INDOOR ENVIRONMENTAL QUALITY ASSESSMENT OF RESIDENCES CONTAINING PROBLEM DRYWALL:
SIX-HOME FOLLOW-UP STUDY

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May 12, 2011

EH&E Report 17131

This report was prepared for the Commission pursuant to contract CPSC-D-10-0002. It has not been reviewed or approved by, and may not necessarily reflect the views of, the Commission.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACH	air changes per hour
ASTM	ASTM International (formerly American Society for Testing and Materials)
CPSC	U. S. Consumer Product Safety Commission
CO_2	carbon dioxide
EH&E	Environmental Health & Engineering, Inc.
EPA	U.S. Environmental Protection Agency
GC/MS	gas chromatography/mass spectrometry
H_2S	hydrogen sulfide
mg/kg	milligram per kilogram
NIOSH	National Institute for Occupational Safety and Health
OSHA	U.S. Occupational Safety and Health Administration
QA/QC	quality assurance/quality control
S_8	elemental sulfur
VOC	volatile organic compound
$\mu g/m^3$	micrograms per cubic meter

1.0 INTRODUCTION

In the autumn of 2009, the U.S. Consumer Product Safety Commission (CPSC) and Environmental Health & Engineering, Inc. (EH&E) completed an in-home investigation of problem drywall (“51-Home Study”) (EH&E 2010a). The results of this investigation highlighted the link between problem drywall and several key parameters monitored in the home, including increased levels of hydrogen sulfide and increased rates of corrosion. This initial study generated questions regarding seasonal variability and the impact of renovations, if any, on the potential for additional corrosion effects. To address these questions, EH&E undertook a follow-up investigation of six homes previously characterized in the 51-Home Study, one of which was remediated after testing was completed as part of the 51-Home Study.

The question of seasonal variability is significant for three primary reasons. First, any changes observed over time may help identify the mechanisms responsible for the observed increase in airborne concentrations of hydrogen sulfide and increased rates of corrosion. Second, understanding any potential seasonal variability is critical for any future health effects study or risk assessment that will need to consider if concentrations measured in the 51-Home Study are a short-term phenomena linked to summer months, or if concentrations are consistent over time. Finally, questions remain regarding how well exposures can be characterized by a single measurement taken over a short time period in one season of one year. Another significant issue is potential seasonality in the criteria for identifying corrosion rates in homes that may contain problem drywall or in remediated homes to assess if remediation had an impact on corrosion rates.

Assessing the impact of remediation on drywall-related off-gassing and corrosion effects, if any, was also a critical need at the time that the 51-Home Study was completed. Although the investigation detailed in this report was not intended to evaluate the efficacy of different proposed problem drywall remediation techniques, it provides critical data for determining whether renovations can modify conditions and potential exposures in impacted homes.

2.0 METHODS

2.1 STUDY HOMES

To address questions surrounding seasonal variability of conditions in homes with problem drywall, a subset of homes (n=5) previously identified as having problem drywall (i.e., drywall that was associated with increased hydrogen sulfide concentrations and corrosion rates) was selected from the 51 homes previously characterized in 2009 (EH&E 2010a). One of these homes had been remediated during the intervening period between the original sampling in 2009 and the follow-up testing in 2010. The remediation procedure for this home involved the complete removal and replacement of all drywall in the home, but did not include replacement of wiring. Adjacent, attached homes in this multi-unit dwelling were not remediated. The remaining four homes with problem drywall have not had any remediation or remodeling performed since the first round of testing in 2009. In addition, one control home (i.e., no problem drywall) from the 51-Home Study was also selected for follow-up in-home testing. Recruitment and final selection of homes for this follow-up study was conducted by the CPSC. A summary of the study homes is presented in Table 2.1.

Table 2.1 Identification of Study Homes

House ID (Short)	House ID (Full)	Location	Status as of May 2010
14	081009FL01	Florida	Problem Drywall
19	081209FL02	Florida	Problem Drywall
21	081309FL02	Florida	Problem Drywall
27	082009FL02	Florida	Problem Drywall
23	081409FL02	Florida	Remediated
22	081409FL01	Florida	Control

2.2 STUDY METHODS

The six homes in this study were revisited beginning in May 2010, approximately eight months after initially being tested as part of the 51-Home Study. During the first visit in May, a thorough indoor environmental quality assessment was performed (Phase I). After that period, follow-up testing was conducted for a subset of parameters (Phase II) in two-week intervals in the spring, fall, and winter. Sampling was not performed during the summer season so that the study could be extended into the fall and winter months when temperature changes would be the greatest. An overview of the sampling periods and corresponding ambient temperature and dew point are presented in Figure 2.1.

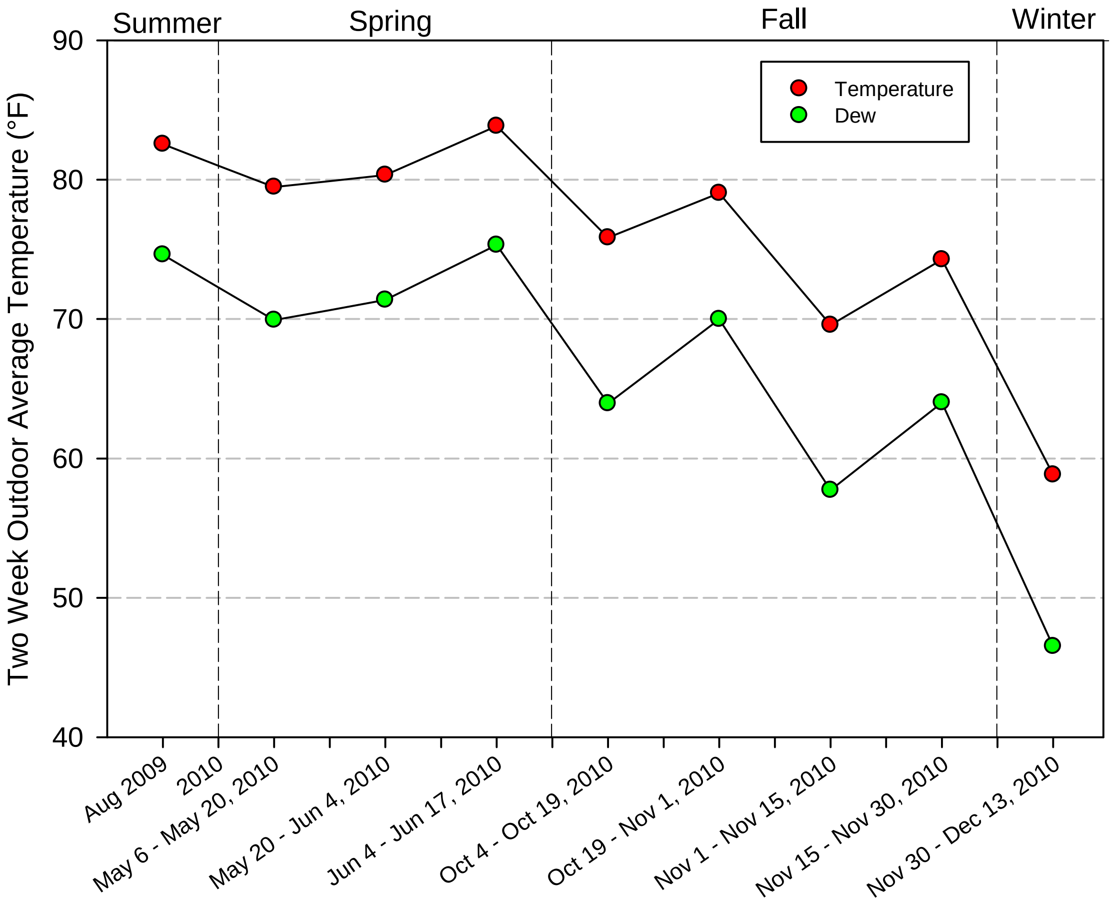

Figure 2.1 Ambient Temperature and Dew Point During the Sampling Periods

2.2.1 Phase I

All six homes were visited in May 2010 over a one-week period. The follow-up home characterization included testing for several key parameters (Table 2.2), as identified based on the results of the 51-Home Study.

Table 2.2 Overview of Assessment Parameters Associated with the Six-Home Study

Assessment Parameter	Description
Drywall Sampling	Collection of core samples for XRF and FTIR analysis
Air Sampling	Includes hydrogen sulfide (H_2S), formaldehyde, and volatile organic compounds (VOCs)
Measurement of Corrosion Effects	Deployment of silver and copper corrosion classification coupons and inspection of potential indicators of corrosive gases including the air handler coils, plumbing lines and electrical fixtures
Environmental Conditions	Continuous logging of temperature and relative humidity conditions in each home
Ventilation	Assessment of air exchange rates in each home
Building Characterization	Documentation of building construction parameters including envelope construction, and mechanical systems

2.2.2 Phase II

Phase II of the study involved a longer term assessment of specific environmental parameters. All six homes underwent ongoing monitoring of the key indicator parameters over several months. During this phase of the study, an EH&E field technician visited the six homes approximately every two weeks to collect and redeploy specific passive samplers. These samplers include hydrogen sulfide (H_2S) and formaldehyde passive air monitors and silver and copper corrosion classification coupons. Temperature and relative humidity monitors remained in the homes and continued to collect data on interior conditions throughout the sampling period.

2.3 MEASUREMENT AND SAMPLING CRITERIA

To ensure comparability, all sampling methods used in this follow-up study were identical to the methods used in the 51-Home Study in 2009. Detailed descriptions of the methods are provided in Appendix B. An overview of the field measurements is provided in Table 2.3 and described in the following sections.

Table 2.3 Summary of Sampling Methods

Parameter	Sampling/Measurement Method	Sample Integration Period
VOCs*	Whole air, SUMMA canister, GC/MS, EPA TO-15	2 hours
Hydrogen sulfide (Passive)	Radiello Diffusive Sampling System, Radiello 170 Spectrophotometer at 665 nm	2 weeks
Formaldehyde (Passive)*	Radiello Diffusive Sampling System , Radiello 165, HPLC-UV	2 weeks
Temperature and relative humidity	HOBO® U10-003 Temperature Relative Humidity Data Loggers	Continuous, 2 weeks
Air exchange rate	TSI, Inc Q-Trak Model 8551, CO_2 decay method	4 – 6 hours
Corrosion coupons	Copper and silver corrosion classification coupons	2 weeks
Core samples (Bulk)*	Drywall core samples collected from behind electrical switch/outlet plates	NA

VOC	volatile organic compound
GC/MS	gas chromatography/mass spectrometry
EPA	U.S. Environmental Protection Agency
nm	nanometers
HPLC-UV	high performance liquid chromatography-ultraviolet
CO_2	carbon dioxide
NA	not applicable

* Phase I Study only

2.3.1 Volatile Organic Compounds

Whole air samples for volatile organic compounds (VOCs) were 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 were calibrated and conditioned by Columbia Analytical Services, Inc. on an individual basis. Flow controllers were calibrated for a two-hour sample duration. VOC samples were analyzed using gas chromatography/ mass spectrometry (GC/MS) according to the methodology outlined in the U.S. Environmental Protection Agency (EPA) Method TO-15 from EPA’s Second Edition *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air*.

2.3.2 Hydrogen Sulfide and Formaldehyde

H_2S and formaldehyde samples were collected using the validated Radiello Diffusive Sampling Systems (Sigma-Aldrich 2006). Specific system components include the diffusive body, supporting plate, and chemiadsorbing cartridge. H_2S was collected using the Radiello 170 sampling system and formaldehyde by the Radiello 165 sampling system. Sampling devices were deployed for 13 to 15 days in each of the test homes. Analysis of the diffusive sampling media was conducted by Air Toxics Ltd. (Folsom, California).

2.3.3 Corrosion Classification Coupons

Corrosion classification coupons (Purafil, Inc., Doraville, Georgia) were placed at multiple indoor locations and at one outdoor location for a nominal two-week sampling period (i.e., 13 to 15 days). At the end of the two-week sampling period, the coupons were collected, placed in sealed containers, and returned to Purafil for analysis of the corrosive film that developed. The laboratory analysis determined a corrosion reactivity rate by measuring the thickness of the copper and silver sulfide films present and normalized it to “angstroms per 30 days of exposure” for each of the coupon surfaces.

2.3.4 Temperature and Relative Humidity Monitors

Temperature and relative humidity were measured continuously using 5-minute average recordings at two indoor locations using U10-003 HOBO® Temperature Relative Humidity Data Loggers manufactured by Onset Computer Corporation (Bourne, Massachusetts).

2.3.5 Air Exchange Rate

Air exchange rate tests were conducted by introducing the carbon dioxide (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 were measured continuously at two locations inside the home using a Q-Trak Model 8551 Indoor Air Quality Monitor, manufactured by TSI, Inc. (St. Paul, Minnesota). Prior to each air exchange rate test, the sensors were calibrated at zero using hydrocarbon free air and spanned to approximately 1,000 parts per million of CO_2. Air exchange rates were calculated from the CO_2 decay results using the regression method.

2.3.6 Visual Corrosion Assessment

Detailed visual inspection was performed on the electrical grounding wires, air handling units, plumbing components, and appliances and other home contents that could show visible evidence of corrosion. Grounding wires were evaluated on a three-point scale as shown in the example provided in Figure 2.2. A score of one indicated no visible corrosion, two indicated moderate visible corrosion, and three indicated significant visible corrosion.

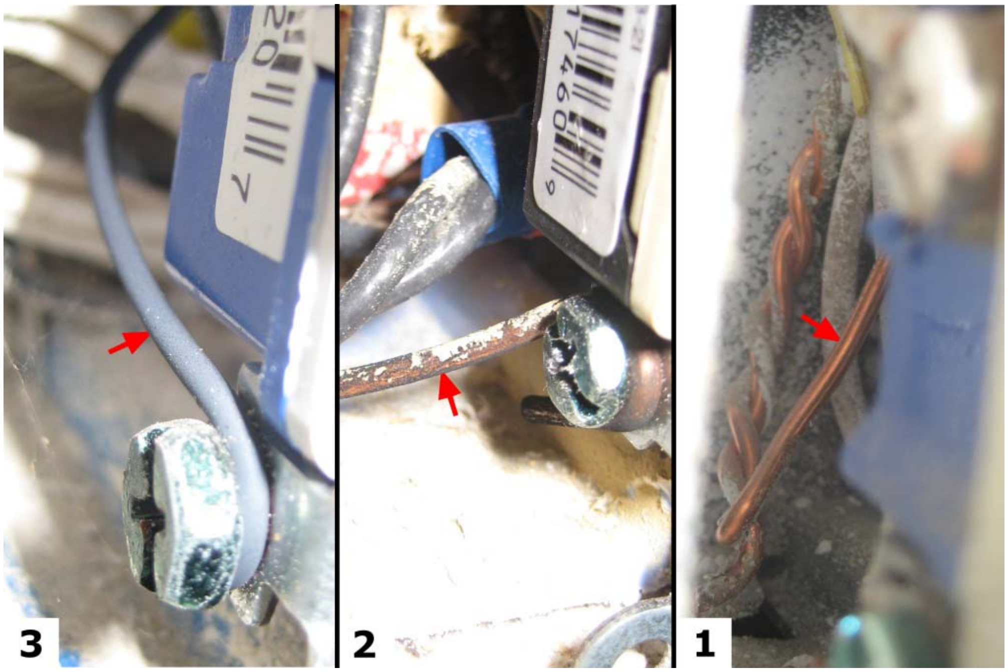

Figure 2.2 Examples of Visual Corrosion Ratings, Electrical Ground Wire
(3—Significant Visible Corrosion, 2—Moderate Visible Corrosion, 1—No Visible Corrosion)

2.4 QUALITY ASSURANCE/QUALITY CONTROL

The overall project quality assurance/quality control (QA/QC) measures used to design, implement, and report the results of the study and analysis described in this report are presented in Appendix B. Every effort was made in each phase of the project to ensure completeness and accuracy of data collection, application of analytical methods, data entry, calculation procedures, and reporting of results.

All sampling and analytical procedures for the project utilized appropriate and valid monitoring methods approved and recommended in relevant published sources, from regulatory agencies such as the EPA and the U.S. Occupational Safety and Health Administration (OSHA); other cognizant governmental organizations such as the National Institute for Occupational Safety and Health (NIOSH); consensus standard organizations such as the American Society for Testing and Materials (ASTM International); or the peer-reviewed scientific literature.

3.0 RESULTS AND DISCUSSION

3.1 SOURCE MARKERS

Elemental sulfur (S_8) and strontium concentrations in drywall were previously found to be highly correlated with each other and useful markers for the identification of problem drywall (EH&E 2010a; EH&E 2010b). Strontium was found to continue to be a useful marker of problem drywall in the present study. For the four homes identified with problem drywall, strontium concentrations were elevated in May 2010, consistent with the testing performed during the 51-Home Study in August 2009 (Figure 3.1). For the one home with problem drywall in the 51-Home Study that was subsequently remediated, the testing conducted in May 2010 did not identify elevated concentrations of strontium after remedial activities were completed. For the control home, elevated strontium concentrations remained not detected.

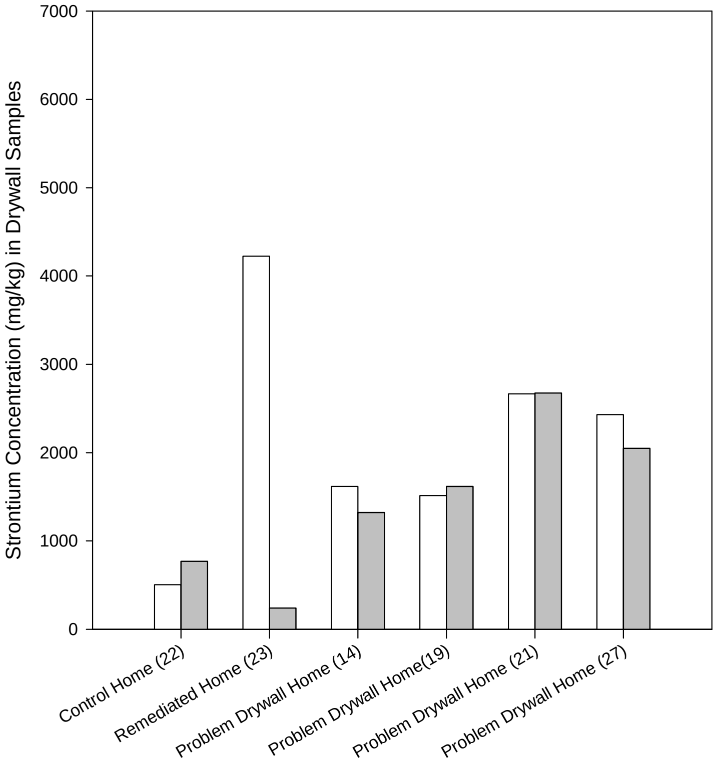

Figure 3.1 Mean Strontium Concentrations (mg/kg) in Drywall Samples from Study Homes. Results from the summer 2009 study are designated in the white bar chart; the data collected during the subsequent 2010 sampling period are designated as the gray bars.

Similarly, S_8 was confirmed as a useful marker of problem drywall. S_8 was previously detected in drywall from all of the five homes that had problem drywall at the time of the 51-Home Study (mean = 184 milligrams per kilogram [mg/kg]). (S_8 concentrations in drywall greater than 10 mg/kg have been previously found to be a marker of problem drywall [EH&E 2010b; CPSC 2011].) Following remediation, S_8 was not detected in drywall samples in the remediated home. S_8 remained not detected in drywall samples from the control home.

3.2 AIR EXCHANGE RATES

Short-term air exchange rates ranged from 0.13 to 0.49 air changes per hour (ACH) (median: 0.21 ACH). Air exchange rate results were similar between the two sampling periods, August 2009 and May 2010, and were not associated with the presence or absence of problem drywall (Figure 3.2). For reference, 0.2 ACH is the seasonal average air exchange rate for tightly constructed homes, and a range of 0.4 to 0.5 ACH is a reasonable estimate of average seasonal air exchange rates for U.S. residences (ASHRAE 2005; Ek et al. 1990; Grimsrud et al. 1982; Palmiter and Brown 1989; Parker et al. 1990).

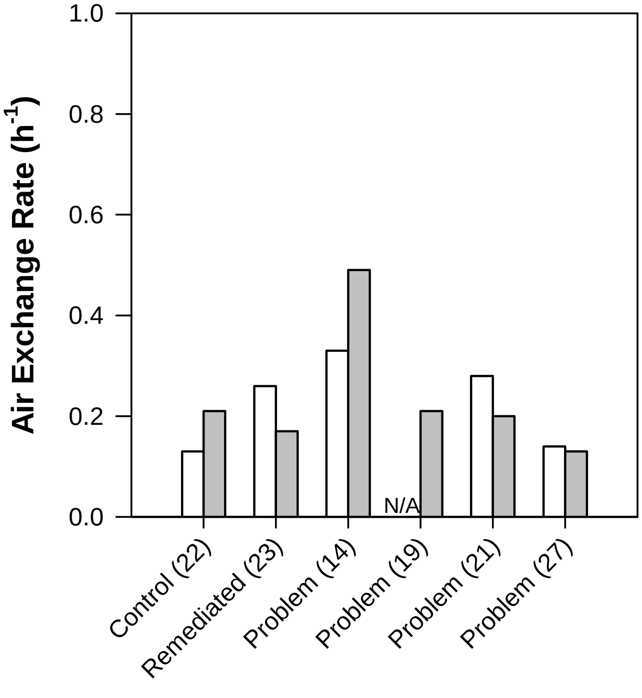

Figure 3.2 Short-term Air Exchange Rates Measured at Each Study Home in August 2009 (white bar) and May 2010 (grey bar)

3.3 VOLATILE ORGANIC COMPOUNDS

VOC concentrations for each home and each location (living room, master bedroom and outdoors) are reported in Appendix A (Tables A.1 – A.6). Only three of the six homes in this study were part of the original subset of homes in the 51-Home Study that were tested for VOCs (Homes 14, 21 and 27). Results for these three homes indicate that the types of VOCs detected and the concentrations at which they were measured were similar across the two study periods. VOCs were not associated with the presence or absence of problem drywall. All of the VOC concentrations were within the range of values from the 51-Home Study, indicating they are typical for newly constructed homes.

3.4 FORMALDEHYDE

The mean indoor formaldehyde concentration for all homes and sampling periods was 32 micrograms per cubic meter ($\mu g/m^3$) (standard deviation: 13 $\mu g/m^3$) and ranged from 10 to 75 $\mu g/m^3$ (Table 3.1). Consistent with the 51-Home Study, formaldehyde concentrations were not associated with the presence or absence of problem drywall. The highest concentrations were observed during the sampling period (August 2009) with the highest temperatures. These formaldehyde concentrations are similar to formaldehyde concentrations measured in newly manufactured houses in 2000, where the median concentration was 47 $\mu g/m^3$ (Hodgson et al. 2000).

Table 3.1 Indoor and Outdoor Formaldehyde Concentrations (μg/m^3) Measured at Each Home During Each Sampling Period

House ID	Status	Location	Aug 2009	May 6 – May 19, 2010	May 20 – June 4, 2010	Jun 4 – Jun 17, 2010	Oct 4 – Oct 19, 2010	Oct 19 – Nov 1, 2010	Nov 1 – Nov 15, 2010	Nov 15 – Nov 30, 2010	Nov 30 – Dec 13, 2010
Concentrations (μg/m^3)											
14	Problem	Living	34	28	26	23	22	24	24	29	19
		Master	35	30	27	23	24	27	24	30	23
		Outdoor	1.7	1.6	1.4	1.8	2.0	1.1	1.4	0.91	1.5
19	Problem	Living	57	29	26	25	42	38	35	48	34
		Master	52	28	11	24	43	28	36	50	36
		Outdoor	1.9	1.4	1.5	1.8	1.6	1.1	1.3	0.90	1.4
21	Problem	Living	48	24	26	27	30	29	33	33	37
		Master	47	23	–	21	27	23	38	34	27
		Outdoor	2.3	1.6	1.9	1.8	1.0	1.0	1.0	1.0	1.7
27	Problem	Living	54	37	22	22	47	36	37	34	27
		Master	60	43	22	21	49	27	32	36	30
		Outdoor	1.9	1.3	1.4	1.6	1.8	1.3	1.6	0.80	1.7
22	Control	Living	65	58	29	24	–	–	36	73	45
		Master	70	42	27	33	–	–	40	75	46
		Outdoor	2.1	1.6	1.6	1.8	–	–	0.58	0.90	1.7
23	Remediated	Living	22	10	13	14	24	21	32	40	29
		Master	23	11	15	13	23	23	27	37	24
		Outdoor	2.1	1.4	1.6	1.7	1.6	1.2	1.3	1.3	2.0

μg/m^3 micrograms per cubic meter

3.5 HYDROGEN SULFIDE

House average hydrogen sulfide concentrations were higher in the homes with problematic drywall compared to the control and remediated homes (average: 0.98 $\mu g/m^3$ v. <0.60 $\mu g/m^3$). This is consistent with the observation from the 51-Home Study that homes with problem drywall had elevated levels of hydrogen sulfide compared to control homes on average (EH&E 2010a). In that study, H_2S was also detected in air in a greater number of complaint homes compared to non-complaint homes (percent detect = 69% v. 35%). Similar results were observed in this study. H_2S was regularly detected in homes with problem drywall but not detected in the remediated or control home. Of note, H_2S was detected in only two of the five homes with problem drywall at the time of the 51-Home Study, a finding that highlights the need to assess homes using results from multiple test parameters (e.g., source markers, gases, and corrosion). Despite this variability observed in August 2009, for all four homes with problem drywall, H_2S was regularly detected in follow-up sampling. Importantly, H_2S was never detected in homes without problem drywall (i.e., not detected in the control home at any time period and not detected in the remediated home post-remediation).

Table 3.2 Summary of H_2S Measurements in Air (Detected or Not Detected) in Each Study Home for Each Sampling Period

House ID	House Type	Aug 2009	Oct 4, 2010	Oct 19, 2010	Nov 1, 2010	Nov 15, 2010	Nov 30, 2010
House 14	Problem	–	+	+	+	+	–
House 19	Problem	–	+	+	+	+	–
House 21	Problem	+	+	+	–	+	+
House 27	Problem	+	+	+	+	+	–
House 23	Remediated	–	–	–	–	–	–
House 22	Control	–	NA	–	–	–	–

H_2S	hydrogen sulfide
–	H_2S not detected above method reporting limit
+	H_2S detected above method reporting limit
NA	not available; testing not performed in this time period

The last sampling period, conducted at the coolest ambient temperature in this study, had the least number of homes with H_2S detected. The conclusions that can be drawn are limited by the small sample size but indicate that the generation of H_2S may be limited in months with cooler temperatures. The relationship between H_2S and temperature was also observed in the 51-Home Study, with higher temperatures associated with increased concentrations of H_2S (EH&E 2010a). The 51-Home Study was designed with sufficient sample size and power to observe associations between variables. Although the present study had a small sample size and was not designed to identify predictors of observed corrosion, we evaluated the relationship between temperature and corrosion to determine if the results were consistent with the 51-Home Study. Results in this study suggest the same positive association for homes with problem drywall (Figure 3.3).

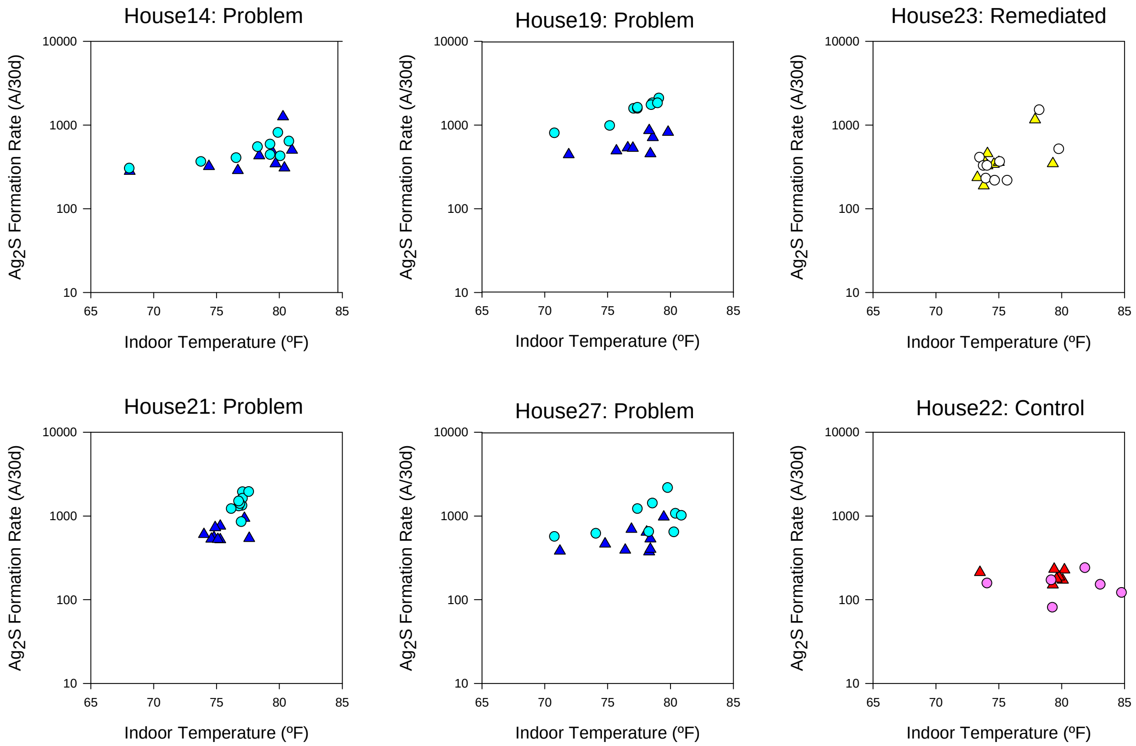

Figure 3.3 Relationship Between Indoor Temperature and Silver Sulfide Formation Rate in Each of the Study Homes (all sampling periods). Circles represent results from the master bedroom and triangles represent results from the main living area.

3.6 CORROSION

3.6.1 Ground Wire Corrosion

Corrosion on ground wires in each home was evaluated during the 51-Home Study and again during the first sampling period in this study (May 2010). Ground wire ratings conducted during the two sampling periods showed strong and consistent agreement

(Figure 3.4). Homes that had problem drywall at any time, including the remediated home, had house average ratings generally between 2.5 and 3, while the control home had ratings closer to 1 (“no visible corrosion”). The high rating for the remediated home, even after remediation was completed, was expected because the remediation did not include replacement of ground wires.

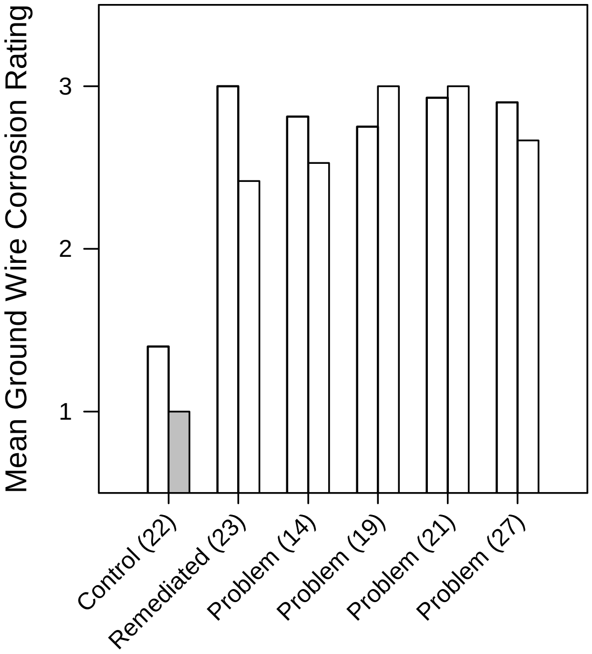

Figure 3.4 Mean Ground Wire Corrosion Rating at Each Study Home in August 2009 (white bar) and May 2010 (grey bar)

3.6.2 Corrosion Classification Coupons

Silver and copper sulfide formation rates for each home, location (living room, master bedroom, air handling unit supply, and outdoors), and sampling period are presented in Appendix A (Tables A.7 and A.8). In general, corrosion rates were highest in the summer sampling period (August 2009) compared to the other seasons, with the lowest average concentration observed in the last, and coldest, sampling period (December 2010). To explore this further, corrosion rates in the four homes with problem drywall were averaged for each home by season and plotted (Figure 3.5). As depicted in the figure, the summer sampling period had the highest corrosion rates with the greatest difference existing between the summer and winter sampling periods, on average. Corrosion rates between the spring and fall sampling periods were consistent. A broader inference is limited by the small sample size.

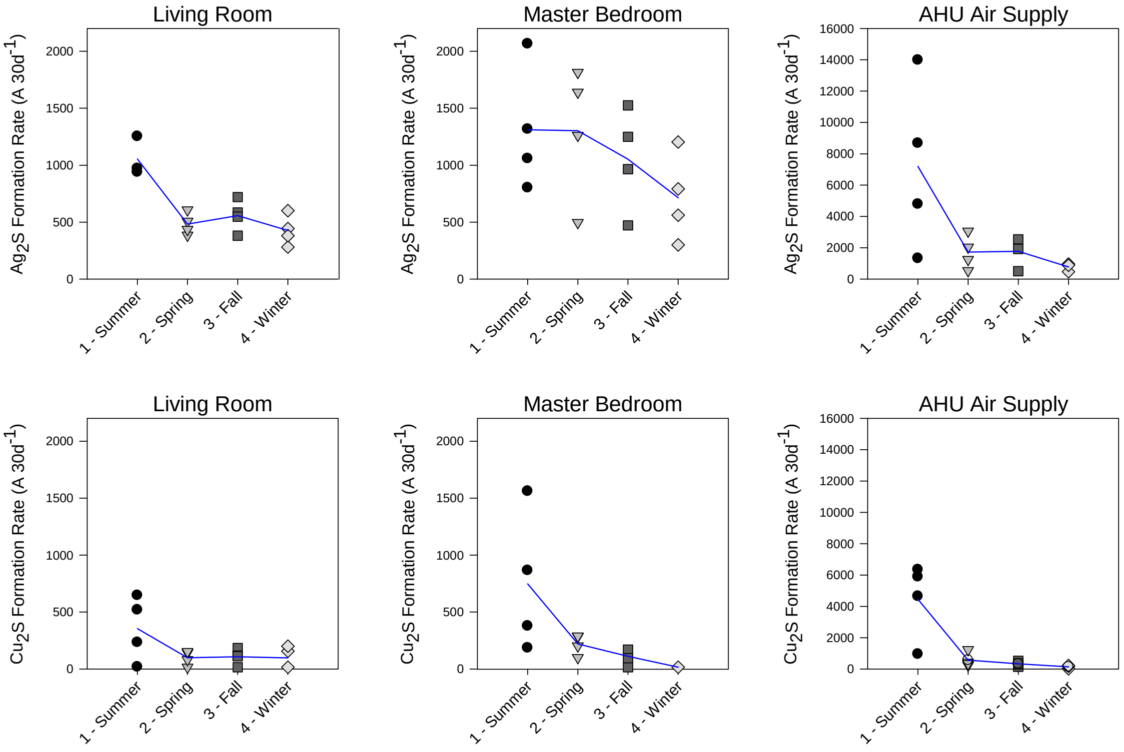

Figure 3.5 Seasonal Average Corrosion Rates for the Four Nonremediated Homes with Problem Drywall

3.7 IMPACT OF REMEDIATION

One home in this study had problem drywall removed from the home in the timeframe between the sampling conducted in August 2009, as part of the 51-Home Study, and the testing performed in this study, conducted between May and December of 2010. This allowed for an initial evaluation of the potential benefit of removing problem drywall. Importantly, the testing performed under both conditions (pre- and post-remediation) was conducted with identical measurement protocols.

The results for the remediated home were compared both pre- and post-remediation, and also against the distribution of values from homes known to be impacted by problem drywall and control homes from the 51-Home Study. Results for this remediated home are presented in Figure 3.6 as red stars, with distributions presented for homes from the 51-Home Study.

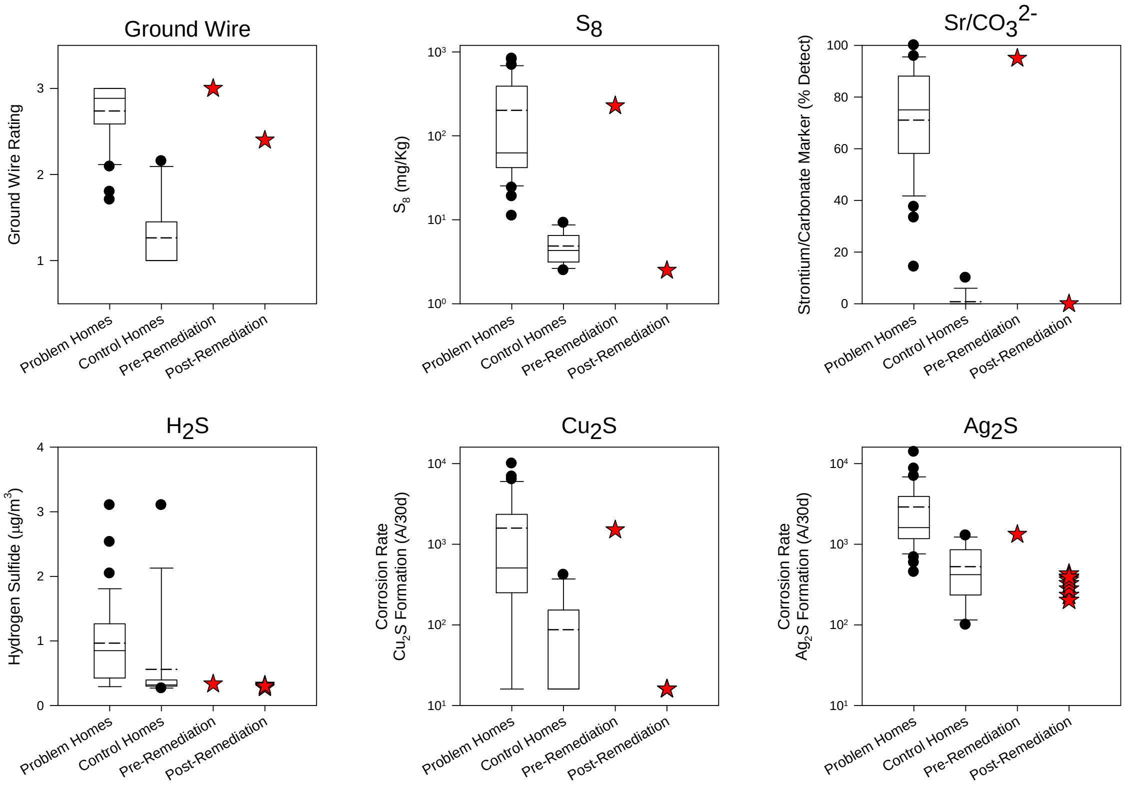

Figure 3.6 Comparison of Results from Remediated Home (Pre- and Post-Remediation) to Distribution of Values for Homes Known To Be Impacted by Problem Drywall ("Problem Homes") and Control Homes from 51-Home Study

The ground wire rating was high in the remediated home both pre- and post-remediation. As previously noted, this was an expected finding because the ground wires were not replaced as part of the remediation and therefore represent historic corrosive conditions in the home. The two markers of problem drywall used in this study, S_8 and strontium/carbonate, were detected prior to remediation but were not found in the home after removal of the problem drywall. Hydrogen sulfide was not detected in the home at any time. Copper sulfide and silver sulfide formation rates, which represent current corrosive conditions in the home, were elevated, while the home had problem drywall but returned to background rates after remediation.

4.0 CONCLUSIONS

This study was undertaken with two primary objectives: 1) to assess potential differences in parameters previously found to be associated with problem drywall (e.g., presence of H_2S, corrosion of metal coupons) as a function of season, and 2) to assess if remediation has the potential to impact indoor parameters associated with problem drywall. Seasonal variability in corrosion rates was observed; indoor environmental conditions associated with the higher temperatures and dew points of summer related to higher rates of corrosion compared to the other seasons, on average. The greatest difference existed between the hottest and coldest sampling periods; corrosion rates in the spring and fall were similar to each other and lower than the rates in the summer sampling period. With regard to remediation, the markers of problem drywall, S_8 and strontium/carbonate, were found in the home prior to remediation but not after replacement of the problem drywall. The remediation that was undertaken was effective at mitigating corrosion; post-remediation corrosion rates were lower than pre-remediation. Lastly, the results in this study were consistent with results from the 51-Home Study and Source Characterization Study: 1) elevated rates of corrosion and hydrogen sulfide were found in homes with problem drywall compared to homes without problem drywall; 2) S_8 and strontium/carbonate are useful markers of corrosive drywall; and 3) there was evidence that elevated rates of corrosion were associated with indoor temperature.

Despite the limited sample size, these results have important implications for future studies exploring the mechanism of H_2S generation, health effects research, material degradation research, interpretation of cross-sectional data, and evaluation of remediation protocols.

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APPENDIX A

SUMMARY DATA TABLES

DATA TABLES

Table A.1 House 14 Volatile Organic Compound Data ($\mu g/m^3$)

Compound Name	August 2009			May 2010		
	Living	Master	Outdoor	Living	Master	Outdoor
1,1,1-Trichloroethane	–	–	–	<0.16	<0.16	<0.16
1,1,2,2-Tetrachloroethane	–	–	–	<0.16	<0.16	<0.16
1,1,2-Trichloroethane	–	–	–	<0.16	<0.16	<0.16
1,1,2-Trichlorotrifluoroethane	–	–	–	0.51	0.51	0.50
1,1-Dichloroethane	–	–	–	<0.16	<0.16	<0.16
1,1-Dichloroethene	–	–	–	<0.16	<0.16	<0.16
1,2,4-Trichlorobenzene	–	–	–	<0.82	<0.81	<0.82
1,2,4-Trimethylbenzene	–	–	–	18	17	<0.82
1,2-Dibromo-3-chloropropane	–	–	–	<0.82	<0.81	<0.82
1,2-Dibromoethane	–	–	–	<0.16	<0.16	<0.16
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	–	–	–	<0.82	<0.81	<0.82
1,2-Dichlorobenzene	–	–	–	<0.16	<0.16	<0.16
1,2-Dichloroethane	–	–	–	<0.16	<0.16	<0.16
1,2-Dichloropropane	–	–	–	<0.16	<0.16	<0.16
1,3,5-Trimethylbenzene	–	–	–	5.4	5.2	<0.82
1,3-Butadiene	–	–	–	<0.33	<0.32	<0.33
1,3-Dichlorobenzene	–	–	–	<0.16	<0.16	<0.16
1,4-Dichlorobenzene	–	–	–	0.51	0.56	<0.16
1,4-Dioxane	–	–	–	<0.82	<0.81	<0.82
2-Butanone (MEK)	–	–	–	<8.2	<8.1	<8.2
2-Hexanone	–	–	–	<0.82	<0.81	<0.82
2-Propanol (isopropyl alcohol)	–	–	–	13	13	<1.6
3-Chloro-1-propene (allyl chloride)	–	–	–	<0.16	<0.16	<0.16
4-Ethyltoluene	–	–	–	5.1	5.0	<0.82
4-Methyl-2-pentanone	–	–	–	2.0	1.9	<0.82
Acetone	–	–	–	63	58	25
Acetonitrile	–	–	–	<0.82	<0.81	<0.82
Acrolein	–	–	–	5.2	4.3	<3.3
Acrylonitrile	–	–	–	<0.82	<0.81	<0.82
Benzene	–	–	–	8.9	8.7	0.16
Benzyl chloride	–	–	–	<0.82	<0.81	<0.82
Bromodichloromethane	–	–	–	3.8	3.7	<0.16
Bromoform	–	–	–	<0.82	<0.81	<0.82
Bromomethane	–	–	–	<0.16	<0.16	<0.16
Carbon disulfide	–	–	–	<8.2	<8.1	<8.2
Carbon tetrachloride	–	–	–	0.64	0.58	0.39
Chlorobenzene	–	–	–	<0.16	<0.16	<0.16
Chloroethane	–	–	–	<0.16	<0.16	<0.16
Chloroform	–	–	–	13	13	0.81
Chloromethane	–	–	–	0.58	0.58	0.39
Cumene	–	–	–	<0.82	0.81	<0.82
Cyclohexane	–	–	–	4.2	4.1	<0.82
Dibromochloromethane	–	–	–	1.4	1.4	<0.16
Dichlorodifluoromethane (CFC 12)	–	–	–	2.2	2.2	2.2
Ethanol	–	–	–	860	850	14
Ethyl acetate	–	–	–	66	65	<0.82

Table A.1 Continued

Compound Name	August 2009			May 2010		
	Living	Master	Outdoor	Living	Master	Outdoor
Ethylbenzene	–	–	–	8.8	8.6	<0.82
Hexachlorobutadiene	–	–	–	<0.82	<0.81	<0.82
Methyl methacrylate	–	–	–	<0.82	<0.81	<0.82
Methyl tert-butyl ether	–	–	–	1.3	1.3	<0.16
Methylene chloride	–	–	–	<0.82	<0.81	<0.82
Naphthalene	–	–	–	3.4	2.8	<0.82
Propene	–	–	–	5.0	5.2	<0.82
Styrene	–	–	–	1.3	1.3	<0.82
Tetrachloroethene	–	–	–	1.4	1.3	<0.16
Tetrahydrofuran (THF)	–	–	–	1.7	0.82	<0.82
Toluene	–	–	–	40	39	<0.82
Trichloroethene	–	–	–	<0.16	<0.16	<0.16
Trichlorofluoromethane	–	–	–	1.2	1.2	1.1
Vinyl acetate	–	–	–	<8.2	<8.1	<8.2
Vinyl chloride	–	–	–	<0.16	<0.16	<0.16
alpha-Pinene	–	–	–	8.8	8.2	<0.82
cis-1,2-Dichloroethene	–	–	–	<0.16	<0.16	<0.16
cis-1,3-Dichloropropene	–	–	–	<0.82	<0.81	<0.82
d-Limonene	–	–	–	15	14	<0.82
m,p-Xylenes	–	–	–	26	26	<0.82
n-Butyl acetate	–	–	–	9.6	9.0	<0.82
n-Heptane	–	–	–	9.8	9.6	<0.82
n-Hexane	–	–	–	15	15	<0.82
n-Nonane	–	–	–	2.4	2.3	<0.82
n-Octane	–	–	–	4.3	4.3	<0.82
n-Propylbenzene	–	–	–	3.3	3.2	<0.82
o-Xylene	–	–	–	11	11	<0.82
trans-1,2-Dichloroethene	–	–	–	<0.16	<0.16	<0.16
trans-1,3-Dichloropropene	–	–	–	<0.82	<0.81	<0.82

$\mu g/m^3$	micrograms per cubic meter
<	less than

Table A.2 House 19 Volatile Organic Compound Data (μg/m^3)

Compound Name	August 2009			May 2010		
	Living	Master	Outdoor	Living	Master	Outdoor
1,1,1-Trichloroethane	<0.13	–	<0.13	<0.16	<0.16	<0.17
1,1,2,2-Tetrachloroethane	<0.13	–	<0.13	<0.16	<0.16	<0.17
1,1,2-Trichloroethane	<0.13	–	<0.13	<0.16	<0.16	<0.17
1,1,2-Trichlorotrifluoroethane	0.74	–	0.66	0.45	0.51	0.48
1,1-Dichloroethane	<0.13	–	<0.13	<0.16	<0.16	<0.17
1,1-Dichloroethene	<0.13	–	<0.13	<0.16	<0.16	<0.17
1,2,4-Trichlorobenzene	<0.65	–	<0.66	<0.79	<0.79	<0.83
1,2,4-Trimethylbenzene	16	–	1.3	11	15	<0.83
1,2-Dibromo-3-chloropropane	<0.65	–	<0.66	<0.79	<0.79	<0.83
1,2-Dibromoethane	<0.13	–	<0.13	<0.16	<0.16	<0.17
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	<0.65	–	<0.66	<0.79	<0.79	<0.83
1,2-Dichlorobenzene	<0.13	–	<0.13	<0.16	<0.16	<0.17
1,2-Dichloroethane	2.7	–	<0.13	1.2	1.5	<0.17
1,2-Dichloropropane	<0.13	–	<0.13	<0.16	0.21	<0.17
1,3,5-Trimethylbenzene	4.7	–	<0.66	3.0	4.2	<0.83
1,3-Butadiene	0.16	–	<0.13	<0.31	<0.31	<0.33
1,3-Dichlorobenzene	<0.13	–	<0.13	<0.16	<0.16	<0.17
1,4-Dichlorobenzene	0.16	–	<0.13	<0.16	<0.16	<0.17
1,4-Dioxane	<0.65	–	<0.66	<0.79	<0.79	<0.83
2-Butanone (MEK)	5.1	–	1.4	<7.9	<7.9	<8.3
2-Hexanone	<0.65	–	<0.66	<0.79	<0.79	<0.83
2-Propanol (isopropyl alcohol)	310	–	1.7	400	510	<1.7
3-Chloro-1-propene (allyl chloride)	<0.13	–	<0.13	<0.16	<0.16	<0.17
4-Ethyltoluene	5.1	–	<0.66	3.6	5.1	<0.83
4-Methyl-2-pentanone	3.1	–	0.89	1.1	1.5	<0.83
Acetone	130	–	13	79	94	9.7
Acetonitrile	–	–	–	<0.79	<0.79	<0.83
Acrolein	3.9	–	1.2	4.4	3.7	<3.3
Acrylonitrile	<0.65	–	<0.66	<0.79	<0.79	<0.83
Benzene	7.9	–	0.73	9.9	14	0.22
Benzyl chloride	<0.13	–	<0.13	<0.79	<0.79	<0.83
Bromodichloromethane	1.8	–	<0.13	1.6	2.7	<0.17
Bromoform	<0.65	–	<0.66	<0.79	<0.79	<0.83
Bromomethane	<0.13	–	<0.13	<0.16	<0.16	<0.17
Carbon disulfide	<0.65	–	<0.66	<7.9	<7.9	<8.3
Carbon tetrachloride	0.58	–	0.50	0.72	0.73	0.43
Chlorobenzene	<0.13	–	<0.13	<0.16	<0.16	<0.17
Chloroethane	<0.13	–	<0.13	<0.16	<0.16	<0.17
Chloroform	2.6	–	<0.13	3.1	5.3	<0.17
Chloromethane	1.5	–	0.53	0.94	1.0	0.38
Cumene	0.88	–	<0.66	<0.79	<0.79	<0.83
Cyclohexane	5.3	–	<0.66	3.2	4.2	<0.83
Dibromochloromethane	0.80	–	<0.13	0.58	1.0	<0.17
Dichlorodifluoromethane (CFC 12)	3.4	–	2.6	2.2	2.3	2.0
Ethanol	870	–	15	750	970	<8.3
Ethyl acetate	12	–	<0.66	13	11	<0.83
Ethylbenzene	17	–	3.3	9.3	13	<0.83
Hexachlorobutadiene	<0.65	–	<0.66	<0.79	<0.79	<0.83
Methyl methacrylate	<0.65	–	<0.66	<0.79	<0.79	<0.83
Methyl tert-butyl ether	<0.13	–	<0.13	<0.16	<0.16	<0.17

Table A.2 Continued

Compound Name	August 2009			May 2010		
	Living	Master	Outdoor	Living	Master	Outdoor
Methylene chloride	<0.65	–	<0.66	<0.79	<0.79	<0.83
Naphthalene	1.2	–	<0.66	0.86	1.2	<0.83
Propene	13	–	1.1	51	81	<0.83
Styrene	2.7	–	<0.66	1.8	1.8	<0.83
Tetrachloroethene	2.4	–	0.83	0.27	0.23	<0.17
Tetrahydrofuran (THF)	<0.65	–	<0.66	<0.79	<0.79	<0.83
Toluene	64	–	3.1	41	57	<0.83
Trichloroethene	<0.13	–	<0.13	<0.16	<0.16	<0.17
Trichlorofluoromethane	1.5	–	1.2	1.1	1.3	1.0
Vinyl acetate	<6.5	–	<6.6	<7.9	<7.9	<8.3
Vinyl chloride	<0.13	–	<0.13	<0.16	<0.16	<0.17
alpha-Pinene	30	–	<0.66	17	20	<0.83
cis-1,2-Dichloroethene	<0.13	–	<0.13	<0.16	<0.16	<0.17
cis-1,3-Dichloropropene	<0.65	–	<0.66	<0.79	<0.79	<0.83
d-Limonene	26	–	<0.66	40	81	<0.83
m,p-Xylenes	62	–	13	33	46	<0.83
n-Butyl acetate	3.8	–	1.0	2.5	4.0	<0.83
n-Heptane	11	–	<0.66	7.6	10	<0.83
n-Hexane	20	–	1.1	18	24	<0.83
n-Nonane	3.0	–	<0.66	3.0	4.0	<0.83
n-Octane	4.1	–	<0.66	3.1	3.9	<0.83
n-Propylbenzene	2.7	–	<0.66	2.0	2.8	<0.83
o-Xylene	23	–	4.8	11	16	<0.83
trans-1,2-Dichloroethene	<0.13	–	<0.13	<0.16	<0.16	<0.17
trans-1,3-Dichloropropene	<0.65	–	<0.66	<0.79	<0.79	<0.83

$\mu g/m^3$	micrograms per cubic meter
<	less than

Table A.3 House 21 Volatile Organic Compound Data ($\mu g/m^3$)

Compound Name	August 2009			May 2010		
	Living	Master	Outdoor	Living	Master	Outdoor
1,1,1-Trichloroethane	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
1,1,2,2-Tetrachloroethane	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
1,1,2-Trichloroethane	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
1,1,2-Trichlorotrifluoroethane	0.74	0.61	0.59	0.48	0.42	0.59
1,1-Dichloroethane	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
1,1-Dichloroethene	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
1,2,4-Trichlorobenzene	<1.3	<0.63	<1.2	<0.85	<0.75	<0.90
1,2,4-Trimethylbenzene	4.4	1.3	3.7	1.8	<0.75	2.2
1,2-Dibromo-3-chloropropane	<1.3	<0.63	<1.2	<0.85	<0.75	<0.90
1,2-Dibromoethane	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	<1.3	<0.63	<1.2	<0.85	<0.75	<0.90
1,2-Dichlorobenzene	<0.26	<0.13	<0.24	0.19	<0.15	0.31
1,2-Dichloroethane	2.7	<0.13	2.2	1.9	<0.15	2.3
1,2-Dichloropropane	<0.26	0.41	<0.24	<0.17	<0.15	<0.18
1,3,5-Trimethylbenzene	1.4	<0.63	<1.2	<0.85	<0.75	<0.90
1,3-Butadiene	0.36	<0.13	0.33	<0.34	<0.3	<0.36
1,3-Dichlorobenzene	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
1,4-Dichlorobenzene	0.89	0.15	0.80	41	0.39	56
1,4-Dioxane	<1.3	<0.63	<1.2	<0.85	<0.75	<0.90
2-Butanone (MEK)	7.9	4.8	8.6	<8.5	<7.5	<9.0
2-Hexanone	0.88	<0.63	<1.2	1.6	<0.75	1.7
2-Propanol (isopropyl alcohol)	30	3.9	27	65	<1.5	84
3-Chloro-1-propene (allyl chloride)	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
4-Ethyltoluene	1.5	<0.63	1.3	<0.85	<0.75	<0.90
4-Methyl-2-pentanone	2.2	7.2	3.0	1.0	<0.75	1.1
Acetone	160	50	150	150	10	180
Acetonitrile	–	–	–	0.87	<0.75	1.0
Acrolein	4.5	0.84	4.6	4.4	<3.0	4.5
Acrylonitrile	<1.3	<0.63	<1.2	<0.85	<0.75	<0.90
Benzene	4.0	0.83	3.3	0.85	0.17	1.0
Benzyl chloride	<0.26	<0.13	<0.24	<0.85	<0.75	<0.90
Bromodichloromethane	4.8	<0.13	4.7	4.6	<0.15	6.3
Bromoform	1.4	<0.63	1.3	<0.85	<0.75	<0.90
Bromomethane	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
Carbon disulfide	1.5	2.8	1.3	<8.5	<7.5	<9.0
Carbon tetrachloride	1.0	0.44	0.94	0.62	0.4	0.77
Chlorobenzene	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
Chloroethane	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
Chloroform	9.1	0.33	8.8	9.3	<0.15	13
Chloromethane	2.0	0.42	2.4	0.55	0.36	0.69
Cumene	<1.3	<0.63	<1.2	<0.85	<0.75	<0.90
Cyclohexane	2.9	<0.63	2.5	2.2	<0.75	2.8
Dibromochloromethane	3.3	<0.13	3.2	2.4	<0.15	3.2
Dichlorodifluoromethane (CFC 12)	2.9	2.6	2.4	2.0	1.8	2.4
Ethanol	2700	53	3400	2100	22	2900
Ethyl acetate	5.8	1.6	5.4	9.3	<0.75	12
Ethylbenzene	7.5	15	6.5	1.9	<0.75	2.3
Hexachlorobutadiene	<1.3	<0.63	<1.2	<0.85	<0.75	<0.90
Methyl methacrylate	<1.3	<0.63	<1.2	<0.85	<0.75	<0.90
Methyl tert-butyl ether	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18

Table A.3 Continued

Compound Name	August 2009			May 2010		
	Living	Master	Outdoor	Living	Master	Outdoor
Methylene chloride	0.69	0.73	<1.2	<0.85	<0.75	<0.90
Naphthalene	0.75	<0.63	<1.2	1.2	<0.75	1.3
Propene	6.0	1.0	5.4	14	<0.75	12
Styrene	3.2	<0.63	2.6	2.6	<0.75	3.2
Tetrachloroethene	1.6	0.42	1.4	0.45	<0.15	0.55
Tetrahydrofuran (THF)	1.6	<0.63	1.5	0.91	<0.75	1.2
Toluene	28	8.4	23	7.4	<0.75	9.3
Trichloroethene	<0.26	0.23	<0.24	<0.17	<0.15	<0.18
Trichlorofluoromethane	1.5	1.9	1.2	1.1	0.91	1.3
Vinyl acetate	<13	<6.3	<12	12	<7.5	<9.0
Vinyl chloride	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
alpha-Pinene	79	1.1	70	43	<0.75	57
cis-1,2-Dichloroethene	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
cis-1,3-Dichloropropene	<1.3	<0.63	<1.2	<0.85	<0.75	<0.90
d-Limonene	68	1.2	59	48	<0.75	74
m,p-Xylenes	26	56	22	5.0	<0.75	6.1
n-Butyl acetate	4.7	4.0	4.7	4.6	<0.75	5.5
n-Heptane	4.5	<0.63	4.0	1.3	<0.75	1.7
n-Hexane	6.3	1.5	5.3	1.6	<0.75	1.9
n-Nonane	2.8	1.9	2.0	2.7	<0.75	3.0
n-Octane	2.2	0.63	1.9	0.96	<0.75	1.1
n-Propylbenzene	0.75	<0.63	<1.2	<0.85	<0.75	<0.90
o-Xylene	9.2	18	8.2	1.9	<0.75	2.4
trans-1,2-Dichloroethene	<0.26	<0.13	<0.24	<0.17	<0.15	<0.18
trans-1,3-Dichloropropene	<1.3	<0.63	<1.2	<0.85	<0.75	<0.90

$\mu g/m^3$	micrograms per cubic meter
<	less than

Table A.4 House 22 Volatile Organic Compound Data (μg/m^3)

Compound Name	August 2009			May 2010		
	Living	Master	Outdoor	Living	Master	Outdoor
1,1,1-Trichloroethane	–	–	–	<0.18	<0.16	<0.16
1,1,2,2-Tetrachloroethane	–	–	–	<0.18	<0.16	<0.16
1,1,2-Trichloroethane	–	–	–	<0.18	<0.16	<0.16
1,1,2-Trichlorotrifluoroethane	–	–	–	0.52	0.51	0.51
1,1-Dichloroethane	–	–	–	<0.18	<0.16	<0.16
1,1-Dichloroethene	–	–	–	<0.18	<0.16	<0.16
1,2,4-Trichlorobenzene	–	–	–	<0.89	<0.82	<0.78
1,2,4-Trimethylbenzene	–	–	–	4.8	5.5	<0.78
1,2-Dibromo-3-chloropropane	–	–	–	<0.89	<0.82	<0.78
1,2-Dibromoethane	–	–	–	<0.18	<0.16	<0.16
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	–	–	–	<0.89	<0.82	<0.78
1,2-Dichlorobenzene	–	–	–	<0.18	<0.16	<0.16
1,2-Dichloroethane	–	–	–	92	100	<0.16
1,2-Dichloropropane	–	–	–	<0.18	<0.16	<0.16
1,3,5-Trimethylbenzene	–	–	–	1.4	1.6	<0.78
1,3-Butadiene	–	–	–	<0.36	<0.33	<0.31
1,3-Dichlorobenzene	–	–	–	<0.18	<0.16	<0.16
1,4-Dichlorobenzene	–	–	–	0.40	0.46	<0.16
1,4-Dioxane	–	–	–	<0.89	<0.82	<0.78
2-Butanone (MEK)	–	–	–	28	31	<7.8
2-Hexanone	–	–	–	1.6	1.6	<0.78
2-Propanol (isopropyl alcohol)	–	–	–	28	88	<1.6
3-Chloro-1-propene (allyl chloride)	–	–	–	<0.18	<0.16	<0.16
4-Ethyltoluene	–	–	–	1.8	2.0	<0.78
4-Methyl-2-pentanone	–	–	–	2.6	2.7	<0.78
Acetone	–	–	–	140	140	13
Acetonitrile	–	–	–	<0.89	<0.82	<0.78
Acrolein	–	–	–	9.1	9.1	<3.1
Acrylonitrile	–	–	–	<0.89	<0.82	<0.78
Benzene	–	–	–	5.6	6.3	0.17
Benzyl chloride	–	–	–	<0.89	<0.82	<0.78
Bromodichloromethane	–	–	–	<0.18	<0.16	<0.16
Bromoform	–	–	–	<0.89	<0.82	<0.78
Bromomethane	–	–	–	<0.18	<0.16	<0.16
Carbon disulfide	–	–	–	<8.9	<8.2	<7.8
Carbon tetrachloride	–	–	–	0.96	1.1	0.38
Chlorobenzene	–	–	–	<0.18	0.20	<0.16
Chloroethane	–	–	–	<0.18	<0.16	<0.16
Chloroform	–	–	–	2.1	1.6	<0.16
Chloromethane	–	–	–	0.68	0.78	0.41
Cumene	–	–	–	<0.89	<0.82	<0.78
Cyclohexane	–	–	–	1.6	1.7	<0.78
Dibromochloromethane	–	–	–	<0.18	<0.16	<0.16
Dichlorodifluoromethane (CFC 12)	–	–	–	2.1	2.2	2.1
Ethanol	–	–	–	1500	2500	16
Ethyl acetate	–	–	–	18	22	<0.78
Ethylbenzene	–	–	–	8.6	9.2	<0.78
Hexachlorobutadiene	–	–	–	<0.89	<0.82	<0.78
Methyl methacrylate	–	–	–	1.2	1.2	<0.78
Methyl tert-butyl ether	–	–	–	<0.18	<0.16	<0.16

Table A.4 Continued

Compound Name	August 2009			May 2010		
	Living	**Master**	**Outdoor**	**Living**	**Master**	**Outdoor**
Methylene chloride	–	–	–	2.3	2.4	<0.78
Naphthalene	–	–	–	1.7	1.6	<0.78
Propene	–	–	–	5.8	16	<0.78
Styrene	–	–	–	18	19	<0.78
Tetrachloroethene	–	–	–	1.6	1.9	<0.16
Tetrahydrofuran (THF)	–	–	–	2.0	2.1	<0.78
Toluene	–	–	–	39	43	<0.78
Trichloroethene	–	–	–	6.7	7.5	<0.16
Trichlorofluoromethane	–	–	–	1.1	1.1	1.1
Vinyl acetate	–	–	–	14	9.3	<7.8
Vinyl chloride	–	–	–	<0.18	<0.16	<0.16
alpha-Pinene	–	–	–	120	120	<0.78
cis-1,2-Dichloroethene	–	–	–	<0.18	<0.16	<0.16
cis-1,3-Dichloropropene	–	–	–	<0.89	<0.82	<0.78
d-Limonene	–	–	–	38	40	0.96
m,p-Xylenes	–	–	–	21	22	<0.78
n-Butyl acetate	–	–	–	14	13	<0.78
n-Heptane	–	–	–	4.5	4.9	<0.78
n-Hexane	–	–	–	5.0	5.4	<0.78
n-Nonane	–	–	–	0.99	1.1	<0.78
n-Octane	–	–	–	1.6	1.6	<0.78
n-Propylbenzene	–	–	–	1.2	1.4	<0.78
o-Xylene	–	–	–	7.5	8.0	<0.78
trans-1,2-Dichloroethene	–	–	–	<0.18	<0.16	<0.16
trans-1,3-Dichloropropene	–	–	–	<0.89	<0.82	<0.78

$\mu g/m^3$	micrograms per cubic meter
<	less than

Table A.5 House 23 Volatile Organic Compound Data (μg/m^3)

Compound Name	August 2009			May 2010		
	Living	Master	Outdoor	Living	Master	Outdoor
1,1,1-Trichloroethane	–	–	–	<0.16	<0.15	<0.17
1,1,2,2-Tetrachloroethane	–	–	–	<0.16	<0.15	<0.17
1,1,2-Trichloroethane	–	–	–	<0.16	<0.15	<0.17
1,1,2-Trichlorotrifluoroethane	–	–	–	0.49	0.51	0.49
1,1-Dichloroethane	–	–	–	<0.16	<0.15	<0.17
1,1-Dichloroethene	–	–	–	<0.16	<0.15	<0.17
1,2,4-Trichlorobenzene	–	–	–	<0.79	<0.76	<0.84
1,2,4-Trimethylbenzene	–	–	–	4.2	4.5	0.90
1,2-Dibromo-3-chloropropane	–	–	–	<0.79	<0.76	<0.84
1,2-Dibromoethane	–	–	–	<0.16	<0.15	<0.17
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	–	–	–	<0.79	<0.76	<0.84
1,2-Dichlorobenzene	–	–	–	0.53	<0.15	<0.17
1,2-Dichloroethane	–	–	–	12	13	<0.17
1,2-Dichloropropane	–	–	–	<0.16	<0.15	<0.17
1,3,5-Trimethylbenzene	–	–	–	1.3	1.4	<0.84
1,3-Butadiene	–	–	–	<0.32	<0.3	<0.33
1,3-Dichlorobenzene	–	–	–	<0.16	<0.15	<0.17
1,4-Dichlorobenzene	–	–	–	0.48	0.51	<0.17
1,4-Dioxane	–	–	–	<0.79	<0.76	<0.84
2-Butanone (MEK)	–	–	–	12	7.8	<8.4
2-Hexanone	–	–	–	<0.79	<0.76	<0.84
2-Propanol (isopropyl alcohol)	–	–	–	26	18	<1.7
3-Chloro-1-propene (allyl chloride)	–	–	–	<0.16	<0.15	<0.17
4-Ethyltoluene	–	–	–	1.1	1.1	<0.84
4-Methyl-2-pentanone	–	–	–	1.1	0.95	<0.84
Acetone	–	–	–	140	140	17
Acetonitrile	–	–	–	1.1	1.1	<0.84
Acrolein	–	–	–	4.5	4.1	<3.3
Acrylonitrile	–	–	–	<0.79	<0.76	<0.84
Benzene	–	–	–	1.7	1.7	1.1
Benzyl chloride	–	–	–	<0.79	<0.76	<0.84
Bromodichloromethane	–	–	–	0.62	0.72	<0.17
Bromoform	–	–	–	<0.79	<0.76	<0.84
Bromomethane	–	–	–	<0.16	<0.15	<0.17
Carbon disulfide	–	–	–	<7.9	<7.6	<8.4
Carbon tetrachloride	–	–	–	0.46	0.49	0.48
Chlorobenzene	–	–	–	<0.16	<0.15	<0.17
Chloroethane	–	–	–	0.25	<0.15	0.17
Chloroform	–	–	–	3.7	4.6	<0.17
Chloromethane	–	–	–	0.61	0.63	0.53
Cumene	–	–	–	<0.79	<0.76	<0.84
Cyclohexane	–	–	–	1.5	1.1	<0.84
Dibromochloromethane	–	–	–	<0.16	<0.15	<0.17
Dichlorodifluoromethane (CFC 12)	–	–	–	2.0	2.1	2.1
Ethanol	–	–	–	2,100	2,300	23
Ethyl acetate	–	–	–	13	5.1	<0.84
Ethylbenzene	–	–	–	4.4	2.1	<0.84
Hexachlorobutadiene	–	–	–	<0.79	<0.76	<0.84
Methyl Methacrylate	–	–	–	<0.79	<0.76	<0.84
Methyl tert-butyl ether	–	–	–	<0.16	<0.15	<0.17

Table A.5 Continued

Compound Name	August 2009			May 2010		
	Living	Master	Outdoor	Living	Master	Outdoor
Methylene chloride	–	–	–	<0.79	<0.76	<0.84
Naphthalene	–	–	–	<0.79	0.80	<0.84
Propene	–	–	–	7.6	5.4	1.3
Styrene	–	–	–	1.2	1.1	<0.84
Tetrachloroethene	–	–	–	6.1	6.3	5.3
Tetrahydrofuran (THF)	–	–	–	2.0	2.1	<0.84
Toluene	–	–	–	55	53	3.7
Trichloroethene	–	–	–	1.4	1.5	0.52
Trichlorofluoromethane	–	–	–	1.2	1.1	1.1
Vinyl acetate	–	–	–	<7.9	<7.6	<8.4
Vinyl chloride	–	–	–	<0.16	<0.15	<0.17
alpha-Pinene	–	–	–	55	60	<0.84
cis-1,2-Dichloroethene	–	–	–	<0.16	<0.15	<0.17
cis-1,3-Dichloropropene	–	–	–	<0.79	<0.76	<0.84
d-Limonene	–	–	–	120	120	0.86
m,p-Xylenes	–	–	–	7.5	6.2	2.3
n-Butyl acetate	–	–	–	3.5	3.2	<0.84
n-Heptane	–	–	–	29	23	<0.84
n-Hexane	–	–	–	4.3	2.8	1.7
n-Nonane	–	–	–	140	140	1.2
n-Octane	–	–	–	67	69	1.3
n-Propylbenzene	–	–	–	<0.79	<0.76	<0.84
o-Xylene	–	–	–	2.9	2.5	0.89
trans-1,2-Dichloroethene	–	–	–	<0.16	<0.15	<0.17
trans-1,3-Dichloropropene	–	–	–	<0.79	<0.76	<0.84

$\mu g/m^3$	micrograms per cubic meter
<	less than

Table A.6 House 27 Volatile Organic Compound Data (μg/m^3)

	August 2009			May 2010		
Compound Name	**Living**	**Master**	**Outdoor**	**Living**	**Master**	**Outdoor**
1,1,1-Trichloroethane	<0.22	<0.13	<0.16	0.25	0.22	<0.13
1,1,2,2-Tetrachloroethane	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
1,1,2-Trichloroethane	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
1,1,2-Trichlorotrifluoroethane	0.51	0.52	0.50	0.51	0.50	0.51
1,1-Dichloroethane	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
1,1-Dichloroethene	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
1,2,4-Trichlorobenzene	<1.1	<0.67	<0.81	<0.86	<0.74	<0.66
1,2,4-Trimethylbenzene	1.2	0.89	<0.81	1.3	1.5	<0.66
1,2-Dibromo-3-chloropropane	<1.1	<0.67	<0.81	<0.86	<0.74	<0.66
1,2-Dibromoethane	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	<1.1	<0.67	<0.81	<0.86	<0.74	<0.66
1,2-Dichlorobenzene	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
1,2-Dichloroethane	5.0	5.4	<0.16	3.4	4.0	<0.13
1,2-Dichloropropane	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
1,3,5-Trimethylbenzene	<1.1	<0.67	<0.81	<0.86	<0.74	<0.66
1,3-Butadiene	<0.22	<0.13	<0.16	<0.34	<0.3	<0.26
1,3-Dichlorobenzene	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
1,4-Dichlorobenzene	0.23	0.21	<0.16	0.29	0.22	<0.13
1,4-Dioxane	<1.1	<0.67	<0.81	<0.86	<0.74	<0.66
2-Butanone (MEK)	32	28	1.4	14	<7.4	<6.6
2-Hexanone	1.4	1.2	<0.81	2.2	1.0	<0.66
2-Propanol (isopropyl alcohol)	240	200	3.9	84	87	<1.3
3-Chloro-1-propene (allyl chloride)	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
4-Ethyltoluene	<1.1	<0.67	<0.81	<0.86	<0.74	<0.66
4-Methyl-2-pentanone	1.6	1.2	<0.81	2.4	1.7	<0.66
Acetone	160	130	8.4	150	120	24
Acetonitrile	–	–	–	<0.86	<0.74	<0.66
Acrolein	5.7	5.7	1.1	8.8	8.3	<2.6
Acrylonitrile	<1.1	<0.67	<0.81	<0.86	<0.74	<0.66
Benzene	1.7	1.6	<0.16	2.4	2.4	0.27
Benzyl chloride	<0.22	<0.13	<0.16	<0.86	<0.74	<0.66
Bromodichloromethane	<0.22	<0.13	<0.16	0.36	0.34	<0.13
Bromoform	<1.1	<0.67	<0.81	<0.86	<0.74	<0.66
Bromomethane	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
Carbon disulfide	5.7	4.9	<0.81	<8.6	<7.4	<6.6
Carbon tetrachloride	0.96	0.83	0.46	0.60	0.59	0.38
Chlorobenzene	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
Chloroethane	0.17	<0.13	<0.16	<0.17	<0.15	<0.13
Chloroform	1.7	1.5	<0.16	4.4	4.2	0.23
Chloromethane	1.0	0.90	0.40	0.82	0.82	0.46
Cumene	<1.1	<0.67	<0.81	<0.86	<0.74	<0.66
Cyclohexane	<1.1	<0.67	<0.81	1.5	1.5	<0.66
Dibromochloromethane	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
Dichlorodifluoromethane (CFC 12)	2.7	2.5	2.2	2.5	2.4	2.2
Ethanol	1600	1400	21	750	660	7.2
Ethyl acetate	63	56	<1.6	34	31	<0.66
Ethylbenzene	1.9	1.4	<0.81	1.6	1.4	<0.66
Hexachlorobutadiene	<1.1	<0.67	<0.81	<0.86	<0.74	<0.66
Methyl methacrylate	<2.2	<1.3	<1.6	<0.86	<0.74	<0.66
Methyl tert-butyl ether	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13

Table A.6 Continued

Compound Name	August 2009			May 2010		
	Living	**Master**	**Outdoor**	**Living**	**Master**	**Outdoor**
Methylene chloride	<1.1	0.69	<0.81	2.2	1.9	<0.66
Naphthalene	<1.1	0.89	<0.81	1.1	1.1	<0.66
Propene	65	38	2.0	21	20	<0.66
Styrene	2.9	2.5	2.1	2.2	2.0	<0.66
Tetrachloroethene	0.18	<0.13	<0.16	<0.17	<0.15	<0.13
Tetrahydrofuran (THF)	14	13	<0.81	1.6	1.4	0.68
Toluene	16	12	1.6	19	18	<0.66
Trichloroethene	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
Trichlorofluoromethane	2.5	2.0	1.1	2.5	2.3	1.1
Vinyl acetate	8.3	7.1	<8.1	19	9.6	<6.6
Vinyl chloride	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
alpha-Pinene	130	110	0.87	110	98	<0.66
cis-1,2-Dichloroethene	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
cis-1,3-Dichloropropene	3.7	4.3	<0.81	<0.86	<0.74	<0.66
d-Limonene	63	56	2.7	47	40	<0.66
m,p-Xylenes	3.0	2.1	<0.81	3.5	2.9	<0.66
n-Butyl acetate	7.5	6.6	1.1	5.6	4.9	<0.66
n-Heptane	1.8	1.4	<0.81	4.1	3.8	<0.66
n-Hexane	1.2	1.0	<0.81	1.8	1.6	<0.66
n-Nonane	1.5	0.87	<0.81	2.1	1.8	<0.66
n-Octane	1.7	1.1	<0.81	1.8	1.6	<0.66
n-Propylbenzene	<1.1	<0.67	<0.81	<0.86	<0.74	<0.66
o-Xylene	1.2	0.84	<0.81	1.3	1.2	<0.66
trans-1,2-Dichloroethene	<0.22	<0.13	<0.16	<0.17	<0.15	<0.13
trans-1,3-Dichloropropene	2.7	3.5	<0.81	<0.86	<0.74	<0.66

$\mu g/m^3$ micrograms per cubic meter
< less than

Table A.7 Indoor and Outdoor Silver Sulfide Formation Rates Measured in Each Home During Each Sampling Period

House ID	Status	Location	Aug 2009	May 6 – May 19, 2010	May 20 – Jun 4, 2010	Jun 4 – Jun 17, 2010	Oct 4 – Oct 19, 2010	Oct 19 – Nov 1, 2010	Nov 1 – Nov 15, 2010	Nov 15 – Nov 30, 2010	Nov 30 – Dec 13, 2010
			Ag_2S (A/30d)								
14	Problem	Living	1,300	350	310	500	430	490	320	290	280
		Master	800	440	420	630	540	580	360	400	300
		Supply	1,300	520	520	580	370	730	460	470	470
		Outdoor	370	140	160	350	280	290	400	230	200
19	Problem	Living	–	540	530	460	710	820	490	860	440
		Master	2,100	1,600	1,600	1,800	1,700	1,800	970	1,600	790
		Supply	4,800	4,300	2,500	2,400	2,300	3,800	710	1,600	960
		Outdoor	280	280	120	140	270	210	190	230	240
21	Problem	Living	940	760	520	540	730	550	530	530	600
		Master	1,300	1,900	1,600	1,900	1,300	1,400	840	1,500	1,200
		Supply	8,700	3,100	1,400	1,600	3,400	2,400	2,200	2,200	–
		Outdoor	350	120	120	200	360	240	160	140	220
27	Problem	Living	970	530	370	400	640	700	460	390	380
		Master	1,100	2,100	640	1,000	640	1,400	610	1,200	560
		Supply	14,000	1,200	900	1,600	1,400	3,400	840	2,100	880
		Outdoor	630	580	410	880	100	240	290	260	240
22	Control	Living	230	170	190	150	–	–	230	180	210
		Master	240	150	75	120	–	–	80	170	160
		Supply	970	220	140	160	–	–	150	220	300
		Outdoor	520	210	200	340	–	–	330	280	280
23	Remediated	Living	1,200	240	190	340	360	330	360	350	460
		Master	1,500	230	220	220	410	320	360	510	330
		Supply	6,800	750	600	1,200	550	2,400	1,700	4,200	2,200
		Outdoor	640	120	110	570	260	300	280	160	180

Ag_2S	silver sulfide
A/30d	angstroms per 30 days

Limit of detection = 32 A/30d

Table A.8 Indoor and Outdoor Copper Sulfide Formation Rates Measured in Each Home During Each Sampling Period

House ID	Status	Location	Aug 2009	May 6 – May 19, 2010	May 20 – Jun 4, 2010	Jun 4 – Jun 17, 2010	Oct 4 – Oct 19, 2010	Oct 19 – Nov 1, 2010	Nov 1 – Nov 15, 2010	Nov 15 – Nov 30, 2010	Nov 30 – Dec 13, 2010
			Cu_2S (A/30d)								
14	Problem	Living	230	<32	<32	<32	<32	<32	<32	<32	160
		Master	380	270	<32	<32	<32	<32	<32	<32	<32
		Supply	960	200	<32	530	220	<32	190	150	<32
		Outdoor	2,700	<32	<32	220	<32	<32	<32	<32	<32
19	Problem	Living	520	200	<32	220	300	290	<32	140	<32
		Master	870	<32	<32	580	310	320	<32	<32	<32
		Supply	4,600	430	420	460	440	970	250	470	180
		Outdoor	460	<32	<32	<32	<32	<32	<32	<32	210
21	Problem	Living	650	430	<32	<32	200	<32	240	<32	200
		Master	1,600	<32	500	350	<32	<32	430	220	<32
		Supply	5,900	2,800	490	450	380	360	<32	410	–
		Outdoor	750	<32	<32	<32	<32	280	<32	<32	<32
27	Problem	Living	<32	210	<32	<32	230	<32	<32	200	<32
		Master	190	490	190	190	<32	<32	<32	330	<32
		Supply	6,300	350	210	460	210	470	380	400	220
		Outdoor	<32	<32	<32	780	200	<32	<32	<32	<32
22	Control	Living	<32	<32	<32	<32	–	–	<32	<32	<32
		Master	<32	<32	<32	<32	–	–	<32	<32	<32
		Supply	260	<32	<32	<32	–	–	<32	<32	<32
		Outdoor	2,500	<32	<32	380	–	–	<32	<32	<32
23	Remediated	Living	810	<32	<32	<32	<32	<32	<32	<32	<32
		Master	2,200	<32	<32	<32	<32	<32	<32	<32	<32
		Supply	6,900	240	<32	690	<32	380	330	<32	200
		Outdoor	4,800	<32	420	760	<32	<32	<32	<32	<32

Cu_2S	copper sulfide
A/30d	angstroms per 30 days
<	less than

Limit of detection = 32 A/30d

APPENDIX B

METHODS

METHODS

B.1 OVERVIEW

Methods developed in earlier CPSC studies for characterizing the composition of drywall, constituents of indoor air, and rates of corrosion were used to address the objectives of this project. To ensure that results from this investigation were directly comparable to previous indoor environment characterizations conducted by the CPSC and EH&E, all sample collection and analytic methods were kept consistent with those used in the "51-Home Study" and the "Source Characterization Study."[1,2]

The "Six-Home Study" included field inspections and measurements in each home between May and December 2010. All six homes were initially visited in May 2010 over a one-week period. The study also involved a longer term assessment of specific environmental parameters. All six homes underwent ongoing monitoring (approximately every two weeks) to collect and redeploy specific passive sampling equipment for measuring hydrogen sulfide (H_2S) and formaldehyde levels, as well as silver and copper (corrosion classification coupons). Temperature and relative humidity monitors remained in the homes throughout the study to collect data on interior conditions. Table B.1 outlines the parameters included in the study and the frequency and duration of each.

Table B.1 Overview of Assessment Parameters Associated with the Six-Home Study

Assessment Parameter	Description	Duration and Frequency
Drywall sampling	Collection of core samples for XRF and FTIR analysis	Initial visit
Air sampling	Hydrogen sulfide and formaldehyde	Eight rounds (approximately two-week period each)*
	Volatile organic compounds	Initial visit
Measurement of corrosion effects	Silver and copper corrosion classification coupons	Eight rounds (approximately two-week period each)
	Corrosion inspection	Initial visit
Environmental conditions	Temperature and relative humidity	Throughout study period (May – December 2010)
Ventilation	Air exchange rates	Initial assessment

XRF x-ray fluorescence
FTIR Fourier transform infrared spectroscopy

* As discussed in Section B.10.1, the hydrogen sulfide measurements from the first three monitoring periods were excluded from the study.

The following sections describe the sampling and analytical procedures used to collect data in each home, the procedures used to process and analyze the data, and the quality assurance and quality control (QA/QC) procedures implemented by EH&E. Every effort was made in each phase of the project to ensure completeness and accuracy of data collection, application of analytical methods, data entry, calculation procedures, and reporting of results.

Field sampling was conducted in accordance with the previously developed Quality Assurance Project Plan (QAPP) described in the 51-Home Study. All sampling and analytical procedures for the project utilized appropriate and valid monitoring methods approved and recommended in relevant published sources, from regulatory agencies such as the U.S. Environmental Protection Agency (EPA) and the U.S. Occupational Safety and Health Administration (OSHA); other cognizant governmental organizations such as the National Institute for Occupational Safety and Health (NIOSH); consensus standard organizations such as the American Society for Testing and Materials (ASTM); or the peer-reviewed scientific literature.

B.2 SOURCE DRYWALL MEASUREMENTS

Material characteristics of representative sections of drywall from each of the six homes were determined using gas chromatography/electron capture detector (GC/ECD), x-ray fluorescence (XRF), and Fourier transform infrared (FTIR) spectrometry. These methods have been previously assessed and validated for analysis of markers in problem drywall.[3] As described in Section B.2.1, the elemental composition analysis was conducted using XRF in the field at each home. More detailed analyses, using a combination of GC/ECD, XRF, and FTIR were subsequently obtained in the laboratory from the bulk samples of drywall collected and archived from each home. A total of 24 representative drywall bulk samples were collected from each of the six homes.

B.2.1 Strontium Analysis by X-Ray Fluorescence

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

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. Samples of drywall with known strontium concentrations were tested repeatedly (at the beginning and at the end of each day of testing) as a means of assessing instrument drift and repeatability. Analysis of the bulk drywall samples removed from the homes was conducted on the core material and not through paint or paper layers.

B.2.2 Carbonate Analysis by Fourier Transform Infrared Spectrometry

Bulk samples of drywall collected from the six 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 nonhydroscopic 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 (DRIFT) spectroscopy technique has been widely accepted as a highly sensitive means of measuring inorganic compounds. DRIFT spectra of pure nondiluted 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 the homes were analyzed using FTIR. Each sample was scanned, analyzed, and the results downloaded with the A2 Technologies Microlab PC software package. Analysis of the bulk drywall samples removed from the homes was conducted on the core material and not through paint or paper layers.

B.3 CORROSION ASSESSMENTS

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

B.3.1 Visual Inspection

Detailed visual inspections were performed on the electrical grounding wires, air handling units (AHUs), plumbing components, and appliances. Notes also were made regarding other home contents that possibly 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. Examples of grounding wires and the associated rating are provided in Figure B.1. 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.

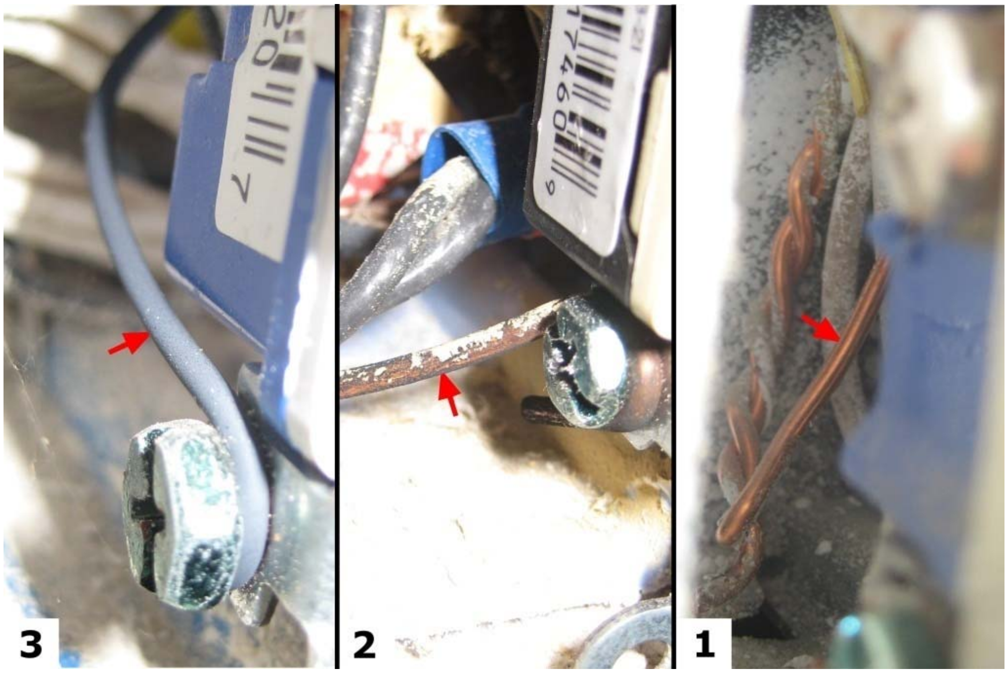

Figure B.1 Examples of Visual Corrosion Ratings, Electrical Ground Wire
(3—Significant Visible Corrosion, 2—Moderate Visible Corrosion, 1—No Visible Corrosion)

AHU inspection focused on the cooling coils and associated copper refrigerant lines. Representative 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.

B.3.2 Corrosion Classification Coupons

Corrosion classification coupons were used to determine the corrosion rate present in the study homes. The corrosion coupons used in this study contained copper and silver metal and were supplied by the Purafil, Inc. Research and Development Laboratory (Doraville, Georgia). Pre-cleaned copper and silver corrosion coupons were placed at three indoor locations and at one outdoor location at each home for an approximate two-week period during each of the eight sampling rounds. In addition, one duplicate sample was collected and analyzed during each period at each home.

At the end of each sampling period, the corrosion coupons were collected, placed in sealed containers, and returned to Purafil, Inc. (Doraville, Georgia) for analysis. The laboratory measured the thickness of several copper and silver compounds, including silver sulfide (Ag_2S), silver chloride (AgCl), Ag “unknown,”[4] 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.” For the 14-day period of exposure in this study, the laboratory reporting limit for the analysis was 32 angstroms. 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 build up 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 build up 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 build up 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 build up per 30 days of exposure.

B.4 VOLATILE ORGANIC COMPOUNDS (SUMMA CANISTER METHOD)

Whole air samples for volatile organic compounds (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 use. Flow controllers were calibrated to achieve 4-hour sample durations. Canisters were protected from radiant heat, as well as moisture, prior to, during, and after sampling.

In each of the six homes, SUMMA canister samples were collected at two indoor locations and at one outdoor location. One duplicate sample and one field blank sample were collected in each home and sent to the analytical laboratory as blinded samples. These procedures were used to assess potential canister contamination during shipping, preparation, or analysis of the samples.

Whole air VOC samples were analyzed using gas chromatography/mass spectrometry (GC/MS). The analyses were performed according to EPA Method TO-15 from the EPA *Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air,* Second Edition. Table B.2 shows the list of 75 VOCs targeted by the laboratory and the corresponding laboratory reporting limits for this study.

Table B.2 Targeted Volatile Organic Compounds (VOCs) and Laboratory Reporting Limits

Compound	Laboratory Reporting Limits ($\mu g/m^3$)
1,1,1-Trichloroethane	0.13 – 0.18
1,1,2,2-Tetrachloroethane	0.13 – 0.18
1,1,2-Trichloroethane	0.13 – 0.18
1,1,2-Trichlorotrifluoroethane	0.13 – 0.18
1,1-Dichloroethane	0.13 – 0.18
1,1-Dichloroethene	0.13 – 0.18
1,2,4-Trichlorobenzene	0.66 – 0.90
1,2,4-Trimethylbenzene	0.66 – 0.90
1,2-Dibromo-3-chloropropane	0.66 – 0.90
1,2-Dibromoethane	0.13 – 0.18
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	0.66 – 0.90
1,2-Dichlorobenzene	0.13 – 0.18
1,2-Dichloroethane	0.13 – 0.18
1,2-Dichloropropane	0.13 – 0.18
1,3,5-Trimethylbenzene	0.66 – 0.90
1,3-Butadiene	0.26 – 0.36
1,3-Dichlorobenzene	0.13 – 0.18
1,4-Dichlorobenzene	0.13 – 0.18
1,4-Dioxane	0.66 – 0.90
2-Butanone (MEK)	6.6 – 9.0
2-Hexanone	0.66 – 0.90
2-Propanol (isopropyl alcohol)	1.3 – 16
3-Chloro-1-propene (allyl chloride)	0.13 – 0.18
4-Ethyltoluene	0.66 – 0.90
4-Methyl-2-pentanone	0.66 – 0.90
Acetone	6.6 – 9.0
Acetonitrile	0.66 – 0.90
Acrolein	2.6 – 3.6
Acrylonitrile	0.66 – 0.90
Benzene	0.13 – 0.18
Benzyl chloride	0.66 – 0.90
Bromodichloromethane	0.13 – 0.18
Bromoform	0.66 – 0.90
Bromomethane	0.13 – 0.18
Carbon disulfide	6.6 – 9.0
Carbon tetrachloride	0.13 – 0.18
Chlorobenzene	0.13 – 0.18
Chloroethane	0.13 – 0.18
Chloroform	0.13 – 0.18

Table B.2 Continued

Compound	**Laboratory Reporting Limits (μg/m^3)**
Chloromethane	0.26 – 0.36
Cumene	0.66 – 0.90
Cyclohexane	0.66 – 0.90
Dibromochloromethane	0.13 – 0.18
Dichlorodifluoromethane (CFC 12)	0.66 – 0.90
Ethanol	6.6 – 90
Ethyl acetate	0.66 – 0.90
Ethylbenzene	0.66 – 0.90
Hexachlorobutadiene	0.66 – 0.90
Methyl methacrylate	0.66 – 0.90
Methyl tert-butyl ether	0.13 – 0.18
Methylene chloride	0.66 – 0.90
Naphthalene	0.66 – 0.90
Propene	0.66 – 0.90
Styrene	0.66 – 0.90
Tetrachloroethene	0.13 – 0.18
Tetrahydrofuran (THF)	0.66 – 0.90
Toluene	0.66 – 0.90
Trichloroethene	0.13 – 0.18
Trichlorofluoromethane	0.13 – 0.18
Vinyl acetate	6.6 – 9.0
Vinyl chloride	0.13 – 0.18
alpha-Pinene	0.66 – 0.90
cis-1,2-Dichloroethene	0.13 – 0.18
cis-1,3-Dichloropropene	0.66 – 0.90
d-Limonene	0.66 – 0.90
m,p-Xylenes	0.66 – 0.90
n-Butyl acetate	0.66 – 0.90
n-Heptane	0.66 – 0.90
n-Hexane	0.66 – 0.90
n-Nonane	0.66 – 0.90
n-Octane	0.66 – 0.90
n-Propylbenzene	0.66 – 0.90
o-Xylene	0.66 – 0.90
trans-1,2-Dichloroethene	0.13 – 0.18
trans-1,3-Dichloropropene	0.66 – 0.90

μg/m^3 micrograms per cubic meter

B.5 PASSIVE AIR SAMPLING FOR H_2S AND FORMALDEHYDE

Passive air samples have been demonstrated to be a valid tool in residential exposure assessment.[5,6] 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.[7] The specific passive sampling system and the analytical technique used for each class of analyte are shown in Table B.3.

Table B.3 Summary of Target Parameters, Passive Air Sampling

Analyte	Radiello Badge Type	Analytical Method*
Formaldehyde	165	Aldehydes by Radiello 165, HPLC-UV
Hydrogen sulfide	170	Hydrogen sulfide by Radiello 170 Spectrophotometer at 665 nm

HPLC	high performance liquid chromatography
UV	ultra violet
nm	nanometer

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

The concentrations of hydrogen sulfide (H_2S) and formaldehyde measured in each study home were calculated using Equation 1:

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

where:

C = concentration in micrograms per cubic meter ($\mu g/m^3$)
m = mass in μg
Q_k = analyte specific sampling rate, adjusted for temperature at the sampling site, in milliliters per minute (ml/min)
t = sample duration in minutes
1,000,000 = conversion factor, milliliters per cuibc meter (ml/m^3)

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 over the time each sample was collected. For outdoor samples, the sampling rates were adjusted using the mean outside temperature over the sampling period.[8] The reported passive sampling results were adjusted for temperature in accordance with Equation 2, which is provided by the supplier of the passive diffusion samplers.[9]

$$Q_k = Q_{298} * \left(\frac{K}{298}\right)^{\exp} \qquad \text{(Equation 2)}$$

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 B.4, and are all provided by the manufacturer, based on a standard temperature of 298 K.[10] 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.[11]

Table B.4 Sampling Rates for Targeted Analytes for Passive Sampling

Compound	CAS #	Sampling Rate in ml/min at 298 K (Q_{298})	Exp
Formaldehyde	50-00-0	99	0.35
Hydrogen sulfide	7783-06-4	69	3.8

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

All analysis of the diffusive sampling media documented in this report was conducted by Air Toxics Ltd. located in Folsom, California. Laboratory reporting limits for the analysis are outlined in Table B.5.

Table B.5 Laboratory Reporting Limits for Passive Diffusion Sampling

Compound	CAS #	Laboratory Reporting Limits (μg/m^3)
Formaldehyde	50-00-0	0.09 – 5.4
Hydrogen sulfide	7783-06-4	0.28 – 0.68

μg/m^3 micrograms per cubic meter

B.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 temperature 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 humidity 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. The data loggers were programmed to record five minute average measurements with a sampling rate of five seconds. Three temperature and humidity monitoring locations were selected in each of the six homes: one in the central living room of the house, one in the master bedroom and one at the air handling unit supply. Temperature and relative humidity measurements were collected throughout the May through December 2010 study period; instruments were downloaded and the data was transferred to EH&E’s servers during each of the eight sample rounds.

B.7 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 used high concentration carbon dioxide (CO_2) as a tracer with decay being 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.

During the first study period in each of the six homes, CO_2 concentrations were measured continuously at two or three locations inside each 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.

B.8 PROCEDURES FOR STATISTICAL ANALYSIS OF DATA

Statistical analyses of the study data were performed using SAS statistical software, version 9.1 (Cary, North Carolina). Field blank samples were analyzed to determine if field samples should be blank corrected. Based on statistical analysis of the field and shipping blank data laboratory reported values did not require corrections for blanks. In accordance with standard procedures, some results were blank corrected by the laboratory prior to reporting (see following discussion). 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 B.10, regression analysis indicated good agreement between paired primary samples and duplicates; samples and duplicates were averaged for all statistical analyses.

Statistical analysis included compiling descriptive statistics 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.

B.9 QUALITY ASSURANCE AND QUALITY CONTROL PROCEDURES

This section describes the overall project QA/QC measures used to design, implement, analyze, and report the results of the study. As discussed, the investigation was conducted in accordance with the previously developed QAPP described in the 51-Home Study.[12] The following sections describe specific measures and procedures implemented to assure quality of the data collected and reported.

B.9.1 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 and two technical directors were 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 were 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.

B.9.2 Quality Assurance and Quality Control Samples

As previously detailed, 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 B.6.

Table B.6 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.

B.9.3 Sample Handling

EH&E followed the requirements for holding times and sample preservation outlined in the respective reference sampling methods used. Samples were stored under appropriate conditions and shipped to the laboratory via overnight express delivery within the holding time specified by the analytical method.

B.9.4 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.

B.9.5 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. Table B.7 summarizes the calibration procedures for real-time instruments used in the study.

Table B.7 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 1,000 parts per million along linear response curve.	Pre and post field measurements

B.9.6 Recordkeeping

B.9.6.1 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.

B.9.6.2 Electronic Documentation

Electronic documentation generated in the field during the study included: digital photographs, CO_2 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 then were transferred from the field computer onto EH&E's central server at the completion of the study. 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 and real-time data monitor deployments on the appropriate field forms.

B.9.7 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 imported directly into the central study database.

- After the database was populated, the number and sample identification labels in the database were compared to those on the field log sheets and the analytical laboratory reports (using a program coded in SAS 9.1).

- As discussed, 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.

B.10 QUALITY ASSURANCE AND QUALITY CONTROL ANALYSIS

As previously described, 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 and laboratory control 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 by EH&E for purposes of analysis.

B.10.1 Completeness

The completeness of 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 B.8 summarizes the data capture efficiency during the study.

Table B.8 Summary of Data Capture Efficiency

Parameter	Number of Samples/ Measurements Collected			Number of Void Samples	Capture Efficiency (%)
	S	**D**	**B**		
Air exchange rate	14	NA	NA	2	85.7
Temperature/relative humidity/dew point	135	NA	NA	6	95.6
Volatile organic compounds (VOCs)	21	6	3	1	96.7
Hydrogen sulfide (H_2S)	138	46	92	108	60.9
Formaldehyde	138	46	46	1	99.6
Corrosion coupons	184	34	NA	2	99.1
Bulk (FTIR and XRF)	144	NA	NA	4	97.2
				Overall Data Capture Efficiency	**88.2**

S	primary samples
D	duplicates
B	field and shipping blanks
NA	not applicable
FTIR	Fourier transform infrared spectroscopy
XRF	x-ray fluorescence

Overall, data capture efficiency was 88.2%. Although not included in Table B.8, no measurements were collected from House 22 during Study Period 4 because no access was available to this home. The following describes the reasons that samples were excluded from the study.

- **Air exchange rate:** Two of the three CO_2 measurements from House 27 were excluded from the study due to instrument drift during monitoring. Upon analysis, the data from these two locations underwent a reasonableness check and were excluded.

- **Temperature and humidity:** Six of the real-time temperature and humidity monitoring log files were excluded from the study due to field conditions, such as incorrect log interval settings or lost of data due to a battery failure.

- **VOCs:** One of the VOC field blanks was voided due to loss of pressure during the sampling period. After cleaning at the laboratory, but prior to sampling, the pressure in this evacuated canister was measured at -29.1 pounds per square inch (psig), and the pressure was measured at -14.1 psig upon receipt back at the laboratory after the sampling event, indicating a leak in the sample canister. The pressure decrease was 15.0 psig, well above the acceptable pressure loss of 2.0 psig allowed during the pre-sampling canister cleanliness verification process by the reference EPA method (TO-15). The underlying cause for the pressure drop is unknown. As discussed in Sections B.10.2 and B.10.3, all other precision and accuracy metrics indicated a high level of data quality for the VOC data set.

- **H_2S:** All passive H_2S samples from the first three rounds were excluded from the study. At the beginning of the current study, passive H_2S samples were sent to Columbia Analytical Services, Inc. for analysis, while samples from the 51-Home Study were analyzed by Air Toxics Ltd. Internal quality assurance review of the data indicated that the results from the current study were consistently higher than measurements during the 51-Home Study; the laboratory was immediately contacted to determine if analytical differences could be contributing to the results. Although equivalent analytical methods were specified by the field team, Columbia Analytical Services, Inc. laboratory staff had modified the extraction solution as well as the calibration standard. Several steps were undertaken to experimentally investigate the implications of the modified extraction and calibration standards and the determination was made to exclude the results. In addition, H_2S samples from study Periods 4 through 8 were analyzed by Air Toxics Ltd. in accordance with equivalent methodology used during the 51-Home Study. As discussed in Sections B.10.2 and B.10.3, precision and accuracy metrics indicated a high level of data quality for the H_2S data set from Periods 4 through 8.

- **Formaldehyde:** One formaldehyde sample was voided because the incorrect passive sampling device was deployed at the location.

- **Coupons:** Two coupons (from the Living Room of House 14 during Period 6 and from the air handling unit air supply in House 21 during Period 8) went missing during the approximately two-week sample period.

- **Bulk:** Analysis of four drywall samples was not possible because the collected bulk sample did not have enough mass for laboratory analysis.

B.10.2 Accuracy

B.10.2.1 Laboratory Measurements

Review of field and shipping blanks analysis were used to assess the accuracy of air sample measurements (VOC, H_2S, formaldehyde). For purposes of comparison of the 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. No blank correction was done in EH&E's analysis of the study data, except for any blank corrections performed by the laboratory as part of their standard reporting procedures.

All field and media blank results were below detection for all VOC and H_2S blank samples included in the study. Formaldehyde was detected at very low levels in several field and shipping blanks, but the results were only slightly above the reporting limit (up to two times the reporting limit); and the highest level detected in a blank (0.41 $\mu g/m^3$) was 24 times lower than the lowest detected indoor concentration in any home (10 $\mu g/m^3$).

EH&E also reviewed the quality assurance procedures implemented by the analytical laboratories to evaluate the accuracy of the laboratory measurements. In accordance with the standard or published methodologies employed for the 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. No laboratory quality assurance flags were noted for laboratory blank samples, although analytes were detected in some formaldehyde laboratory blanks. In all cases, results reported by the laboratories were blank, corrected in accordance with the appropriate standard laboratory protocols. Matrix interference, which could bias the result high, was indicated for propene and/or chlorobenzene in eight measurements (out of the 2,175 laboratory measurements obtained for this group). The recovery of formaldehyde (117%) also was slightly above the upper acceptance criteria of 115% in one laboratory control sample and one laboratory control sample duplicate (2 out of 20 control measurements), indicating that the reported concentrations may be biased slightly high (due to the recovery exception).

EH&E also evaluated the laboratory results to determine if there was potential sample media saturation; no saturation occurred during the study. Finally, the laboratory reports were reviewed to determine if sample handling (e.g., temperature control issues) or holding time exceedances occurred during the study; no issues were found. No analytical quality assurance exceptions were noted; therefore, no data adjustment or exclusion was warranted.

B.10.2.2 Direct-Read Instruments

The accuracy of the XRF instruments was ensured using several measures. First, the XRF analyzer was 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. In addition, internal instrument background checks were run on each instrument before use.

The accuracy of the XRF readings was evaluated in this study by examining repeat XRF strontium readings obtained each day during the laboratory analysis period from reference materials with known strontium concentrations, as well as of a material known not to contain strontium. The repeat laboratory XRF measurements are summarized in Table B.9.

Table B.9 Summary of Repeat XRF Laboratory Measurements

Reference Material	Sr Concentration by ICP-AES (mg/kg)	Number of Measurements	Mean Sr Concentration by XRF (mg/kg)	Coefficient of Variation (%)
CPSC14	570	8	569	1.4
CPSC19	1,500	8	1,523	3.6
CPSC26	2,720	8	3,071	1.5
SRM 2702	120	9	118	2.3
Blank (silicon dioxide)	None	9	<6	0

XRF	x-ray fluorescence
Sr	strontium
ICP-AES	inductively coupled plasma atomic emission spectroscopy
mg/kg	milligrams per kilograms
CPSC	U.S. Consumer Product Safety Commission
SRM	Standard Reference Material

Overall, the repeat XRF strontium measurements indicated strong agreement with the reference materials and a high degree of accuracy. This is consistent with a recent, extensive study undertaken by EH&E, which has indicated excellent accuracy of measurements of strontium by XRF analyzers compared to analysis by inductively coupled plasma atomic emission spectroscopy (ICP-AES) (slope = 0.85-0.95, R^2 = 0.96-0.99, $p<0.01$).[13]

For FTIR spectroscopy, internal calibration programs were run on the instrument monthly in accordance with manufacturer’s recommendations. Also, the accuracy of the FTIR instrument used in testing at EH&E’s laboratory was examined by evaluating the agreement between measurements repeated daily from a reference drywall sample, which indicated a coefficient of variation (CV) of 1.8% and strong agreement.

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.

B.10.3 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.[14] The analysis of precision for the different sample types collected during this study is discussed in the following sections.

B.10.3.1 VOC Samples

Due to the limited number of sample and duplicate pairs (N=6), an evaluation of detection agreement between samples and corresponding duplicates was undertaken for the VOC samples and is summarized in Table 10. In addition to detection agreement, the precision of the VOC measurements was evaluated by calculating the relative percent difference (RPD) between each duplicate pair, where both measurements were above the laboratory reporting limit. RPDs were calculated as follows, and summarized in Table B.10:

$$RPD\ (\%) = \frac{Absolute\ Value(Concentration_{sample} - Concentration_{Duplicate})}{(Concentration_{sample} + Concentration_{Duplicate})/2} x100$$

Table B.10 Summary of Detection Agreement Between VOC Sample and Duplicate Pairs

Number of Pairs	Number of Target Analytes	Detection Agreement	Number of Pairs Above Detection	Average RPD Between Sample/Duplicate Pairs
6	75	98%	223	9.3

VOC	volatile organic compound
RPD	relative percent difference

There was a 98% detection agreement between the VOC sample and duplicate pair measurements during the study and the RPD indicate a high level of precision between paired measurements.

B.10.3.2 Non-VOC Samples

The method for estimating precision for all measurements other than the VOC samples was based upon guidance from the EPA.[15] In this method, precision is calculated as the root mean square of the scaled relative differences between pairs of duplicate samples (Equation 3). The one standard deviation estimate of precision derived from this method provides a concentration range within which the actual concentration is expected to occur 68% of the time.

$$Root\ mean\ square = \sqrt{\frac{1}{n}\sum_{i=1}^{n} D_i^2} \times 100\% , \qquad \text{(Equation 3)}$$

where

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

Precision estimates for each non-VOC parameter targeted during the study, except copper corrosion coupons, are provided in Table B.11. Precision estimates were calculated for all duplicate pairs, where both measurements were above the reporting limit. There was only one duplicate pair of copper corrosion coupons that were above detection; no precision estimate was calculated for this parameter. As seen in Table B.11, all measurements exhibited a high level of precision.

Table B.11 Estimates of Measurement Precision for the Study

Parameter	Number of Pairs	Precision (%)
Formaldehyde	46	13.2
Carbonate (FTIR)	12	7.8
Hydrogen sulfide (H_2S)	13	8.4
Silver Sulfide Corrosion	33	21.3
Strontium (XRF)	15	1.1

FTIR Fourier transform infrared spectroscopy
XRF x-ray fluorescence

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) were evaluated utilizing several measures. For the temperature, relative humidity, and dew point temperature measurements, the CV between the hourly average values at each measurement location within each home over each approximate two-week sample period was used as an indicator of agreement (CV=[standard deviation/mean]∗100). The mean CV of indoor temperature, relative humidity, and dew point temperatures in each home is shown in Table B.12.

Table B.12 Estimates of Inter-Home Temperature, Relative Humidity, and Dew Point Temperature Variability

Home ID	Number of Days	Coefficient of Variation (%)		
		Temperature	Relative Humidity	Dew Point
14	115	3.7	8.2	3.4
19	111	4.4	12.8	3.7
21	100	6.7	16.4	6.3
22	99	3.2	7.1	2.9
23	114	6.0	14.0	3.4
27	115	4.5	11.9	3.4

The precision of air exchange rate measurements was evaluated using linear regression analysis between the coincident air exchange rate estimates in the living rooms and master bedrooms within each home, which were based on CO_2 readings. The agreement between in-home CO_2 measurements was excellent (R^2s ranged from 0.89 to 1.0 and CVs ranged from 2.7% to 13%).

ENDNOTES

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[1] EH&E. 2010a. *Final Report on an Indoor Environmental Quality Assessment of Residences Containing Chinese Drywall*, prepared for the U.S. Consumer Product Safety Commission. Needham, MA: Environmental Health & Engineering, Inc. January 28, 2010.

[2] EH&E. 2010b. *Draft Identification of Problematic Drywall: Source Markers and Detection Methods*, prepared for the U.S. Consumer Product Safety Commission. Needham, MA: Environmental Health & Engineering, Inc. May 28, 2010.

[3] EH&E. 2010b.

[4] "Unknown" refers to a corrosive layer where the laboratory was able to quantify thickness in angstroms but was unable to determine the compound.

[5] Pellizzari ED, Smith DJ, Clayton CA, Michael LC and Quackenboss JJ. 2001. An assessment of the data quality for NHEXAS—Part I: Exposure to metals and volatile organic chemicals in Region 5. *Journal of Exposure Analysis and Environmental Epidemiology*. 11(2):140-154.

[6] WHO. 2000. *Environmental Health Criteria 214: Human Exposure Assessment, International Program on Chemical Safety.* Geneva: World Health Organization.

[7] Sigma-Aldrich. 2006. *Radiello® Manual*. Bellefonte, PA: Sigma-Aldrich Co.

[8] The outdoor samples at one home were adjusted based on the mean temperature obtained from the nearest National Weather Service weather station due to data logger malfunction.

[9] Sigma-Aldrich. 2006.

[10] Sigma-Aldrich. 2006.

[11] Sigma-Aldrich. 2006.

[12] EH&E. 2010a.

[13] EH&E. 2010b.

[14] Hyslop NP and White WH. 2009. Estimating precision using duplicate measurements. *Journal of Air & Waste Management Association*. 59:1032-1039.

[15] EPA. 2008. *Quality Assurance Handbook for Air Pollution Measurement Systems Volume II Ambient Air Quality Monitoring Program*. Research Triangle Park, NC: U.S. Environmental Protection Agency.