.5 (41.8)	0.2
49	AL	Complaint	3	9.9 (11.3)	1.5	1.8 (2.7)	0.2	16.7 (17.2)	0.2
50	AL	Complaint	3	16.7 (18.6)	1.8	3.1 (3.3)	0.6	27.4 (30.5)	0.5
51	AL	Non-complaint	3	9.5 (9.8)	1.8	2.2 (2.2)	0.5	12.4 (13.9)	0.5

$\mu g/m^3$	micrograms per cubic meter	ave	average	OA	outdoor air
n	number of samples	max	maximum		

States: FL = Florida, LA = Louisiana, MS = Mississippi, VA = Virginia, AL = Alabama

Table A.6 Summary Statistics for Analyte Concentrations (ppb) Collected Using Passive Monitors in Indoor and Outdoor Air, by House

				Hydrogen Sulfide		Ozone		Nitrogen Dioxide	
No.	State	Status	n	Indoor Ave (Max)	OA	Indoor Ave (Max)	OA	Indoor Ave (Max)	OA
1	FL	Complaint	3	0.21 (0.21)	0.8	0.33 (0.33)	12.5	0.18 (0.21)	1.0
2	FL	Non-complaint	3	0.2 (0.2)	0.7	0.33 (0.33)	10.2	1.25 (1.76)	0.5
3	FL	Complaint	3	0.45 (0.54)	0.8	0.33 (0.33)	11.3	0.1 (0.13)	1.1
4	FL	Complaint	3	0.64 (0.67)	1.9	0.45 (0.74)	17.5	7.06 (8.28)	1.6
5	FL	Non-complaint	3	0.48 (0.55)	2.2	0.31 (0.31)	13.4	2.03 (2.27)	1.3
6	FL	Complaint	3	0.71 (0.82)	1.7	0.33 (0.33)	9.9	3.09 (3.65)	0.6
7	FL	Complaint	3	1.28 (1.56)	NA	0.3 (0.3)	NA	0.64 (1.11)	NA
8	FL	Non-complaint	3	2.23 (2.68)	0.7	0.33 (0.33)	15.7	0.89 (0.99)	1.8
9	FL	Complaint	3	0.82 (0.93)	1.4	0.33 (0.33)	9.1	1.17 (1.39)	1.0
10	FL	Complaint	3	0.81 (1.18)	0.6	0.36 (0.36)	12.4	0.61 (0.8)	1.3
11	FL	Complaint	3	0.46 (0.97)	0.8	0.34 (0.34)	12.6	2.36 (2.64)	1.5
12	FL	Complaint	3	0.26 (0.26)	3.0	0.42 (0.42)	12.4	0.5 (0.62)	1.0
13	FL	Complaint	3	0.94 (1)	0.6	0.38 (0.38)	10.6	0.06 (0.06)	0.5
14	FL	Complaint	3	0.21 (0.21)	1.6	0.33 (0.33)	14.6	0.76 (0.93)	1.0
15	FL	Complaint	3	0.55 (0.61)	0.2	0.32 (0.32)	15.9	3.92 (6.42)	5.1
16	FL	Complaint	3	0.44 (0.56)	0.9	0.36 (0.36)	13.5	1.09 (1.31)	2.7
17	FL	Non-complaint	3	0.22 (0.22)	0.2	0.34 (0.34)	14.7	2.27 (2.64)	4.0
18	FL	Complaint	3	0.19 (0.19)	NA	0.31 (0.31)	NA	0.81 (0.92)	NA
19	FL	Complaint	3	0.22 (0.22)	0.2	0.35 (0.35)	13.3	2.41 (3.54)	4.6
20	FL	Complaint	3	0.63 (0.7)	0.2	0.33 (0.33)	11.2	1.16 (1.25)	1.5
21	FL	Complaint	3	0.59 (0.73)	0.2	0.36 (0.36)	10.8	1.03 (1.22)	3.0
22	FL	Non-complaint	3	0.22 (0.22)	0.5	0.35 (0.35)	15.3	1.84 (1.9)	3.2
23	FL	Complaint	3	0.24 (0.24)	0.6	0.38 (0.38)	11.2	0.84 (0.93)	7.4
24	FL	Complaint	3	0.29 (0.47)	1.4	0.31 (0.31)	8.7	0.84 (1.04)	1.5
25	FL	Complaint	3	0.29 (0.46)	1.3	0.34 (0.34)	10.3	0.61 (0.83)	1.3
26	FL	Complaint	3	0.8 (0.83)	1.6	0.35 (0.35)	10.5	0.29 (0.47)	1.7
27	FL	Complaint	3	0.9 (1.04)	0.9	0.35 (0.35)	13.3	0.2 (0.23)	1.3
28	FL	Complaint	3	1.18 (1.19)	0.7	0.37 (0.37)	11.7	0.91 (1.22)	1.0
29	LA	Complaint	3	0.85 (1)	1.2	0.35 (0.35)	12.2	11.86 (13.87)	2.6
30	LA	Complaint	2	0.4 (0.58)	0.2	0.33 (0.33)	6.4	0.98 (1.02)	1.1
31	LA	Complaint	3	1.47 (1.66)	1.1	0.35 (0.35)	12.2	3.87 (4.7)	2.6
32	LA	Complaint	3	0.88 (1)	0.7	0.35 (0.35)	11.9	1.5 (1.68)	1.1
33	LA	Non-complaint	3	0.23 (0.23)	1.2	0.36 (0.36)	15.6	4.33 (4.95)	3.6
34	LA	Complaint	3	0.95 (1.12)	1.5	0.33 (0.33)	12.5	4.12 (4.65)	1.5
35	LA	Non-complaint	3	0.28 (0.43)	1.6	0.33 (0.33)	11.3	5.03 (5.83)	0.8
36	LA	Complaint	3	1.82 (2.02)	2.7	0.32 (0.32)	12.0	2.74 (2.98)	2.5
37	LA	Complaint	3	0.86 (1.44)	3.2	0.33 (0.33)	14.6	4.98 (5.04)	4.0
38	LA	Complaint	3	2.23 (2.54)	3.5	0.92 (1.39)	11.9	2.92 (3.18)	3.0
39	MS	Complaint	3	0.29 (0.45)	0.2	0.33 (0.33)	7.2	0.68 (0.89)	0.8
40	MS	Complaint	3	0.42 (0.55)	0.2	0.33 (0.33)	5.8	0.76 (0.81)	0.2
41	VA	Complaint	3	0.31 (0.5)	0.8	0.36 (0.36)	13.3	3.92 (4.8)	4.8
42	VA	Non-complaint	3	0.23 (0.23)	0.8	0.36 (0.36)	16.9	18.67 (20.93)	NA
43	VA	Complaint	3	1.01 (1.53)	0.2	0.34 (0.34)	NA	5.51 (6.55)	NA
44	VA	Complaint	3	0.22 (0.22)	0.8	0.35 (0.35)	13.3	3.61 (4.18)	12.7
45	VA	Complaint	3	0.98 (1.1)	0.5	0.36 (0.36)	15.6	3.67 (4.25)	8.5
46	VA	Non-complaint	3	0.23 (0.23)	0.6	0.36 (0.36)	15.7	6.11 (6.63)	7.4
47	VA	Complaint	3	0.59 (0.85)	0.2	0.34 (0.34)	19.0	12.49 (15.2)	7.8
48	VA	Complaint	3	0.31 (0.46)	0.2	0.36 (0.36)	20.3	10.75 (14.26)	9.4
49	AL	Complaint	3	0.21 (0.21)	0.2	0.33 (0.33)	8.7	0.7 (0.77)	0.8
50	AL	Complaint	3	0.21 (0.21)	0.2	0.33 (0.33)	7.7	1 (1.27)	0.8
51	AL	Non-complaint	3	0.21 (0.21)	0.2	0.33 (0.33)	5.8	1.77 (2.58)	1.1

ppb	parts per billion	ave	average	OA	outdoor
n	number of samples	max	maximum		

States: FL = Florida, LA = Louisiana, MS = Mississippi, VA = Virginia, AL = Alabama

Table A.6 Summary Statistics for Analyte Concentrations (ppb) Collected Using Passive Monitors in Indoor and Outdoor Air, by House

No.	State	Status	n	Sulfur Dioxide Indoor Ave (Max)	OA	Hydrogen Fluoride Indoor Ave (Max)	OA
1	FL	Complaint	3	1.38 (1.38)	1.4	0.88 (0.88)	0.9
2	FL	Non-complaint	3	1.36 (1.36)	1.4	0.86 (0.86)	0.9
3	FL	Complaint	3	1.36 (1.36)	1.4	0.86 (0.86)	0.9
4	FL	Complaint	3	1.29 (1.29)	1.3	0.82 (0.82)	0.8
5	FL	Non-complaint	3	1.73 (2.65)	1.3	0.81 (0.81)	0.8
6	FL	Complaint	3	1.36 (1.36)	1.4	0.87 (0.87)	0.9
7	FL	Complaint	3	1.28 (1.28)	NA	0.81 (0.81)	NA
8	FL	Non-complaint	3	1.37 (1.37)	1.4	0.87 (0.87)	0.9
9	FL	Complaint	3	1.36 (1.36)	1.4	0.87 (0.87)	0.9
10	FL	Complaint	3	1.48 (1.48)	1.5	0.94 (0.94)	0.9
11	FL	Complaint	3	1.38 (1.38)	1.4	0.88 (0.88)	0.9
12	FL	Complaint	3	1.72 (1.72)	1.7	1.09 (1.09)	1.1
13	FL	Complaint	3	1.58 (1.58)	1.6	1 (1)	1.0
14	FL	Complaint	3	1.39 (1.39)	1.4	0.88 (0.88)	0.9
15	FL	Complaint	3	1.29 (1.29)	1.3	0.82 (0.82)	0.8
16	FL	Complaint	3	1.49 (1.49)	1.5	0.95 (0.95)	1.0
17	FL	Non-complaint	3	1.37 (1.37)	1.4	0.87 (0.87)	0.9
18	FL	Complaint	3	1.27 (1.27)	NA	0.81 (0.81)	NA
19	FL	Complaint	3	1.47 (1.47)	1.5	0.93 (0.93)	0.9
20	FL	Complaint	3	1.37 (1.37)	1.4	0.87 (0.87)	0.9
21	FL	Complaint	3	1.48 (1.48)	1.5	0.94 (0.94)	0.9
22	FL	Non-complaint	3	1.46 (1.46)	1.5	0.93 (0.93)	0.9
23	FL	Complaint	3	1.58 (1.58)	1.6	1 (1)	1.0
24	FL	Complaint	3	1.29 (1.29)	1.3	0.82 (0.82)	0.8
25	FL	Complaint	3	1.38 (1.38)	1.4	0.88 (0.88)	0.9
26	FL	Complaint	3	1.48 (1.48)	1.5	0.94 (0.94)	0.9
27	FL	Complaint	3	1.47 (1.47)	1.5	0.93 (0.93)	0.9
28	FL	Complaint	3	1.56 (1.56)	1.6	0.99 (0.99)	1.0
29	LA	Complaint	3	1.46 (1.46)	1.5	0.92 (0.92)	0.9
30	LA	Complaint	2	1.36 (1.36)	1.4	0.87 (0.87)	0.9
31	LA	Complaint	3	1.46 (1.46)	1.5	0.92 (0.92)	0.9
32	LA	Complaint	3	1.45 (1.45)	1.5	0.92 (0.92)	0.9
33	LA	Non-complaint	3	1.45 (1.45)	1.5	0.92 (0.92)	0.9
34	LA	Complaint	3	1.36 (1.36)	1.4	0.86 (0.86)	0.9
35	LA	Non-complaint	3	1.34 (1.34)	1.3	0.85 (0.85)	0.9
36	LA	Complaint	3	1.35 (1.35)	1.4	0.86 (0.86)	0.9
37	LA	Complaint	3	1.36 (1.36)	1.4	0.86 (0.86)	0.9
38	LA	Complaint	3	1.34 (1.34)	1.3	0.85 (0.85)	0.9
39	MS	Complaint	3	1.36 (1.36)	1.4	0.86 (0.86)	0.9
40	MS	Complaint	3	1.35 (1.35)	1.4	0.86 (0.86)	0.9
41	VA	Complaint	3	1.46 (1.46)	1.5	0.93 (0.93)	0.9
42	VA	Non-complaint	3	1.47 (1.47)	NA	0.93 (0.93)	NA
43	VA	Complaint	3	1.39 (1.39)	NA	0.89 (0.89)	NA
44	VA	Complaint	3	1.46 (1.46)	1.5	0.92 (0.92)	0.9
45	VA	Complaint	3	1.48 (1.48)	1.5	0.94 (0.94)	0.9
46	VA	Non-complaint	3	1.45 (1.45)	1.5	0.92 (0.92)	0.9
47	VA	Complaint	3	1.38 (1.38)	1.4	0.88 (0.88)	0.9
48	VA	Complaint	3	1.46 (1.46)	1.5	0.93 (0.93)	0.9
49	AL	Complaint	3	1.36 (1.36)	1.4	0.86 (0.86)	0.9
50	AL	Complaint	3	1.36 (1.36)	1.4	0.86 (0.86)	0.9
51	AL	Non-complaint	3	1.36 (1.36)	1.4	0.86 (0.86)	0.9

ppb	parts per billion	ave	average	OA	outdoor
n	number of samples	max	maximum		

States: FL = Florida, LA = Louisiana, MS = Mississippi, VA = Virginia, AL = Alabama

Table A.7 Volatile Organic Compound Concentrations ($\mu g/m^3$) in Indoor Air by House Status

Component	Status	Pct Detect	Mean	Min	p25	Median	p75	Max
1,1,1-Trichloroethane	Complaint	6.6	0.16	0.06	0.07	0.08	0.08	1.2
	Non-complaint	0	NA	NA	NA	NA	NA	NA
1,1,2,2-Tetrachloroethane	Complaint	0	NA	NA	NA	NA	NA	NA
	Non-complaint	0	NA	NA	NA	NA	NA	NA
1,1,2-Trichloroethane	Complaint	0	NA	NA	NA	NA	NA	NA
	Non-complaint	0	NA	NA	NA	NA	NA	NA
1,1,2-Trichlorotrifluoroethane	Complaint	95.6	0.57	0.06	0.51	0.57	0.64	0.74
	Non-complaint	85	0.56	0.14	0.49	0.67	0.73	0.78
1,1-Dichloroethane	Complaint	0	NA	NA	NA	NA	NA	NA
	Non-complaint	0	NA	NA	NA	NA	NA	NA
1,1-Dichloroethene	Complaint	2.2	0.09	0.06	0.06	0.08	0.08	0.33
	Non-complaint	0	NA	NA	NA	NA	NA	NA
1,2,4-Trichlorobenzene	Complaint	0	NA	NA	NA	NA	NA	NA
	Non-complaint	0	NA	NA	NA	NA	NA	NA
1,2,4-Trimethylbenzene	Complaint	70.3	6.97	0.31	2.58	5.01	9.48	28.83
	Non-complaint	65	5.44	0.62	0.93	5.05	6.42	14.17
1,2-Dibromo-3-chloropropane	Complaint	0	NA	NA	NA	NA	NA	NA
	Non-complaint	0	NA	NA	NA	NA	NA	NA
1,2-Dibromoethane	Complaint	0	NA	NA	NA	NA	NA	NA
	Non-complaint	0	NA	NA	NA	NA	NA	NA
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	Complaint	2.2	0.52	0.31	0.32	0.38	0.4	3.96
	Non-complaint	0	NA	NA	NA	NA	NA	NA
1,2-Dichlorobenzene	Complaint	3.3	0.09	0.06	0.06	0.08	0.08	0.27
	Non-complaint	0	NA	NA	NA	NA	NA	NA
1,2-Dichloroethane	Complaint	62.6	3.04	0.06	0.29	1.33	3.1	17.5
	Non-complaint	60	1.67	0.06	0.32	0.77	0.91	6.32
1,2-Dichloropropane	Complaint	9.9	0.11	0.06	0.07	0.08	0.11	0.37
	Non-complaint	10	0.08	0.06	0.06	0.06	0.07	0.15
1,3,5-Trimethylbenzene	Complaint	53.8	2.06	0.31	0.86	1.68	2.68	8.27
	Non-complaint	45	1.54	0.31	0.31	1.45	1.75	3.88
1,3-Butadiene	Complaint	15.4	0.41	0.06	0.07	0.08	0.13	8.15
	Non-complaint	15	0.45	0.06	0.06	0.06	0.07	2
1,3-Dichlorobenzene	Complaint	0	NA	NA	NA	NA	NA	NA
	Non-complaint	0	NA	NA	NA	NA	NA	NA
1,4-Dichlorobenzene	Complaint	40.7	0.25	0.06	0.08	0.17	0.3	1.24
	Non-complaint	20	0.1	0.06	0.07	0.08	0.1	0.17
1,4-Dioxane	Complaint	3.3	0.43	0.31	0.33	0.38	0.4	0.93
	Non-complaint	0	NA	NA	NA	NA	NA	NA
2-Butanone (MEK)	Complaint	95.6	7.88	0.31	4.51	5.73	10.5	29.5
	Non-complaint	95	11.52	3.22	3.57	4.48	8.35	38
2-Hexanone	Complaint	52.7	1.14	0.31	0.6	1.05	1.37	3.73
	Non-complaint	60	1.05	0.31	0.8	1.03	1.16	1.95
2-Propanol (isopropyl alcohol)	Complaint	86.8	66.38	0.31	7.62	13.85	92.75	355
	Non-complaint	75	11.42	5.45	6.26	9.93	11.47	24
3-Chloro-1-propene (allyl chloride)	Complaint	0	NA	NA	NA	NA	NA	NA
	Non-complaint	0	NA	NA	NA	NA	NA	NA
4-Ethyltoluene	Complaint	51.6	2.12	0.31	0.4	1.27	2.68	9.37
	Non-complaint	45	1.68	0.31	0.31	1.6	1.82	4.37
4-Methyl-2-pentanone	Complaint	52.7	1.92	0.31	0.51	1.07	2.02	17.17
	Non-complaint	65	1.5	0.8	0.82	1.07	1.17	3.62
Acetone	Complaint	94.5	112.17	3.05	64.75	115	155	220
	Non-complaint	85	74.75	41.5	55.9	80.67	85	110.67

Table A.7 Continued

Component	Status	Pct Detect	Mean	Min	p25	Median	p75	Max
Acetonitrile	Complaint	81.8	134.03	0.36	58.25	107.54	233.33	265
	Non-complaint	88.9	141.56	58	58	76.67	290	290
Acrolein	Complaint	91.2	5.88	0.31	4.08	5.51	6.98	14.67
	Non-complaint	95	4.38	1.62	2.77	5.5	5.87	6.13
Acrylonitrile	Complaint	3.3	0.47	0.31	0.32	0.38	0.4	2.37
	Non-complaint	0	NA	NA	NA	NA	NA	NA
Benzene	Complaint	94.5	5.88	0.06	1.38	2.92	7.85	30.83
	Non-complaint	85	4.27	0.27	0.4	2.07	4.45	14.17
Benzyl chloride	Complaint	1.1	0.08	0.06	0.07	0.08	0.08	0.19
	Non-complaint	0	NA	NA	NA	NA	NA	NA
Bromodichloromethane	Complaint	29.7	0.53	0.06	0.08	0.12	0.38	2.41
	Non-complaint	50	0.29	0.08	0.1	0.23	0.43	0.62
Bromoform	Complaint	4.4	0.48	0.31	0.32	0.38	0.4	1.85
	Non-complaint	0	NA	NA	NA	NA	NA	NA
Bromomethane	Complaint	16.5	0.14	0.06	0.07	0.08	0.1	0.59
	Non-complaint	25	0.19	0.06	0.06	0.08	0.29	0.47
Carbon disulfide	Complaint	54.9	1.76	0.31	0.52	1.31	2.3	9.1
	Non-complaint	25	0.57	0.31	0.31	0.39	0.69	1.15
Carbon tetrachloride	Complaint	94.5	0.61	0.06	0.48	0.57	0.67	1.23
	Non-complaint	85	0.48	0.13	0.45	0.59	0.62	0.62
Chlorobenzene	Complaint	0	NA	NA	NA	NA	NA	NA
	Non-complaint	0	NA	NA	NA	NA	NA	NA
Chloroethane	Complaint	1.1	0.08	0.06	0.06	0.08	0.08	0.19
	Non-complaint	5	0.07	0.06	0.06	0.06	0.07	0.08
Chloroform	Complaint	80.2	1.9	0.06	0.32	1.01	2.55	9.23
	Non-complaint	70	1.08	0.3	0.43	1.06	1.66	1.97
Chloromethane	Complaint	93.4	1.19	0.06	0.72	0.87	1.1	9.67
	Non-complaint	70	0.47	0.06	0.19	0.53	0.68	0.88
Cumene	Complaint	14.3	0.63	0.31	0.36	0.39	0.76	2.62
	Non-complaint	15	0.5	0.31	0.31	0.37	0.39	1.11
Cyclohexane	Complaint	56	2	0.31	0.86	1.26	2.08	8.97
	Non-complaint	35	0.91	0.31	0.37	0.56	1.17	2.13
Dibromochloromethane	Complaint	17.6	0.21	0.06	0.07	0.08	0.19	1.66
	Non-complaint	0	NA	NA	NA	NA	NA	NA
Dichlorodifluoromethane (CFC 12)	Complaint	96.7	3.4	0.31	2.43	2.78	2.95	16.75
	Non-complaint	85	2.31	0.64	2.23	2.65	2.9	3.12
Ethanol	Complaint	90.1	1106.18	3.05	131.67	389.17	1450	5066.67
	Non-complaint	80	362.61	100.5	235.9	328.33	421.67	726.67
Ethyl acetate	Complaint	71.4	10.22	0.31	1.88	4.88	9.82	58
	Non-complaint	75	7.51	2.09	3.37	6.23	6.35	19.5
Ethylbenzene	Complaint	65.9	6.4	0.31	1.68	5.04	7.6	24.67
	Non-complaint	60	4.47	0.59	1.09	4.47	6.27	9.95
Hexachlorobutadiene	Complaint	0	NA	NA	NA	NA	NA	NA
	Non-complaint	0	NA	NA	NA	NA	NA	NA
Methyl methacrylate	Complaint	2.2	0.55	0.31	0.36	0.39	0.77	1.88
	Non-complaint	0	NA	NA	NA	NA	NA	NA
Methyl tert-Butyl Ether	Complaint	7.7	0.14	0.06	0.06	0.08	0.08	0.82
	Non-complaint	5	0.07	0.06	0.06	0.07	0.08	0.09
Methylene chloride	Complaint	16.5	0.78	0.31	0.32	0.39	0.49	4.65
	Non-complaint	30	1.3	0.31	0.31	0.31	2.58	3
Naphthalene	Complaint	54.9	1.86	0.12	0.75	1.13	2.33	7.28
	Non-complaint	65	3.46	0.92	1.28	2.45	2.7	9.94

Table A.7 Continued

Component	Status	Pct Detect	Mean	Min	p25	Median	p75	Max
Propene	Complaint	60.4	12.39	0.31	0.4	2.75	15.65	77.33
	Non-complaint	75	9.75	1.45	2.09	2.28	2.75	40.17
Styrene	Complaint	71.4	3.53	0.31	1.81	2.98	4.28	10
	Non-complaint	65	1.85	0.52	1.28	1.47	1.68	4.28
Tetrachloroethene	Complaint	49.5	0.76	0.06	0.08	0.22	0.84	4.75
	Non-complaint	70	11.14	0.13	0.19	1.97	2.1	51.33
Tetrahydrofuran (THF)	Complaint	57.1	2.05	0.31	0.41	1.1	2.03	13.67
	Non-complaint	20	10.35	0.31	0.31	0.37	1.27	49.5
Toluene	Complaint	91.2	32.77	0.31	14.17	21.03	42	124.67
	Non-complaint	70	20.91	1.62	5.45	21.67	28	47.83
Trichloroethene	Complaint	17.6	0.55	0.06	0.07	0.08	0.12	7.1
	Non-complaint	45	0.33	0.07	0.1	0.14	0.15	1.18
Trichlorofluoromethane	Complaint	96.7	1.4	0.06	1.25	1.42	1.55	2.2
	Non-complaint	85	1.14	0.25	1.18	1.3	1.4	1.55
Vinyl acetate	Complaint	16.5	5.27	3.05	3.73	3.92	5.43	17.17
	Non-complaint	35	5.83	3.08	3.91	4.12	6.77	11.26
Vinyl chloride	Complaint	3.3	0.09	0.06	0.07	0.08	0.08	0.22
	Non-complaint	0	NA	NA	NA	NA	NA	NA
α-Pinene	Complaint	86.8	88.47	0.31	36.25	77.58	116.67	235
	Non-complaint	80	53.08	7.92	30.67	52.33	83.83	90.67
cis-1,2-Dichloroethene	Complaint	1.1	0.08	0.06	0.07	0.08	0.08	0.19
	Non-complaint	0	NA	NA	NA	NA	NA	NA
cis-1,3-Dichloropropene	Complaint	12.1	0.87	0.31	0.32	0.38	0.48	7.32
	Non-complaint	0	NA	NA	NA	NA	NA	NA
d-Limonene	Complaint	79.1	25.86	0.31	15	24.63	39.5	57
	Non-complaint	65	12.09	5.09	7.2	14.83	15.17	18.17
m,p-Xylenes	Complaint	81.3	20.5	0.31	6.93	14.46	24.17	82.5
	Non-complaint	65	14.46	1.92	2.92	14.63	19.5	33.33
n-Butyl acetate	Complaint	72.5	4.87	0.31	1.68	3.22	5.07	26.33
	Non-complaint	65	2.7	0.54	1.81	3.05	3.17	4.95
n-Heptane	Complaint	67	4.66	0.31	1.55	3.03	5.9	25.67
	Non-complaint	50	3.05	0.31	0.61	1.08	3.38	9.85
n-Hexane	Complaint	72.5	10.28	0.31	1.05	5.08	12.65	71.33
	Non-complaint	50	6.14	0.31	0.47	1.62	9.15	19.17
n-Nonane	Complaint	64.8	2.3	0.31	1.1	1.44	2.97	8.43
	Non-complaint	45	1.19	0.31	0.57	0.66	1.27	3.12
n-Octane	Complaint	71.4	2.25	0.31	1.25	1.6	2.23	12.67
	Non-complaint	70	1.91	0.42	0.77	1.05	2.05	5.27
n-Propylbenzene	Complaint	44	1.26	0.31	0.39	0.85	1.55	5.32
	Non-complaint	40	0.94	0.31	0.31	0.79	0.94	2.35
o-Xylene	Complaint	67	7.34	0.31	1.43	5.23	9.09	27.83
	Non-complaint	65	4.69	0.83	1.07	4.93	5.07	11.53
trans-1,2-Dichloroethene	Complaint	6.6	0.34	0.06	0.07	0.08	0.08	6.3
	Non-complaint	0	NA	NA	NA	NA	NA	NA
trans-1,3-Dichloropropene	Complaint	12.1	0.74	0.31	0.32	0.38	0.48	5.17
	Non-complaint	0	NA	NA	NA	NA	NA	NA

$\mu g/m^3$	micrograms per cubic meter
pct	percent
min	minimum
p	percentile
max	maximum

Table A.8 Summary Statistics for Acid Concentrations (ppb) in Indoor and Outdoor Air, by House

No.	State	Status	n	Acetic Acid		Formic Acid		Hydrofluoric Acid	
				Indoor Ave (Max)	OA	Indoor Ave (Max)	OA	Indoor Ave (Max)	OA
1	FL	Complaint	3	19.7 (28.0)	5.5	4.2 (4.3)	4.6	20.5 (21.0)	22.5
2	FL	Non-complaint	3	47.7 (51.0)	4.8	4.1 (4.2)	4.2	22.3 (26.5)	20.0
3	FL	Complaint	3	59.7 (66.0)	5.0	4.3 (4.5)	4.5	20.3 (20.5)	21.0
4	FL	Complaint	3	42.0 (61.0)	4.8	3.9 (4.0)	4.2	19.5 (20.5)	19.0
5	FL	Non-complaint	3	69.3 (71.1)	5.5	6.5 (8.0)	4.9	18.2 (19.0)	19.5
6	FL	Complaint	3	15.0 (16.0)	4.7	3.9 (4.0)	4.1	19.3 (19.5)	20.0
7	FL	Complaint	3	440.0 (510.0)	4.2	23.7 (26.0)	3.7	93.7 (110.0)	18.0
8	FL	Non-complaint	3	16.7 (17.9)	4.9	4.1 (4.3)	4.2	19.6 (20.3)	21.5
9	FL	Complaint	3	65.3 (81.0)	160.0	3.8 (3.8)	4.1	18.7 (19.0)	20.5
10	FL	Complaint	3	28.5 (34.4)	16.0	4.1 (4.3)	4.0	19.2 (19.5)	18.5
11	FL	Complaint	3	90.0 (94.0)	4.6	6.7 (8.4)	4.0	18.8 (19.0)	19.5
12	FL	Complaint	3	57.5 (59.0)	4.5	3.9 (4.0)	3.9	19.7 (20.5)	20.0
13	FL	Complaint	3	46.4 (50.0)	4.3	3.7 (3.8)	3.8	18.3 (18.5)	18.0
14	FL	Complaint	3	42.3 (44.0)	4.5	3.7 (3.8)	3.9	18.3 (18.5)	18.0
15	FL	Complaint	3	32.3 (35.0)	4.5	4.1 (4.2)	3.9	19.7 (20.0)	19.5
16	FL	Complaint	3	34.3 (37.0)	4.2	3.8 (3.9)	3.6	18.7 (19.0)	18.5
17	FL	Non-complaint	3	36.0 (37.0)	5.0	3.9 (4.0)	4.4	19.6 (20.0)	22.0
18	FL	Complaint	3	41.3 (61.2)	4.6	5.4 (8.2)	4.0	18.8 (19.0)	19.5
19	FL	Complaint	3	26.7 (35.0)	4.9	4.5 (5.5)	4.3	19.8 (20.5)	20.0
20	FL	Complaint	3	80.2 (83.3)	4.5	4.0 (4.1)	3.9	19.5 (20.0)	19.5
21	FL	Complaint	3	40.7 (42.0)	4.9	4.0 (4.1)	4.3	19.2 (20.5)	20.5
22	FL	Non-complaint	3	61.9 (68.0)	4.5	3.9 (4.0)	3.9	18.8 (19.0)	19.5
23	FL	Complaint	3	9.1 (13.0)	4.6	4.0 (4.1)	4.1	19.1 (20.0)	24.5
24	FL	Complaint	3	46.3 (50.0)	4.9	10.0 (12.0)	4.4	19.7 (20.0)	19.5
25	FL	Complaint	3	33.3 (41.0)	5.0	7.4 (14.0)	4.4	19.4 (19.5)	NA
26	FL	Complaint	3	115.0 (130.0)	4.6	18.7 (24.0)	4.1	22.6 (27.0)	19.5
27	FL	Complaint	3	58.3 (68.0)	5.0	4.2 (4.3)	4.4	16.4 (19.5)	19.0
28	FL	Complaint	3	153.0 (180.0)	4.9	18.0 (22.0)	4.4	20.6 (21.5)	23.5
29	LA	Complaint	3	54.5 (58.2)	4.5	10.7 (12.0)	4.0	18.8 (19.0)	6.5
30	LA	Complaint	3	118.9 (139.9)	4.8	26.8 (32.0)	4.2	19.0 (19.5)	19.0
31	LA	Complaint	3	226.3 (239.0)	4.6	23.6 (27.9)	4.1	18.4 (18.8)	23.5
32	LA	Complaint	3	231.6 (350.0)	360.0	34.7 (51.0)	46.0	33.2 (41.0)	19.5
33	LA	Non-complaint	3	120.0 (130.0)	4.7	13.3 (14.0)	4.2	18.8 (19.0)	19.5
34	LA	Complaint	0	NA	NA	NA	NA	NA	NA
35	LA	Non-complaint	3	43.0 (44.0)	4.5	14.0 (15.0)	4.0	18.6 (19.0)	18.5
36	LA	Complaint	3	276.8 (360.2)	4.3	25.0 (33.0)	3.8	47.3 (56.0)	18.5
37	LA	Complaint	3	42.3 (51.0)	4.5	14.0 (16.0)	4.0	18.8 (19.0)	19.0
38	LA	Complaint	0	NA	NA	NA	NA	NA	NA
39	MS	Complaint	3	82.6 (100.0)	4.7	9.5 (14.0)	4.2	20.3 (21.0)	NA
40	MS	Complaint	3	42.3 (46.0)	19.0	4.0 (4.1)	4.1	19.0 (19.5)	20.5
41	VA	Complaint	3	209.8 (249.0)	4.7	21.3 (31.2)	4.1	41.9 (53.7)	19.5
42	VA	Non-complaint	3	42.0 (48.0)	NA	5.6 (8.6)	NA	16.2 (19.0)	NA
43	VA	Complaint	3	216.6 (270.0)	4.4	17.3 (24.0)	3.9	40.5 (56.1)	18.5
44	VA	Complaint	3	117.2 (149.9)	4.5	13.3 (16.0)	4.0	19.7 (20.0)	18.5
45	VA	Complaint	3	232.9 (258.8)	4.3	12.5 (14.0)	3.8	48.0 (53.0)	19.0
46	VA	Non-complaint	3	136.7 (140.1)	5.0	12.0 (12.0)	4.5	19.8 (20.8)	20.5
47	VA	Complaint	3	203.9 (230.9)	4.0	21.1 (23.1)	3.6	44.7 (47.2)	18.5
48	VA	Complaint	3	76.3 (89.0)	4.5	12.6 (16.0)	4.0	19.3 (21.0)	19.0
49	AL	Complaint	3	88.0 (120.1)	4.5	17.4 (24.0)	4.0	18.8 (19.5)	18.5
50	AL	Complaint	3	73.7 (100.0)	4.5	19.0 (24.0)	4.0	19.8 (20.0)	18.0
51	AL	Non-complaint	3	98.3 (120.0)	4.7	19.7 (24.0)	4.2	18.7 (19.5)	19.0

ppb	parts per billion	ave	average	OA	outdoor air
n	number of samples	max	maximum		

States: FL = Florida, LA = Louisiana, MS = Mississippi, VA = Virginia, AL = Alabama

Table A.9 Summary Statistics for House Average, Short-Term Air Exchange Rate, by House

No	State	Status	Air Exchange Rate per Hour
1	FL	Complaint	0.22
2	FL	Non-complaint	0.23
3	FL	Complaint	0.19
4	FL	Complaint	0.24
5	FL	Non-complaint	0.19
6	FL	Complaint	0.15
7	FL	Complaint	0.13
8	FL	Non-complaint	0.32
9	FL	Complaint	0.19
10	FL	Complaint	0.16
11	FL	Complaint	0.2
12	FL	Complaint	0.16
13	FL	Complaint	0.2
14	FL	Complaint	0.33
15	FL	Complaint	0.19
16	FL	Complaint	0.06
17	FL	Non-complaint	NA
18	FL	Complaint	0.18
19	FL	Complaint	NA
20	FL	Complaint	0.13
21	FL	Complaint	0.28
22	FL	Non-complaint	0.13
23	FL	Complaint	0.26
24	FL	Complaint	0.05
25	FL	Complaint	0.1
26	FL	Complaint	0.09
27	FL	Complaint	0.14
28	FL	Complaint	0.12
29	LA	Complaint	0.14
30	LA	Complaint	0.12
31	LA	Complaint	0.19
32	LA	Complaint	0.13
33	LA	Non-complaint	0.24
34	LA	Complaint	NA
35	LA	Non-complaint	0.23
36	LA	Complaint	0.17
37	LA	Complaint	0.46
38	LA	Complaint	0.63
39	MS	Complaint	0.18
40	MS	Complaint	0.2
41	VA	Complaint	0.18
42	VA	Non-complaint	0.28
43	VA	Complaint	0.08
44	VA	Complaint	NA
45	VA	Complaint	0.8
46	VA	Non-complaint	0.27
47	VA	Complaint	0.12
48	VA	Complaint	0.2
49	AL	Complaint	0.42
50	AL	Complaint	0.16
51	AL	Non-complaint	0.46

States: FL = Florida, LA = Louisiana, MS = Mississippi, VA = Virginia, AL = Alabama

Table A.10 Summary Statistics for Indoor Air Temperature and Dew Point, by House

No	State	Status	n	Temperature—Fahrenheit		Dew Point—Fahrenheit	
				Average	Range	Average	Range
1	FL	Complaint	3	78.3	77.3 – 79.0	56.3	55.9 – 56.6
2	FL	Non-complaint	3	79.9	78.8 – 81.3	61.5	60.4 – 62.4
3	FL	Complaint	3	78.2	77.6 – 78.8	60.3	60.2 – 60.6
4	FL	Complaint	3	80.6	78.1 – 83.8	64.8	58.2 – 75.6
5	FL	Non-complaint	2	78.1	75.9 – 80.3	59.8	58.3 – 61.3
6	FL	Complaint	2	75.2	74.1 – 76.2	58.0	57.8 – 58.2
7	FL	Complaint	2	86.8	85.5 – 88.1	74.5	74.2 – 74.8
8	FL	Non-complaint	2	76.0	75.6 – 76.5	54.6	54.1 – 55.0
9	FL	Complaint	3	78.2	77.8 – 78.3	62.1	61.2 – 63.4
10	FL	Complaint	2	78.1	77.5 – 78.6	55.4	54.7 – 56.1
11	FL	Complaint	2	77.2	76.9 – 77.6	66.3	66.1 – 66.5
12	FL	Complaint	2	77.0	76.6 – 77.3	54.5	54.0 – 55.0
13	FL	Complaint	2	84.2	83.7 – 84.6	64.5	64.4 – 64.6
14	FL	Complaint	2	80.1	79.9 – 80.3	58.8	58.1 – 59.6
15	FL	Complaint	2	73.5	73.2 – 73.8	54.9	53.4 – 56.4
16	FL	Complaint	2	79.3	79.0 – 79.6	58.6	57.7 – 59.5
17	FL	Non-complaint	2	72.4	72.0 – 72.8	52.8	51.7 – 53.9
18	FL	Complaint	2	76.9	76.2 – 77.6	53.7	50.6 – 56.8
19	FL	Complaint	2	79.4	79.1 – 79.7	53.2	52.2 – 54.3
20	FL	Complaint	2	83.6	82.4 – 84.8	63.5	63.2 – 63.9
21	FL	Complaint	2	77.1	77.1 – 77.2	56.9	56.5 – 57.3
22	FL	Non-complaint	2	81.1	80.2 – 81.9	60.2	58.8 – 61.7
23	FL	Complaint	2	78.1	77.9 – 78.2	51.6	51.3 – 52.0
24	FL	Complaint	3	76.6	75.6 – 77.9	54.5	54.3 – 54.7
25	FL	Complaint	3	77.2	75.4 – 78.8	54.8	54.5 – 55.1
26	FL	Complaint	3	84.5	83.8 – 85.8	68.9	68.7 – 69.1
27	FL	Complaint	3	79.5	78.7 – 80.4	63.2	61.6 – 64.0
28	FL	Complaint	3	83.2	82.7 – 83.5	64.8	64.4 – 65.5
29	LA	Complaint	3	76.5	76.3 – 76.6	56.5	56.1 – 56.8
30	LA	Complaint	2	74.6	74.0 – 75.1	55.6	55.5 – 55.8
31	LA	Complaint	3	77.2	76.6 – 78.3	60.2	59.5 – 60.9
32	LA	Complaint	3	84.3	83.1 – 84.9	70.3	70.2 – 70.5
33	LA	Non-complaint	3	73.1	70.2 – 76.5	55.0	51.6 – 60.0
34	LA	Complaint	2	72.7	72.3 – 73.0	54.8	54.4 – 55.2
35	LA	Non-complaint	2	75.1	75.0 – 75.2	55.0	54.6 – 55.4
36	LA	Complaint	2	86.4	85.3 – 87.5	72.8	71.9 – 73.8
37	LA	Complaint	2	72.1	69.4 – 74.9	55.0	53.6 – 56.5
38	LA	Complaint	2	86.5	86.3 – 86.8	72.5	72.2 – 72.8
39	MS	Complaint	2	75.9	75.4 – 76.4	56.7	55.2 – 58.2
40	MS	Complaint	2	72.4	71.4 – 73.3	50.5	50.5 – 50.6
41	VA	Complaint	2	75.7	75.5 – 76.0	63.5	61.3 – 65.6
42	VA	Non-complaint	3	72.4	71.7 – 73.4	59.9	59.4 – 60.4
43	VA	Complaint	2	77.6	75.8 – 79.3	62.8	62.7 – 62.9
44	VA	Complaint	3	76.9	76.4 – 77.4	61.3	59.8 – 62.7
45	VA	Complaint	2	80.1	79.7 – 80.5	63.4	63.3 – 63.4
46	VA	Non-complaint	3	71.4	70.9 – 72.0	62.3	61.8 – 63.0
47	VA	Complaint	2	74.9	74.8 – 75.0	58.2	58.1 – 58.2
48	VA	Complaint	3	71.6	69.7 – 73.3	54.2	53.3 – 56.0
49	AL	Complaint	2	73.8	73.5 – 74.1	51.3	50.8 – 51.8
50	AL	Complaint	2	77.1	74.8 – 79.5	55.9	53.2 – 58.6
51	AL	Non-complaint	2	76.2	75.3 – 77.2	57.6	56.1 – 59.1

n number

States: FL = Florida, LA = Louisiana, MS = Mississippi, VA = Virginia, AL = Alabama

APPENDIX B

QUALITY ASSURANCE PROJECT PLAN

INDOOR AIR QUALITY ASSESSMENT OF RESIDENCES CONTAINING CHINESE DRYWALL

Quality Assurance Project Plan

EH&E-QAP-001 REV. NO.2:08/09

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August 10, 2009

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LIST OF ABBREVIATIONS AND ACRONYMS

ASTM	American Society for Testing and Materials
CPSC	Consumer Product Safety Commission
CO_2	carbon dioxide
CV	coefficient of variation
DNPH	2,4-dinitrophenyl hydrazine
EH&E	Environmental Health & Engineering, Inc.
EPA	U.S. Environmental Protection Agency
FOSC	Field Operations Support Center
FTIR	Fourier transform infrared
ml/min	milliliters per minute
NIOSH	National Institute for Occupational Safety and Health
NIST	National Institute of Standards and Technology
ppm	parts per million
QA	quality assurance
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance, quality control
VOC	volatile organic compound
XRF	x-ray fluorescence
°C	degrees Celsius
°F	degrees Fahrenheit

1.0 INTRODUCTION

1.1 PROJECT DESCRIPTION AND GOALS

In December 2008, the Consumer Product Safety Commission (CPSC) began to receive drywall related complaints from consumers that included odors emanating from the drywall, corrosion of metal items inside the homes, and short-term health effects. Complaints have been received from consumers residing in many states and the District of Columbia; however; the majority of reports are from Florida, Louisiana, Mississippi, Alabama, and Virginia. The CPSC in conjunction with the U.S. Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention (CDC), and the Agency for Toxic Substances and Disease Registry (ASTDR) initiated a multi-agency approach to investigate the drywall-related complaints.

One component of this investigation is the implementation of an in-home study to investigate the relationship between indoor environmental conditions and imported drywall in residential buildings. Environmental Health & Engineering, Inc. (EH&E) is conducting this study on behalf of CPSC. The objective of the in-home study is to characterize the indoor environment in representative complaint homes to that of non-complaint homes through air sampling and other objective measurements. The key objectives of the study will be to identify markers of imported drywall, measure select indoor air parameters of representative complaint and non-complaint homes, collect building characteristic metrics of complaint and non-complaint homes, evaluate corrosion in homes, and examine relationships among drywall properties, building characteristics, constituents of indoor air, and rates of corrosion.

1.2 QUALITY ASSURANCE POLICY

EH&E has prepared this Quality Assurance Project Plan (QAPP) to ensure the collection of quality data throughout all field collection and data reduction/analysis activities associated with the study. This plan is based upon full implementation of established policies and procedures and fully documented recordkeeping practices. These basic and established principles for data collection and data processing activities will insure uniformly reliable data from all homes included in the study.

The policy of EH&E is that there shall be sufficient quality assurance (QA) to assure that the data collected and reported from all homes is of acceptable precision, accuracy, representativeness, and completeness. The policies stated in this plan define the QA activities that will be practiced by EH&E throughout the implementation of the in-home study. These policies have been established to ensure uniform and standardized data collection and data processing activities throughout the study. The policies are dynamic and will be reviewed, amended, deleted, or added to as needed to ensure acceptable data and to accommodate changes to study design. The policies listed in this QAPP will be implemented and adhered to by all EH&E project team members.

1.3 QUALITY ASSURANCE ELEMENTS AND GOALS

Obtaining quality data is crucial to the goals of the CPSC in-home study. The study will involve field activities that include the collection of data as well as data reduction activities to facilitate data analysis and reporting. The field activities will comprise the collection of various types of indoor air samples, quantitative assessments of corrosion, qualitative assessment of building component corrosion, and elemental analysis of select building materials. All data collected as part of the study will be stored in a central data repository at EH&E and specific quality assurance elements will be implemented and followed throughout all aspects of field and data reduction activities.

The basic elements of EH&E’s QA program will include program planning, implementation, and assessment.

- **Program planning** involves the process of identifying data quality objectives and will form the basis for the development of EH&E’s QAPP.

- **Program implementation** involves the quality assurance quality control activities conducted for all field data collection and data reduction activities undertaken as part of the study.

- **Program assessment** will be made based on the outcomes of data validation and verification procedures. Inputs to this assessment will include field measurement performance and data reporting verifications, and data review.

To meet these basic elements, EH&E will rely on the following key concepts and activities.

- Developing an appropriate project organization and responsibility structure.
- Conducting field staff training to ensure consistent data collection activities
- Ensuring that sample collection and analysis is conducted in accordance with appropriate sampling methods and procedures.
- Adhering to consistent and specified calibration requirements, including traceability standards and schedules.
- Conducting regularly scheduled preventive maintenance.
- Implementing appropriate data reporting and data validation procedures.

1.4 EH&E ORGANIZATION AND LINE OF AUTHORITY

In order to meet the project objectives, EH&E selected qualified personnel to conduct the in-home study and its related quality assurance, quality control (QA/QC) procedures. Appendix A provides EH&E's project organization and line of authority.

The study will comprise in-home field activities to be conducted over an approximate eight week schedule with data reduction, verification, and analysis occurring in tandem. The field activities will be conducted by two three person field teams chosen for his/her expertise in the areas of air sampling, building heating ventilating and air-conditioning (HVAC) assessment, field study management, and communications. Prior to the commencement of the field study, EH&E will conduct training sessions with field team members to ensure consistency among field data collection techniques and procedures. Field team members will be instructed to follow methods described in study sampling protocols and associated methods for each measurement parameter.

Non field personnel will comprise the project QA Officer, equipment, media and supply support personnel and data entry support personnel. Non field personnel will be equally responsible for ensuring data quality with respect to the QAPP through project specific training and procedural documents. Note that the QA Officer will remain independent of the field and non-field personnel for the duration of the project.

2.0 STUDY DESIGN

The study design will compose integrated measures of corrosion and odor, measurements of gases in indoor and outdoor air, characterization of drywall, and the collection of building characteristics. An overview of the field activities are described below.

2.1 OVERVIEW OF IN-HOME STUDY

Measures of corrosion rates will be obtained through the use of copper and silver coupons placed at locations within each home. The coupons will be exposed to indoor air for approximately two weeks and rates of corrosion will be quantified. Evidence of existing corrosion in each home will be made from an inspection of copper ground wires in accessible electrical outlets and other accessible metal objects. Field personnel will record the presence of malodors in homes as an additional measure of impact.

Measurements of indoor and outdoor air will be obtained through active and passive air sampling. A summary of the types of air samples to be obtained and the anticipated sampling duration in each home is provided in Table 2.1.

Table 2.1 CPSC Study Environmental Monitoring Parameters

Monitoring Parameter	Sampling Duration
Volatile organic compounds (active)	120 minutes
Aldehydes (active)	200 minutes
Inorganic acids (active)	200 minutes
Organic acids (active)	200 minutes
Reduced sulfur compounds	Grab sample
Sulfur dioxide (passive)	2 weeks
Aldehydes (passive)	2 weeks
Hydrogen sulfide (passive)	2 weeks
Ozone (passive)	2 weeks
Hydroflouric acid (passive)	2 weeks
Nitrogen dioxide (passive)	2 weeks

The study will evaluate selected elemental and mineral characteristics of drywall in the test homes through the use of x-ray fluorescence (XRF) and Fourier transform infrared (FTIR) spectroscopy. XRF methods will be employed in the field to characterize the amount of imported and domestic drywall in homes. In addiotn, a combination of XRF and FTIR analysis will occur at EH&E's facility by analyzing bulk samples collected from each home.

Physical attributes and other indoor air quality parameters will be obtained including building floor area, ventilation design, air exchange rate, temperature, and relative humidity. A visual inspection of the home and baseline questionnaire will also be conducted including an inspection to document general home construction related characteristics and the visual assessment of corrosion.

2.2 IN-HOME STUDY SCHEDULE

The field activities in each home will be completed during two site visits to the home. On the first site visit, field activities will be completed by a three person team over the course of an anticipated nine to ten hour visit (~8:00 a.m. to 5:00 p.m.) The second site visit will occur approximately two weeks after the first by a single field investigator. The anticipated sequence of activities to be completed in each home are described below and summarized in the daily activity schedule provided as Table 2.2.

Table 2.2 Schedule of Field Sampling and Inspection Activities for the CPSC In-home Study

Day 1	
8:00 – 8:30 a.m.	• Arrive at test home to unpack, setup and calibrate equipment.
8:30 – 9:00 a.m.	• Select three indoor and one outdoor air sampling locations • Setup and start continuous temperature and relative humidity monitors • Setup active air monitoring equipment for volatile organic compounds, aldehydes, organic and inorganic acids
9:00 – 11:00 a.m.	• Start active air sampling • Begin home inspection and questionnaire • Begin XRF analyzer wall survey
11:00 a.m. – 12:00 p.m.	• End active air sampling • Begin bulk sampling of drywall from of areas behind electrical outlet switch plates • Setup and start continuous carbon dioxide monitors • Begin carbon dioxide release throughout the home (air exchange rate assessment)
1:00 – 3:00 p.m.	• Continue and complete home inspection activities and questionnaire • Continue and complete XRF wall scanning survey • Continue and complete drywall bulk sampling of areas behind electrical outlet switch plates
3:00 – 4:00 p.m.	• Setup and start passive air sampling equipment for sulfur dioxide, nitrogen dioxide, hydrogen fluoride, hydrogen sulfide, aldehydes, and ozone • Setup and expose silver and copper coupons
4:00 – 5:00 p.m.	• Collect reduced sulfur samples
5:00 p.m.	• Depart the test home

Table 2.2 Continued

Day 12 to 15	
Time varies	• Collect passive air samplers • Collect temperature and relative humidity monitors • Collect silver and copper coupons

XRF x-ray fluorescence

Field personnel will arrive at each home at approximately 8:00 a.m. and began the unpacking, set-up, and calibration of equipment. Once inside the home, the field personnel will select the indoor and outdoor locations where all active and passive environmental sampling and monitoring are to be conducted. Following the selection of the indoor sites, temperature and relative humidity monitors are to be placed at two or three of the locations (depending on the characteristics of the home) and set to continuously log conditions over the course of the two week monitoring period.

At 9:00 a.m. active air sampling equipment will be set up at the indoor locations and at the outdoor location to measure volatile organic compounds (VOCs), aldehydes, inorganic acids, and organic acids. VOC samplers will be set up in two or three indoor locations with one duplicate, and at one outdoor location. One field blank will be included for every ten samples. Similarly, aldehydes, inorganic acids, and organic acids are to be collected at three indoor locations with one duplicate and one field blank or media blank. The active air sampling systems will be started at approximately 9:00 a.m. and sampled for approximately 200 minutes. While active air samples are being collected, field personnel will survey walls in the home using a handheld XRF analyzer. During this time, field personnel will also initiate a visual home inspection to document general home construction related characteristics, a visual assessment for corrosion, and the questionnaire.

Once the active air sampling is completed, field personnel will collect small bulk samples of wall board from behind the cover plates of light switches and electrical boxes. In addition, at each of the light switch and electrical boxes where bulk samples are collected, field personnel will document the condition of the copper electrical ground in terms of the level of corrosion identified. The drywall at each of these locations will also be scanned utilizing a handheld XRF analyzer. Following the completion of active air sampling, the home air exchange rate will be evaluated by releasing carbon dioxide (CO_2) throughout the home and monitoring the decay in CO_2 concentration over approximately four hours. CO_2 monitors will be placed at the three indoor sampling locations and will continuously monitor the concentration of the gas over the test period.

During afternoon hours, field personnel will complete the XRF wall survey, the home inspection/questionnaire, and the bulk sampling. Once CO_2 monitoring is completed, passive air sampling equipment for sulfur dioxide (SO_2), nitrogen dioxide (NO_2) , hydrogen fluoride (HF), hydrogen sulfide (H_2S), aldehydes, and ozone will be deployed. Passive air samplers will be placed at three indoor locations with one duplicate, one field blank or media blank and at one outdoor location. The passive air samplers will collect air from the various locations for approximately two weeks.

To measure the integrated rate of corrosion, copper/silver coupons will be placed at the three indoor sampling locations, at one outdoor location, and at the outlet of a supply air diffuser for the air conditioning unit serving the home. Due to the anticipated limited availability of copper/silver coupon kits, duplicate samples will be collected at approximately five percent of the site locations. Sampling of reduced sulfur gases will be initiated late in the day in order to ensure that samples are received by the laboratory within 24 hours of the sample collection time. Samples of reduced sulfur gases will be obtained from the three indoor locations, with one duplicate, and from one outdoor location.

A single field investigator will return to the home approximately two weeks following the date of the initial survey to collect the passive air samplers, temperature, and relative humidity monitors, and copper/silver coupons.

3.0 MEASUREMENT QUALITY GOALS

Collecting high quality data is critical to the success of the in-home study. The study design will involve the collection of indoor air samples and the characterization of drywall using field and laboratory measurement techniques. Assessing the quality of these data will consider precision, accuracy, representativeness, reliability, comparability, and completeness. A description of each is provided below and further discussed in specific sections of this QAPP.

3.1 PRECISION AND ACCURACY

Two central themes in the discussion of error analysis are the concepts of precision and accuracy. For application to environmental sampling, the definitions of accuracy and precision can be defined as follows:

Accuracy—the degree of correctness with which a measurement reflects the true value of the parameter being assessed

Precision—the degree of variation in repeated measurements of the same quantity of a parameter

For example, if ten measurements for a given parameter are taken at the same time at the same location by the same method, the accuracy would be indicated by how well the average of the ten measurement results reflects the actual concentration present and the precision would be indicated by the variation in the results of the ten measurements.
A high degree of precision and accuracy do not necessarily occur simultaneously in a process. Measurements may have a high degree of precision, while not being very accurate. Conversely, a set of data may have high accuracy but lack precision. When results are both precise and accurate, confidence in data quality is maximized. The assessments to be undertaken concerning the precision and accuracy of the in-home study data are discussed in Section 7.2.

3.2 REPRESENTATIVENESS

The objectives of the in-home study are to characterize potential imported drywall-related constituents that may be present in the indoor air of complaint and non-complaint homes. The data will be used to support the review of potential associations between these two home groups and may also be utilized to support human health risk assessment. Target homes participating in the study were selected by CPSC based on a number of factors including geography and reports of health effects and corrosion. The study population will comprise 50 single-family residential buildings made up of complaint homes and non-compliant homes. Non-complaint homes will be selected by CPSC and will be located geographically proximate to complaint homes such that they would have similar ambient conditions to that of the complaint homes. Non-complaint homes will have similar attributes to the complaint homes including the period of construction, style of home, and floor area.

3.3 RELIABILITY

Reliability of an environmental monitoring plan is defined as the probability that the systems utilized will perform their intended function for a prescribed period of time under the operating conditions specified. Data interpretation depends to a great degree on data completeness for trend analysis and this demands continuous reliability in the operational systems. In order to ensure a sustained high degree of reliability, the following procedures will be followed:

- Only highly reliable equipment will be used.
- Incoming equipment will be inspected and tested for adherence to specifications prior to acceptance.
- Control, whenever and wherever possible, of environmental operating factors which can influence the reliability of the measurement systems.
- Adequate training of operating and supervisory personnel will be provided through on-the-job training, and in-house training sessions.
- Preventive maintenance will be provided to reduce and minimize equipment failure.

3.4 COMPLETENESS

The completeness of air sampling data from the study will be evaluated by examining overall data capture efficiency for field measurements.

4.0 PROJECT PLANNING

4.1 TRAINING OF PERSONNEL

Personnel involved in any function affecting data quality (sample collection, analysis, data reduction, and quality control) will have sufficient training in their appointed roles to contribute to the reporting of complete, comparable, representative, precise, and accurate environmental monitoring data. The Project Manager will insure that the required training is available for all personnel involved in the study.

Training objectives will be to develop personnel to the necessary level of knowledge and skill required for proper operation of the environmental monitoring equipment and performance of the necessary inspectional activities. Primary methods of training that wiil be utilized by EH&E will include the following:

- On-the-job training will comprise
  - Observing an experienced operator performing the function
  - Understanding of the QAPP and operating procedures
  - Use of the QAPP and operating procedures as guides to the operations
  - Performing the operation under the direct supervision of an experienced operator
  - Independent performance of the operations with a high level of quality control

- Internal training will consist of completion of in-house training on project specific equipment and documentation prior to participation in field work.

Evaluation of training will encompass the level of knowledge and skill achieved by the operator and the overall effectiveness of the training, including determination of areas in which the training program requires improvement.

4.2 PREVENTATIVE MAINTENANCE

Preventive maintenance is an orderly program of positive actions (equipment cleaning, lubricating, reconditioning, adjustment, and/or testing) designed to prevent failure of monitoring systems or parts thereof during use. The most important effect of a good preventive maintenance program is to increase measurement system reliability and thus to increase data completeness. Preventive maintenance status of each piece of equipment will be confirmed prior to use. At a minimum, equipment used during the study will be subject to respective manufacturer’s recommended preventative maintenance recommendations. A record of preventive maintenance and service checks is maintained centrally at the EH&E Field Operations Support Center (FOSC).

5.0 DATA COLLECTION

5.1 MEASUREMENT PARAMETERS AND METHODS

Environmental samples and measurements will be collected in accordance with published standards and methods according to the schedule outlined in the in-home study protocol described in Section 2.2 of this QAPP. The following sampling and analytical procedures will be utilized.

5.1.1 Source Drywall Measurements

Material characteristics of drywall will be determined using a combination of XRF analysis (for metal analysis), and FTIR analysis (to determine the compounds present).

The XRF Spectrometer (Innov-X ALPHA™ Handheld XRF, Innov-X Systems, Inc., Woburn, Massachusetts) will provide on-site metals analysis in this study. This device is a handheld, tube-based, portable XRF analyzer and will be used to identify and quantify the elements in representative wall surfaces in each home as well as in the bulk samples collected from each home.

FTIR measurements will be obtained using A2 Technologies Exoscan instrument, a full scanning Fourier Transform mid-infrared spectrometer, equipped with a Michelson interferometer and non-hydroscopic optics. The diffuse reflectance Exoscan will be configured for porous and rough surfaced materials. The FTIR will be employed to identify and profile spectra of the collected drywall samples.

5.1.2 Reduced Sulfur Compounds

Grab air samples will be collected and analyzed for a suite of twenty reduced sulfur compounds in accordance with American Society for Testing and Materials (ASTM) Method D5504 *Standard Test Method for Determination of Sulfur Compounds in Natural Gas and Gaseous Fuels by Gas Chromatography and Chemiluminescence*. Whole air samples will be collected into Tedlar Bags (Zefon International) using a SKC Vac-U-Chamber™. All surfaces that come in contact with sample air will be constructed of stainless steel or Teflon tubing (SKC Cat. No. 231-940). The sampling pumps used to fill/evacuate the chambers will be adjusted to a flow rate of 1000 milliliter per minute (ml/min). Sample analysis will be conducted by Columbia Analytical Services, Inc. located in Simi Valley, California. In accordance with recommendations outlined in the ASTM method, samples will be analyzed within 24 hours of collection.

5.1.3 Volatile Organic Compounds

Whole air samples for VOCs will be collected with individually cleaned and certified SUMMA canisters obtained from Columbia Analytical Services, Inc. located in Simi Valley, California. The flow controllers used to fill the SUMMA canisters during sampling will also be calibrated and conditioned by Columbia Analytical Services, Inc. on an individual basis. Flow controllers will be calibrated for two hour sample durations. VOC samples will be analyzed using gas chromatography/mass spectrometry (GC/MS). The analyses will be performed according to the methodology outlined in EPA Method TO-15 from EPA's Second Edition *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*.

5.1.4 Aldehydes (Active)

Active air samples will be collected and analyzed according to EPA Method TO-11A for aldehydes, including formaldehyde, using 2,4-dinitrophenyl hydrazine (DNPH) coated sorbent tubes with a built-in ozone scrubber (SKC Cat. No. 226-120). Each tube will be connected to a personal sampling pump adjusted to a nominal flow rate of 500 ml/min. Analysis will be conducted by Columbia Analytical Services, Inc. in Simi Valley, California in accordance with EPA Method TO-11A, *Determination of Formaldehyde in Ambient Air Using Adsorbent Cartridge Followed by High Performance Liquid Chromatography (HPLC)*. All sample media will be refrigerated before, during, and after sampling.

5.1.5 Passive Diffusive Sampling

Passive diffusion samples for analysis of sulfur dioxide, nitrogen dioxide, hydrofluoric acid, hydrogen sulfide, aldehydes, and ozone will be collected using Radiello Diffusive Sampling Systems. Specific system components included the diffusive body, supporting plate, and chemiadsorbing cartridge. The type of passive sampling system and the analytical technique to be used for each class of analyte are summarized in Table 5.1

Table 5.1 Summary of Target Parameters, Passive Air Sampling

Compound	Analytical Method*
Aldehydes	Aldehydes by Radiello 165, HPLC-UV
Hydrogen sulfide	Hydrogen sulfide by Radiello 170 Spectrophotometer at 665 nm
Ozone	Ozone by Radiello 172 Spectrophotometer at 430 nm
Sulfur dioxide	Sulfur dioxide by Radiello 166 Ion Chromatography
Nitrogen dioxide	Nitrogen dioxide by Radiello 166 Spectrophotometer at 537 nm
Hydrofluoric acid	Hydrofluoric acid by Radiello 166 Ion Chromatography

HPLC	high performance liquid chromatography
UV	ultra violet
nm	nanometer

* Analytical methods provided by Fondazione Salvatore Laboratory, Radiello Manual, Supelco Edition.

To achieve the desired limit of detection the sampling devices will be deployed for 13 to 15 days in each of the test homes. All analysis of the diffusive sampling media will be conducted by Air Toxics LTD, located in Folsom, California.

5.1.6 Inorganic and Organic Acids

Air samples for analysis of targeted inorganic and organic acids will be collected using silica gel tubes (SKC Cat. No. 226-10-03) and personal sampling pumps set to draw at 500 ml/min over the sampling period. Analysis for inorganic and organic acids will be conducted using ion chromatography (IC) according to National Institute for Occupational Safety and Health (NIOSH) Methods 7903 and 2011, respectively, by Liberty Mutual Industrial Hygiene Laboratory in Hopkinton, Massachusetts.

5.1.7 Relative Humidity/Temperature

Real-time temperature and relative humidity measurements will be collected in each home using U10-003 HOBO® Temperature Relative Humidity Data Loggers manufactured by Onset Computer Corporation, Bourne, Massachusetts. The temperature sensor is a thermistor and relative humidity is measured by a thin-film capacitive sensor. The temperature sensor has a range of -20 degrees Celsius (°C) to

70 °C (-4 to 158 degrees Fahrenheit [°F]) with accuracy of ± 0.4 °C at 25 °C (± 0.7 °F at 77 °F). The sensor is factory rated to achieve a resolution of 0.1 °C at 25 °C (0.2 °F at 77 °F). The relative humidity sensor has a range of 25% to 95% with accuracy of ± 3.5% from 25% to 85%. The sensor is factory rated to achieve a resolution of 0.07%. Temperature and relative humidity measurements will be collected for approximately 13 – 15 days in each home.

5.1.8 Air Exchange Rate

The air exchange rates in each test home will be measured in accordance with the test methods outlined in ASTM standard E741-00, *Standard Test Method for Determining Air Change Rate in a Single Zone by Means of a Tracer Gas Dilution*. CO_2 will be utilized as the tracer gas and air exchange rates will be measured using the concentration decay test method as outlined in ASTM Standard E741-00. The tests will be conducted by introducing the CO_2 tracer throughout the home and analyzing the decaying part of the tracer curve after all tracer is injected and allowed to mix within the home.

CO_2 concentrations will be measured continuously at multiple locations inside the home using a Q-Trak Model 8551 Indoor Air Quality Monitor, manufactured by TSI, Inc. (St. Paul, Minnesota). The CO_2 sensor utilized by this monitor is non-dispersive infrared (NDIR) and is accurate within 3% (or 50 parts per million [ppm] at 25 °C [78 °F]) of the reading. Prior to each air exchange rate test, the sensors will be calibrated at zero using hydrocarbon free air and spanned to approximately 1,000 ppm of CO_2. Air exchange rates will be calculated from the CO_2 decay results using the regression method.

5.1.9 Corrosion Assessment, Visual

Detailed visual inspections will be performed on the air handling units, plumbing components, appliances, and electrical grounding wires. Notes will also be made regarding other home contents that could show visible evidence of corrosion.

Grounding wires will be evaluated on a three point scale. A score of one will indicate no visible corrosion, two will indicate moderate visible corrosion and three will indicate significant visible corrosion. Field team members will perform cross reference evaluations during training to ensure consistency between teams in the field. Visual corrosion ratings will be recorded in the master field log binder.

Air handling unit inspection will focused on the cooling coils and associated copper refrigerant lines. Surfaces will be photographed and all locations will be logged into the master field log binder. Appliances and fixtures including accessible refrigerator components, hot water heaters, faucets, plumbing lines, and other items indicating patterns of corrosion will also be logged and photographed.

5.1.10 Corrosion Assessment, Coupons

Corrosion classification coupons will be employed to determine the integrated corrosion rate present in the study homes. Copper and silver coupons were supplied by Purafil, Inc., research and development laboratory in Doraville, Georgia. Copper and silver coupons will be placed at indoor locations and one outdoor location for an approximately two week period. At the end of the two week sampling period, the coupons will be collected, placed in sealed containers and returned to Purafil for analysis of the corrosive film that developed. The laboratory analysis will determine a corrosion reactivity rate by measuring the thickness of the copper sulfide film present and normalized it to “angstroms per 30 days of exposure” for each of the coupon surfaces.

5.2 QUALITY CONTROL SAMPLES

A number of samples will be collected and analyzed in each sample set to evaluate the quality and reasonableness of the data collected during the study. The types and frequency of QA/QC samples to be collected during the study are outlined in Table 5.2.

Table 5.2 Quality Assurance, Quality Control Samples Collected During the Project

Sample Type	Frequency	Definition
Duplicate sample	Minimum of one per sample set and one per every 10 primary samples	A sample collected concurrently with a primary field sample to assess repeatability of methods.
Field blank	Minimum of one per sample set and one per every 10 primary samples	A sample prepared by the field team that represents the procedure for preparing for integrated sampling, and is handled as such, but is not actually used for sampling. This is sent in a blinded fashion to the laboratory. The results of the field blanks can be used to determine whether there was any contamination in the preparation, handling or shipping process in the field, or during the analysis of the samples by the laboratory.
Shipping Blank	Minimum of one per sample set and one per every 10 primary samples	An unused sample that is not handled in the field other than to have it incorporated into a regular sample shipment and sent in a blind fashion to the laboratory. The results of shipping blanks can be used to determine whether there was any contamination during the shipping process.

5.3 EQUIPMENT CALIBRATION

Calibration procedures require the application of primary or secondary standards. The standards used for apparatus or materials will be certified as being traceable to standards of the National Institute for Standards and Technology (NIST) or some other recognized fundamental standard. Regardless of the type of calibration equipment or material, an effective QA program requires accuracy levels of these materials that are consistent with the method of analysis. The calibration policies and procedures set forth within this section will apply to all measuring and test equipment identified, including environmental sampling equipment, and measuring devices (e.g., rotameters, dry gas meters, temperature sensors, etc.).

The calibration standards used will be referenced against higher-level, primary standards having unquestionable and higher accuracy. The higher-level standards will be certified by the NIST or another recognized organization or derived from accepted values of physical or chemical constants. Calibration gases purchased from commercial vendors normally contain a certificate of analysis. Whenever a certified gas is available from the NIST, commercial gas vendors will be requested to establish traceability of the certificate of analysis.

Measuring equipment, test equipment, and calibration standards will be calibrated in an area that provides control of environmental conditions to the degree necessary to assure required accuracy. The calibration area will be reasonably free of dust, vapor, and vibration, and it will not be close to equipment that produces noise, vibration, or chemical emissions that can affect the calibration results. All calibration standards, measuring equipment, and test equipment are assigned an established interval for calibration and these documents will be maintained centrally at the EH&E FOSC.

All measuring, monitoring, and sampling instrument calibrations, except those requiring factory calibrations will be performed in EH&E's FOSC prior to shipment of instruments to the field. All instruments that are factory calibrated are checked periodically in the FOSC by comparing them against other, recently calibrated instruments. Table 5.3 summarizes the calibration procedures for instruments used in the study.

Table 5.3 Equipment and Sensor Calibration

Parameter	Instrument Type	Instrument	Calibration Method	Frequency
Air temperature	Thermistor, data logger	HOBO® U10-003 (Onset Computer Corp)	Calibrations performed by the manufacturer	Annual
Relative humidity	Thin-film capacitive sensor, data logger	HOBO® U10-003 (Onset Computer Corp)	Calibrations performed by the manufacturer	Annual
Carbon dioxide	Non-dispersive infrared sensor	Q-Trak Model 8551 Indoor Air Quality Monitor,	Multipoint with standard gas mixtures ranging from 0 to 2000 ppm along linear response curve.	Pre and post field measurements
Active air sampling	Air-sampling pump	Gilair-3/5 (Sensodine, Inc.) SKC Inc.	Compared against calibrated flow meter.	Pre and post measurements
Active air sampling	Flow meter	Dry-Cal DC-Lite, Bios International Corporation	Annual factory calibration	Pre and post measurements
Volatile organic compounds	SUMMA canister flow controller	6 Liter SUMMA canister	Provided pre-calibrated by laboratory	Each canister

5.4 CORRECTIVE ACTION

In a QA program, one of the most effective means of preventing trouble is to respond immediately to reports from the operator of suspicious data or equipment malfunctions. Application of proper corrective actions can reduce or prevent the collection of poor quality data and/or the loss of data. Established procedures for corrective actions are available in the methods if the performance limits are found to be exceeded. Specific control procedures, calibration, or operational checks, etc. are designed to detect instances in which corrective action is necessary. Troubleshooting guides for operators are found in the instrument manufacturer's manuals. On-the-spot corrective actions routinely made by field technicians will be documented as normal operating procedures, and no specific documentation other than notations in operations logbooks need be made. Corrective actions are a continual part of the environmental monitoring system for quality, and they will be documented throughout the in-home study.

5.5 INTEGRATED SAMPLE FLOW RATES

QA/QC of integrated air samples will include verification of pump flows by use of calibrated flowmeters at the start and end of each sampling period. The start and stop flow rates will then be averaged to obtain an average flow rate. Sample duration will also be calculated from the start and stop times recorded on the field data sheets. Total sample volumes will then be calculated using the average flow rate and the duration of sampling as follows:

Total Sample Volume (L) = Average Flow Rate (L/min) x Total Sample Time (minutes)

6.0 DOCUMENT MANAGEMENT

Strict attention will be paid to sample custody and record keeping throughout all aspects of the in-home study as described below.

6.1 SAMPLE CUSTODY

EH&E will follow the requirements for holding times and sample perseveration outlined in the respective reference sampling methods to be used. After each day of sampling, samples will shipped to the laboratory via overnight express delivery within the holding time specified by the analytical method. The reduced sulfur air samples will be shipped immediately after sampling via first priority overnight express delivery so that they would be received at the laboratory within 24 hours of sample collection.

All project samples will be handled in accordance with appropriate chain of custody procedures. Compliance will be overseen by the lead field technician. The lead field technician will also be responsible for ensuring that all unused sample media as well as collected samples are properly cared for before, during, and after sampling. At the time of use, each sample will be assigned a unique sample identification label. Each sample label will be recorded on the field sample log sheets prior to sample collection. All log sheets will be stored in a master field binder during the study.

6.2 RECORDKEEPING

All data and documentation generated during the study, except that generated in electronic formats (raw data files, digital photographs), will be transcribed into the appropriate field collection forms which will be subsequently stored in a single data collection binder. Hardcopies of final analytical laboratory reports (and the completed chains of custody) will also be received and retained in EH&E's central filing system. Any changes in data entries will be done in a manner that does not obscure the original entry. The reason for the revision will be indicated, dated, and signed at the time of change. All original hard copy records for the project will be retained (together) in a central file system at EH&E's main office.

Electronic documentation generated in the field during the study will include digital photographs, XRF data files, carbon dioxide measurements, temperature and relative humidity data files. All files generated during the field phases of the study will be downloaded and stored temporarily on a field computer under the control of the lead field technician. Electronic files will then be transferred from the field computer onto EH&E's central server routinely (typically at the end of each day). In order to track the various electronic data files, a standardized filing and naming system will be used to clearly differentiate between files by type and study home. Also, field personnel will document the location of digital photographs, XRF measurements, and real-time data monitor deployments on the appropriate field forms.

6.3 DATA ENTRY AND DATA REDUCTION

A systematic, standardized approach will be implemented by EH&E for all data entry and data reduction activities. EH&E will develop a database (Microsoft Access), where all field data and laboratory results will be stored. All (100%) field log entries and calculations will be reviewed by independent staff members prior to entry into the study database. Data entry personnel will initiate data entry activities as soon as the respective data binders are reviewed. Data entry personnel will be trained on all data entry procedures and requirements. Once in the database, all (100%) of the data entry fields will be reviewed and verified by independent, qualified personnel.

To minimize database entry errors, EH&E will request that, when possible, all laboratory reports be provided in electronic data delivery (EDD) formats, such as Microsoft Excel so that the data can be directly imported into the central study database. All laboratory data will be uploaded to the project database through program codes developed using SAS 9.1. All programming codes developed and executed for processing the data will be independently reviewed by qualified personnel. In the limited instances where data entry or recording errors are identified during the QA/QC review processes described above, the entry will be corrected in all relevant locations (back to the original entry). Corrections will be noted on all original documentation.

7.0 DATA VALIDATION

All data will undergo a validation process whereby data are accepted or rejected based on a set of specific quality control and QA criteria. A number of measures will be implemented to ensure the collection of reproducible and accurate data during the study including the assessment of precision and accuracy, a review of QA samples, and an assessment of sample completeness.

The assessment of sample duplicates, field blanks, and shipping blanks will be used for evaluating the error within the data set. The completeness of the data set will be evaluated by analyzing the capture efficiency for each environmental parameter targeted in the study. Precision will be evaluated by calculating relative percent differences between paired primary and duplicate samples while accuracy will be evaluated by reviewing results of blank samples. The data validation methods to be employed are described below.

7.1 POST DATA REDUCTION

After the database is populated, the number and sample identification labels in the database will be compared with those on the field log sheets and the analytical laboratory reports (using a program coded in SAS 9.1) to ensure all samples are accounted for. All programming codes developed and executed for processing the data will be independently reviewed by qualified personnel.

7.2 PRECISION AND ACCURACY

While the sampling and analytical methods for the integrated parameters vary widely, the analyses of precision and accuracy do not. Duplicate laboratory samples, field blanks, and laboratory limit of detection will be the tools used for measuring confidence with the integrated samples. The following paragraphs describe methods that will be used to estimate the precision and accuracy of integrated samples collected as part of the study.

Precision will be evaluated by analyzing statistical variance between primary sample and duplicate samples. For the real-time and continuous data, precision will be evaluated by comparison of differential results between instrument readings. It will be essential to have an understanding of how data quality will potentially be impacted by measurement error.

Compared to estimates of precision, there will be less certainty in available estimates of accuracy with respect to the environmental integrated data collected. Field and shipping blanks will be used for assessing the accuracy of the data. It should be noted that many of the estimates of accuracy may have considerable variation in their values. However, this variation reflects the precision, which is best estimated by the field duplicate samples discussed above.

The concepts of precision and accuracy are more inherent to continuous and real time monitoring than time-integrated sampling, as sensor performance can be more directly evaluated and/or manipulated. While integrated data requires laboratory intervention and subsequent analysis, continuous and real time data records can be adjusted and tracked in the field.

At the beginning of sampling event instrument response will be set or calibrated to a primary standard device in the EH&E field operations support center or by the factory. Each day the performance of each sensor will be measured or verified against the appropriate standard. This method will allow both the repeatability (precision) and the instrument accuracy to be evaluated. Evaluating the precision and accuracy of continuous and real time monitoring parameters will be based upon predictable and repeatable instrument response as well as on comparisons to NIST traceable standards.

7.3 DATA COMPLETENESS

The completeness of air sampling data from the study will be evaluated by examining the overall data capture efficiency for each sample group and sample type collected in the field (primary samples, duplicate samples, and field blanks and shipping blanks).

APPENDIX A

PROJECT TEAM ORGANIZATION

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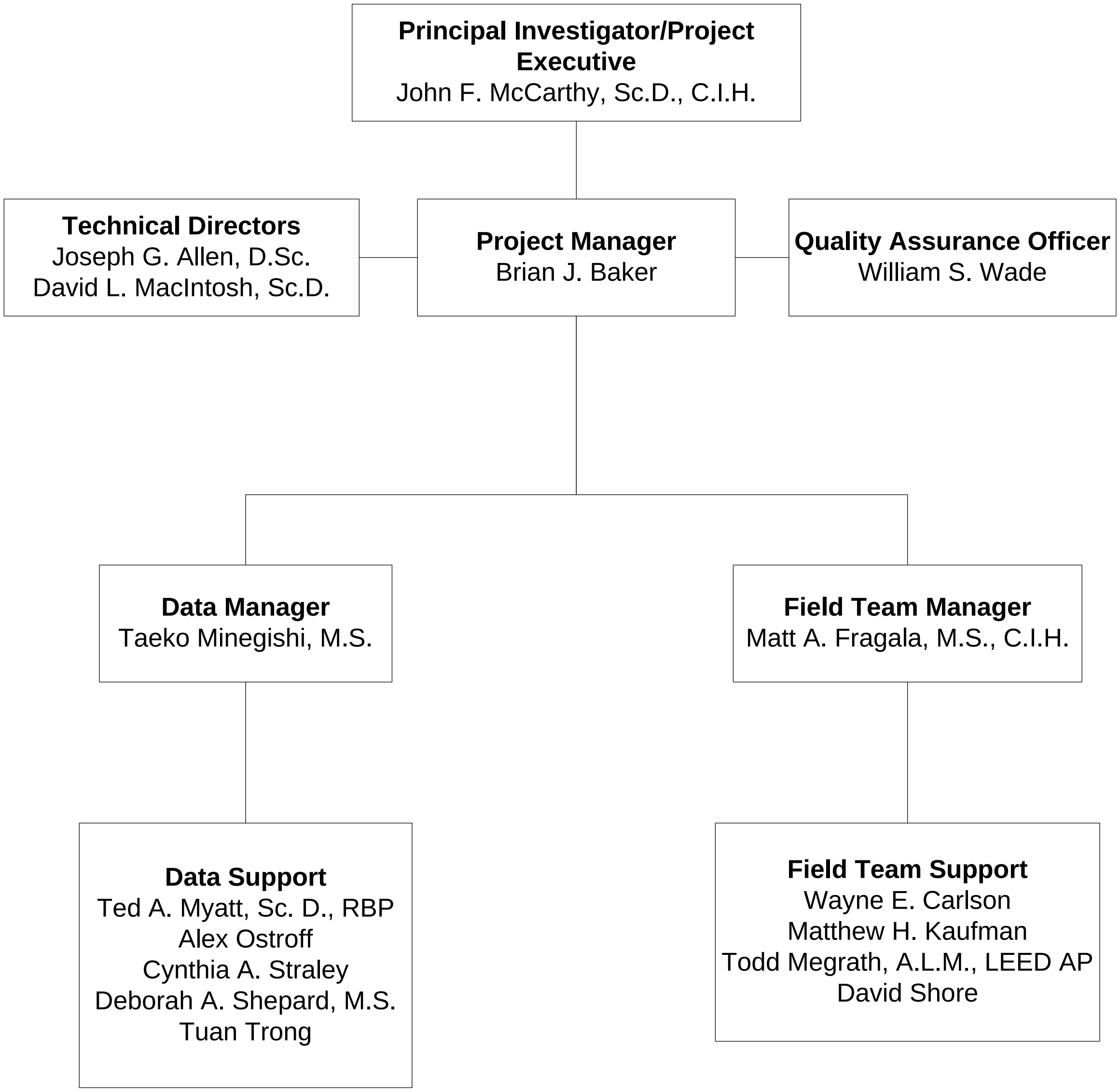

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