CA/DHS/EHLB/R-172

LONG-TERM BUILDING AIR MEASUREMENTS FOR VOLATILE ORGANIC COMPOUNDS INCLUDING ALDEHYDES AT A CALIFORNIA FIVE-BUILDING SUSTAINABLE OFFICE COMPLEX

VOLUME 1 of 2

California
Department of
Health Services

Final Report Submitted to:

Dr. David Mudarri, Contract Manager
United States Environmental Protection Agency

Through

The Public Health Institute
Contract Number 3W-2265-NANX
August 31, 2006

ARNOLD SCHWARZENEGGER, Governor

State of California

Kimberly Belshé
Secretary
California Health and Human Services Agency

Sandra Shewry
Director
California Department of Health Services

Principal Investigator and Report Author:

Leon Alevantis, M.S., P.E.
Senior Mechanical Engineer[1]
Program Support Branch
Administration Division
California Department of Health Services

Co-Principal Investigators:

Robert Miller, Supervising Chemist
Indoor Air Quality Section
Environmental Health Laboratory Branch
Division of Environmental and Occupational Disease Control
California Department of Health Services

&

Hal Levin, Research Architect
Building Ecology Research Group, Santa Cruz, California

This report is available on-line to download at http://www.cal-iaq.org/VOC/

[1] Formerly: Deputy Chief
Indoor Air Quality Section
Environmental Health Laboratory Branch
Division of Environmental and Occupational Disease Control

Preface

This study was conducted by the California Department of Health Services, beginning in 2003 and ending in June 2004. The research was conducted by the Indoor Air Quality Section of the Department's Environmental Health Laboratory Branch with the goal of expanding scientific investigation data for pre- and post-occupancy IAQ components. This study and accompanying data outline the role of IAQ and its relationship to the sustainable construction practices implemented at the Capitol Area East End Complex (CAEEC).

The study was supported, in part, through funding from the Indoor Environments Division, Office of Radiation and Indoor Air, United States Environmental Protection Agency, Contract Number 3W-2265-NANX, under the auspices of the Public Health Institute. This Final report is submitted in fulfillment of the contract requirements. Substantial in-kind support was provided by the Department of Health Services.

The report consists of two volumes: Volume 1 contains the study description, results, lessons learned, supporting tables and figures, whereas, Volume 2 contains detailed data and graphs for all sampled locations.

Disclaimer

This study was not requested or funded by the Department of General Services (DGS). As such, DGS is not responsible for any of the test results or interpretations of the scientific data associated with this study.

The CAEEC was constructed under the requirements of a detailed commissioning process that also included building material emissions testing and measurements of the chemicals in the indoor environment after completion of the construction. This information was submitted to California Department of Health Services (CDHS) and California Department of Education, the primary tenants of the CAEEC.

All sample results and discussions or interpretations of the data associated with this research study are not necessarily related to operations and maintenance of the CAEEC facilities by DGS.

Occupants of the CAEEC should contact their employer's Health and Safety Officer with any questions associated with this research study.

Acknowledgements

The principal investigator and co-investigators of this study thank the following individuals:

1. PHI chemist, Mr. Weldon Hall, and CDHS chemist, Mr. Nitin Kapadia, for their efforts in the chemical sampling and analyses of all the samples.

2. PHI assistants, Mr. Van Tran and Mr. Igor Lacan, for their field assistance and data analyses, respectively.

3. DHS scientists, Dr. Jed Waldman, Dr. Peter Flessel, and Dr. Feng Tsai (now with Cal-EPA/OEHHA), for their advice, input, and support during the study.

4. Dr. David Mudarri (USEPA), Mr. John Girman (USEPA), Dr. Andy Persily (NIST), and Dr. Dimitrios Kotzias (JRC at Ispra), for the review of this report.

5. Ms. Eileen Adams, former Secretary of State and Consumer Services Agency, as well as, Mr. Arnie Sowell, former Deputy Secretary of State and Consumer Services Agency for their vision and leadership in promoting sustainability in state building construction and their support for this study.

6. The Sustainable Building Task Force, the CAEEC Green Team, the California Department of General Services, the California Integrated Management Board, and the Clark/Gruen and Hensel Phelps teams for their input during the study.

7. Anthony Bernheim, SMWM, green architect for Building 225, for his extraordinary efforts in implementing the state’s sustainable goals.

8. Alfred T. Hodgson, Lawrence Berkeley National Laboratory (LBNL), and Richard Lam, Office of Environmental Health Hazard Assessment, Cal/EPA, for their advice throughout this study.

9. Contract manager, Dr. David Mudarri for his assistance throughout this study.

10. The USEPA for funding this work.

Executive Summary

Background

In 1999, the State Legislature directed the Department of General Services (DGS) to incorporate sustainable practices in the design and construction of a 1.5 million ft^2 of the Capitol Area East End Complex (CAEEC). To address the Legislature's directive, a multi-agency team, known as the Green Team, was formed under the leadership of the Secretary of the State and Consumer Services Agency and, in partnership with the Department of Health Services, California Integrated Waste Management Board, California Energy Commission, California Air Resources Board, and Department of Water Resources worked with DGS to develop sustainable criteria for the CAEEC. These criteria, among others, included several to ensure good indoor air quality, including setting target limits on chemical emissions from interior finishing building materials and conducting airborne contaminant testing after completion of the construction and prior to occupancy. Two design/build teams were selected: one for Building 225 and another for the remaining four buildings (171, 172, 173,174). The design/build teams were responsible for the design of the buildings (the basic shell design had been done previously by the State) and the construction.

Goals

In order to ascertain the post-occupancy indoor air quality of the CAEEC, a complex with numerous sustainable features, and to find out how it performs over time, the concentrations of Volatile Organic Compounds (VOCs) including aldehydes were measured along with local and building ventilation rates. Based on the measured VOC concentrations and ventilation rates, emissions from building materials and occupant activities (such as cleaning products and perfumes) to the indoor environment could be identified and their temporal changes could be studied. It is noted that due to the narrow scope of this study, other important aspects of indoor environmental quality, such as semi-volatile organic compounds, or noise and lighting were not studied. The specific goals of this research study were to:

1. Measure VOC (including aldehyde) concentrations periodically several times for at least 12 months after occupancy of the five buildings. Compare measured concentrations: (a) to those referenced in Section 1350 as issued for the project and in its most current version; and (b) to those measured in U.S. EPA's indoor air quality database of 100 randomly-selected office buildings known as the Building Assessment Survey and Evaluation (BASE) study.

2. Study temporal changes of measured concentrations to determine the effect of building materials, office furniture, occupant activities, and cleaning/maintenance products on indoor air quality.

3. Determine how emissions of target chemicals in the indoor environment correlate to the emissions derived from small chamber tests.

4. Investigate the association between occupant survey responses for Blocks 225 and 172 collected by Center for the Built Environment (CBE) at University of California, Berkeley and the measured VOC and aldehyde concentrations.

5. Discuss the lessons learned that can be used in future projects.

Results

1. The VOC concentration targets established for this project were not exceeded in the majority of the locations. However, acetaldehyde and formaldehyde targets were exceeded in numerous locations of more than one building. Concentrations of chemicals measured at the newly-constructed CAEEC were compared to those reported in the BASE study in which older office buildings were monitored. The concentrations of common chemicals to both studies were comparable and only the concentrations of a few chemicals at the CAEEC were higher than those reported in the BASE study. However, comparisons of concentrations without normalizing for building age and ventilation rates provide only limited information.

2. Eight building- and occupant-related chemicals were identified and source strengths were calculated to determine the effect of building materials, office furniture, occupant activities, and cleaning/maintenance products on indoor air quality. The five building-related chemicals are: acetaldehyde, caprolactam, formaldehyde, naphthalene, and nonanal; the three occupant-related chemicals include: benzaldehyde, decamethylcyclopentasiloxane (d-5) and d-limonene. However, very few chemicals could be traced to a unique source. Only one building-related compound (caprolactam) and one occupant-related compound (d-5) studied were clearly identifiable from unique sources. In the case of caprolactam, there was a clear decrease over time in its emissions and in the case of d-5, there was a clearly identifiable increase over time in its emissions. Emission factors of some of the other target chemicals (i.e., acetaldehyde, benzaldehyde, naphthalene, d-limonene, and nonanal) fluctuated throughout the study.

   Local emission factors of some of these eight chemicals during the post-occupancy period were fairly uniform within each building, whereas, others differed substantially from building median values. Chemicals with highly variable local emission factors were: d-5 (occupant-related), d-limonene (cleaning-related), caprolactam (variable only in certain sampling scenarios – this chemical is emitted by carpeting and variability was presumably due to hallway carpet replacement), and formaldehyde (variability was presumably due to local generation of this chemical from cleaning and other activities).

3. One of the goals of this study was to determine the correlation between emissions of target chemicals in indoor environments and the emissions derived from small chamber tests. Caprolactam (a chemical with unique source, carpet) was selected for this analysis, and its emissions, after carpet installation, correlated to the chamber-derived emission factor within a factor of 2.

4. We could not compare our findings to those by CBE conducting occupant surveys in two of the five buildings because their final report has not been issued yet.

5. There was a number of lessons learned. These include:

   a. Importance of data on cleaning and maintenance activities, touch up or other introduction of building materials, and furnishings, or finishes after the initial occupancy. Collection of emissions data from cleaning and maintenance products was beyond the scope of this study, but it would likely have been very useful to have had collected these data.
   b. Variations of building ventilation rates and local ventilation rates. Despite the efforts to provide consistently the same amount of ventilation from one sampling session to the next by setting the ventilation systems to provide their minimum design outdoor airflows, variations of building ventilation rates and local ventilation rates occurred from one sampling session to the next, necessitating ventilation measurements during each sampling scenario.
   c. Emissions testing of building material samples by their manufacturer does not necessarily guarantee that materials of similar chemical profile would be delivered and installed in a building. Despite the fact that the office furniture systems for the entire complex were tested to the State's IAQ emissions specifications, there were substantial differences in the formaldehyde concentrations of two buildings (172 and 225) and those of the other three buildings in which these systems were supplied by a different vendor. In some locations of these two buildings the formaldehyde concentration targets for the CAEEC were exceeded, indicating that the office furniture systems delivered in these two buildings may not have met the State's emissions requirements. These requirements were developed independently of the CAEEC and they were part of the State's procurement specifications.
   d. Accurate characterization of indoor air chemical concentrations requires numerous samples and ventilation measurements at several locations over an extended period of time. Many variables need to be considered and controlled in the building, or accounted for in the data analysis.
   e. Analytical procedure and ventilation rate variations need to be accounted for when air sampling in buildings is conducted to determine whether concentration targets have been met. It is important that duplicate samples are collected at each site and samples with variability above a pre-determined threshold be discarded. It is also important to relate concentration targets to a specific outdoor air ventilation rate or design value.

Table of Contents

Section 5. Conclusions and Lessons Learned 37

Section 1. Introduction

1.1 Background

Coordinated efforts by the State of California to address sustainability in State-government construction started in 1999 when the Legislature directed the California Department of General Services (DGS) to incorporate sustainable-building measures into the design and construction of the Capitol Area East End Complex (CAEEP), a $392 million state office-building complex in Sacramento. This five-building complex encompassing 1.5 million ft^2 was completed in 2002 and 2003 and was the largest State government office-construction project in California history.

As a result of the Legislature's directive, a multi-agency *Green Team* was formed under the direction of the Secretary of the State and Consumer Services Agency to assist DGS in integrating sustainable building measures into this project. These measures included general requirements for improved indoor air quality, energy efficiency, environmentally preferred building materials, recycling, water conservation, and other resource efficiency measures. Guided by DGS, the two design/build teams selected by the State to design and construct this complex developed their own sustainable designs and specifications. These included several specifications for enhancing healthy indoor air quality (IAQ), energy efficiency, and efficient use of resources.

The indoor air quality measures for building materials included:

- Require manufacturers to test building materials according to a specified protocol (Section 01350)
- Specify formaldehyde-free ceiling tiles, paints, and thermal insulation
- Specify the sequence of installing certain materials according to their volatile organic compound (VOC) emission characteristics
- Require the builders to operate the heating, ventilating, and air-conditioning (HVAC) system on maximum outdoor air during finish work
- Specify a 30-day building flush-out after substantial completion and before occupancy
- Specify building air quality sampling prior to and after occupancy as part of the building commissioning process

Other measures for enhanced building sustainability (including indoor air quality) included:

- Require airflow monitoring stations and minimum airflow injection fans so that the design minimum amount of outdoor air can always be supplied to each building
- Specify 85% or higher efficiency air filters
- Minimize the use of internal lining in the ductwork
- Mandate that all oil residues be removed from the internal surfaces of the ductwork prior to installation
- Require that the open ends of all ductwork be covered during transportation and storage
- Stipulate that all open ends of the installed ductwork be covered
- Require the HVAC systems and their components be easily accessible for inspection and maintenance
- Specify local exhaust(s) for high-volume copier rooms
- Mandate that all building outdoor air intakes be located upwind and at least 25 feet away

from any potential sources of contamination, such as cooling towers and building exhausts

- Specify adequate slope for condensate pans to avoid accumulation of standing water
- Exceed the 1998 California energy code standards in effect at the time the bid documents were written for this project, by at least 30%[2].
- Develop and implement a building and IAQ commissioning plan
- Maximize use of natural lighting
- Specify materials which have a high percentage of recycled contents, a high potential for being recycled in the future, and are durable
- Specify water-efficient irrigation and plumbing systems
- Require LEED™ certification [LEED, or "Leadership in Energy and Environmental Design" was developed by the United States Green Building Council (USGBC), and is a nationally recognized system for rating sustainable buildings]

The *design/build* process was used for the design and construction of this project. In the traditional *design-bid-build* procurement process the owner contracts for the design of the project. The construction documents produced are then circulated for competitive bidding. The owner then contracts for the construction of the project. Design-build is a project delivery process in which these two responsibilities are combined and are contracted under a single entity. This entity, usually referred to as the design-builder, is responsible for the design and the subsequent construction of the project. The design-build method used to deliver the CAEEC is more correctly defined as *bridged* or *modified design-build*. This method provides that the owner contracts for the design of the project. The design is usually developed to the preliminary plan level. The design then forms the basis for a *Request for Proposal* to design-build entities. The contracted design-builder is then responsible to complete the design, produce construction documents, and construct the project. This method of delivery allowed the design-build teams of the CAEEC to offer innovations and enhancements to the project that would not have been possible until the traditional design-bid-build process.

1.2 Goals

The purpose of this research was to monitor the indoor air quality (IAQ) of the five buildings at the CAEEC for VOCs including aldehydes. The data collected from Block 225 and Blocks 171-174 will be used to provide guidance for ensuring enhanced IAQ for future State projects. Staff of the California Department of Health Services' (CDHS) Indoor Air Quality Section conducted these activities in consultation with the Sustainable Building Task Force, representatives of CAEEC tenants, as well as an independent collaborator who is also co-investigator of this research study (Hal Levin, Building Ecology Research Group).

This research complements and enhances the sampling conducted by the two-design/build teams as well as the occupant surveys for Blocks 225 and 172 conducted by the Center for the Built Environment (CBE) of the University of California (Berkeley). This research study provides valuable measurements from finished buildings that have implemented numerous measures to enhance IAQ.

---

[2] The 1998 version of the California Energy Code was generally equivalent to the 1999 ASHRAE Standard 90.1. However, the 2001 version of the California code, on the average, is more stringent than the 1999 ASHRAE Standard. An average building that is 8% better than the 2001 California energy code, is 20% better than the 1999 ASHRAE Standard

The specific goals of this research study were to:

1. Measure VOC (including aldehyde) concentrations periodically several times for at least 12 months after occupancy of the five buildings. Compare measured concentrations: (a) to those referenced in Section 1350 as issued for the project and in its most current version; and (b) to those measured in U.S. EPA's indoor air quality database of 100 randomly-selected office buildings known as the Building Assessment Survey and Evaluation (BASE) study.

2. Study temporal changes of measured concentrations to determine the effect of building materials, office furniture, occupant activities, and cleaning/maintenance products on indoor air quality.

3. Determine how emissions of target chemicals in the indoor environment correlate to the emission data from small chamber tests.

4. Investigate the association between occupant survey responses for Blocks 225 and 172 collected by Center for the Built Environment (CBE) at University of California, Berkeley and the measured VOC and aldehyde concentrations.

5. Discuss the lessons learned that can be used in future projects.

Section 2. Methodology

2.1 Monitoring Plan for VOCs and Aldehydes

In order to measure VOC and aldehyde concentrations periodically in all five buildings of the CAEEC, i.e., Buildings 171, 172, 173, 174, and 225, a sampling plan was developed and implemented. The plan described below was implemented in all five buildings. Active sampling methods were applied as discussed in Section 3.

Samples were taken from the return air stream of each HVAC system. Buildings 225 and 171 have four return air streams in each building – Building 172 has three and Buildings 173, and 174 have only two. In all buildings except 225, a 1/2" opening was drilled into the side of each HVAC system and a ¼" brass Swagelok™ bulkhead union fitting was mounted through the opening. A custom sampling manifold was attached to the bulkhead outside of the HVAC system with two Tenax™ samplers and one DNPH sampler. In Building 225, the samplers were placed inside the return air plenums.

During the 20-month study, four buildings were sampled four times each and one building five times, for a total of 21 site visits. In the 21 site visits, there were 270 sampling sites, 7 to 15 sites per building. Each sampling site had one Tenax™ sampler (270 samples), one Tenax™ duplicate sampler (270 samples), and one DNPH sampler (270 samples). In addition, a limited number of sites had duplicate DNPH samplers (30 samples). At each building, one outdoor air sample was collected near an outdoor air intake. A total of 840 samples were collected and analyzed.

The following locations were sampled at each building:

1. Building 171
   - Return air streams: 4 locations
   - Outdoor air: 1 location (roof level)
   - 5th floors: 1 location
   - 2nd, 4th, and 6th floors: 2 locations
   - 3rd floor: 3 locations

2. Building 172
   - Return air streams: 3 locations
   - Outdoor air: 1 location (roof level)
   - 2nd, 3rd, 4th, 5th, and 6th floors: 2 locations
   - 1st floor: 1 location

3. Building 173
   - Return air streams: 2 locations
   - Outdoor air: 1 location (roof level)
   - 1st, and 3rd: 1 location
   - 2nd, 4th, 5th, 6th, and 7th floors: 2 locations

4. Building 174
   - Return air streams: 2 locations
   - Outdoor air: 1 location (roof level)
   - 1st, 3rd, 5th, and 7th floors: 2 locations
   - 2nd, 4th,and 6th floors: 1 location

5. Building 225
   - Return air streams: 4 locations
   - Outdoor air: 1 location (roof level)
   - 1st, 3rd, 4th, and 6th floors: 2 locations
   - 2nd and 5th floors: 1 location

Table 1. Dates each building was sampled (includes samples taken by the design/build teams, as noted)

		Building Number				
		171	**172**	**173**	**174**	**225[3,4]**
Pre-Occupancy	#1	04-30-03	10-10-03	04-11-03	06-04-03	2-26-02 (see footnote 1) before furniture
	#2					04-02-02 (see footnote 1) after furniture
	#3					06-25-02 (see footnote 1) week before occupancy
	#4					06-28-02 (see footnote 1) 3 days before occupancy
Move-in dates		5-2-03 to 10-31-03	11-7-03 to 11/21/03	4-11-03 to 5-9-03	6-20-03 to 6-27-03	7-1-02
Post-Occupancy	#1	10-15-03	02-11-04	10-29-03	10-07-03	10-29-02 (see footnote 2)
	#2	03-24-04	03-30-04	03-03-04	02-04-04	06-05-03 (see footnote 2)
	#3	06-02-04	06-08-04	04-27-04	04-21-04	10-23-03
	#4					03-10-04
	#5					05-19-04

Indoor sampling locations were selected at or near workstation cubicles. Exact locations depended on the arrangement of the floor to be sampled. For Block 225 and when possible, samples were collected from the same locations sampled earlier by the design/build team (sampling dates by the design/build team of Block 225 are shown in Table 1). In Block 225, a total of six indoor locations had been monitored and in Blocks 171-174 only two indoor locations per building had been monitored by the design/build teams. Given the fact that Blocks 172 - 174 have identical construction, similar floor area, and numbers of HVAC units, each of these three buildings was sampled approximately once every other month.

The afternoon prior each sampling day, the building engineer was instructed to set the HVAC systems via each building's energy management system (EMS) at the design minimum outdoor airflow rate and to lock this setting until sampling had been concluded the afternoon of the following day. The amount of outdoor air supplied by each HVAC system was monitored and

[3] All pre-occupancy data provided by Indoor Environmental Engineering (IEE)
[4] Side-by-side sampling by the researchers of the CAEEC study and IEE on 10-29-02 and 06-05-03

recorded using each building's individual airflow measuring stations and, at the conclusion of each test, the building energy management's personnel printed a histogram of these airflows.

2.2 Target Chemicals

Samples were analyzed qualitatively for all VOCs [up to 15 carbon chain length (C-15) for VOCs and C-4 for aldehydes]. The samples were quantitatively analyzed for chemicals on the following lists:

1. Non-Cancer Chronic Reference Exposure Levels (CRELs). Non-cancer CREL of a chemical is the airborne concentration of that chemical that would pose no significant health risk to the general public, including sensitive individuals exposed to that concentration over their lifetime. Non-cancer CRELs are published by the Office of Environmental Health Hazard Assessment of the Cal-EPA and are based on health considerations reported in the scientific literature. The most recent list of CRELs was used for this study. The complete list of CRELs is available at: www.oehha.org/air/chronic_rels/allChrels.html.

2. The Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65): Chemicals known to the State of California to cause cancer or reproductive toxicity effective January 25, 2002. Available at: www.oehha.org/prop65.html.

3. Toxic Air Contaminants (TAC) List: The TAC List is a list of 244 substances that have either been identified by the ARB as known or suspected contaminants to be emitted in California and have potential adverse health effects. The most recent published list was used (December 1999 version). Available at: http://www.arb.ca.gov/toxics/taclist.htm.

4. Human Olfactory Thresholds as listed in Devos et al.[5] It is noted that odor is a highly complex biological response, especially in the case of chemical mixtures.

In addition, the following criteria were used to identify and quantify compounds not shown on the above four lists:

1. List of 121 chemicals developed by the research team as a result of an intensive emission study of 77 building materials conducted by our team and supported by an 18-month grant from the California Integrated Waste Management Board (CIWMB) (California Building Material Emissions Study[6]).

2. The emissions test data of the building materials submitted to the State by the two design/build teams.

---

[5] Devos, M., et al. *Standardized Human Olfactory Thresholds*. New York, Oxford University Press, 1990.

[6] L. Alevantis. 2003. Building Material Emissions Study. California Department of Health Services. Final Report, submitted to the California Integrated Management Board through the Public Health Institute. Available at: http://www.ciwmb.ca.gov/greenbuilding/Specs/Section01350/METStudy.htm

3. The building air concentrations submitted to the State by the two design/build teams as part of their commissioning process.

For compounds not listed in the above lists, the following criteria for their identification and quantification were used:

1. Compounds with chromatography peaks exceeding five percent of the Total Ion Current (TIC) area. Total Volatile Organic Compounds (TVOCs) were calculated from the Total Ion Current (TIC) from the GC/MS analysis. More specifically, the areas of the integrated peaks with retention times greater than eight minutes and less than thirty one minutes were added, the sum the area of the internal standard, chlorobenzene-d5 was subtracted, and then the TVOC concentration was calculated using the response factors of chlorobenzene-d5 and toluene. It is noted that: (a) some aldehydes, including formaldehyde and acetaldehyde, are not detected by the ATD-GC/MS methodology used in the study and therefore were not included in the TVOC calculation; (b) there are many different ways for analyzing and calculating TVOCs, the term generally refers to a summation of integrated areas of the total ion current, then comparing it to some reference; and (c) TVOC it is at best an inexact measurement that has not been shown to correlate to health effects and, therefore, should be used with caution.

2. Ten most abundant compounds not included in the above criteria. Compounds that have had a concentration equivalent to less than or equal to 45 ng on the Tenax™ tube were not reported.

Based on the above criteria a list of 110 target chemicals was developed. The list of chemicals is shown in Table A1 (Appendix A) of this report.

Section 3. Analysis

3.1 Sampling and Analytical Methods

VOC samples were collected using stainless steel thermal desorption tubes that were filled with Tenax™ sorbent. Samples were collected for a period of 5 – 6 hours at a flow rate of 50 mL/min, resulting in a 15 to 18 L sample volume.

Aldehyde samples were collected using a Waters Sep-Pak® XpoSure™ aldehyde sampler cartridge, which traps aldehydes in air by reacting them with DNPH, forming stable hydrazone derivatives. Aldehyde samples were collected for a period of 5 – 6 hours at a flow rate of 500 mL/min, resulting in a 150 to 180 L sample volume.

More details about the sampling and analytical methods used for VOCs and aldehydes can be found in CDHS's *SOPs and 115*[7] *and 116*[8].

VOCs (up to C-15-pentadecane) collected on the Tenax™ thermal desorption tubes were analyzed by thermal desorption gas chromatography/mass spectroscopy (ATD-GC/MS). A 116 ng aliquot of chlorobenzene-d5 gas was added to each tube before analysis. A mixture of eight gas standards and 52 liquid standards in five concentration levels was analyzed by ATD-GC/MS as calibration standards. A response concentration curve was developed for each of the 60 compounds with chlorobenzene-d5 used as an internal standard. Calibration was performed quarterly, or as conditions merit. Other chemicals were identified using the NIST Mass Spectra Library. Concentrations of uncalibrated chemicals were calculated using the response factor for chlorobenzene-d5. The method of quantitation is noted in Table A-1 (Appendix A) under the column entitled "Calibration". Assuming a 15 to 18-liter sample volume, the estimated limit of quantitation (LOQ) for individual VOCs ranged from approximately 1 $\mu g/m^3$ to 4 $\mu g/m^3$, depending on the chemical detected and the sample volume. The LOQs for the target VOCs are listed in Table A-1.

Tenax™ thermal desorption tubes were conditioned and sealed in clean glass tubes the day before sampling. DNPH cartridges were stored in the factory packaging until time of use. At the start of sampling a Tenax™ tube and a DNPH cartridge were removed from their respective packages, briefly exposed to the atmosphere and then stored in their packaging until sample analyses. After sampling, each Tenax™ tube was resealed in its glass tube. Each DNPH cartridge was placed in a foil packet that was supplied by the cartridge manufacturer. The foil packets containing the DNPH cartridges were placed in a refrigerated chest during transportation to the lab and were placed in a refrigerator upon arrival at the lab. The Tenax™ tubes were stored at ambient temperature until time of analysis. All Tenax™ tubes were

---

[7] California Department of Health Services, 2002c. *Standard Operating Procedure: Aldehyde Emissions from Building Materials. SOP/Rev. No. 115/R0 Environmental Health Laboratory Branch. Richmond, California*. March 20.

[8] California Department of Health Services, 2002. *Standard Operating Procedure: The Determination of Volatile Organic Compounds in Building Material Emission by Gas Chromatography/Mass Spectrometry. SOP/Rev. No. 116/R0 Environmental Health Laboratory Branch. Richmond, California*. April 17.

analyzed on the day following field sampling. All DNPH cartridges were extracted and analyzed within two days of field sampling.

Aldehydes (up to C4—butanal or butyraldehyde) were analyzed using high performance liquid chromatography (HPLC) with UV detection following extraction of the aldehyde sampler cartridges with acetonitrile. A mixture of four aldehyde-DNPH derivatives was analyzed at five concentration levels as calibration standards. The calibration was checked daily. Assuming a 150-liter sample volume, the estimated LOQ for individual aldehydes ranged from approximately 1 μg/m^3 for formaldehyde to 2 μg/m^3 for butanal. Earlier in the study, the aldehyde samplers were analyzed for 20 different aldehyde-DNPH derivatives. It was found, that aldehydes with five or more carbons were generally not found in quantitable levels. It should be noted that aldehydes of five carbons or more are detectable also by ATD-GC/MS. Table A1 lists the LOQs for all the target chemicals.

The estimated uncertainty for VOC including aldehyde measurements was 10% and the uncertainty for TVOC calculations was 40%. Since the anticipated concentrations of the VOCs were generally low, breakthrough was not anticipated and, as such, it was not measured.

Emission factors (i.e., mass emitted per hour per floor area also referred to as source strengths or area specific emission rates) for each measured concentration were calculated using the equation below. By measuring chemical concentrations and ventilation rates simultaneously, emission factors can be calculated for each measured chemical. This allows comparison of the emissions on different sampling scenarios and buildings.

For each analyzed sample an emission factor (EF) was calculated for each target compound at steady state conditions using the following equation:

$$EF = (C - Co) \bullet ACH \bullet H$$

where:

EF = emission factor [μg/m^2·h]

C = measured indoor concentration of the compound [μg/m^3]

Co = measured outdoor concentration of the compound [μg/m^3]

ACH = air change rate [1/h]

H = ceiling height [m]

3.2 Measurement of Building Ventilation Rates

As was noted earlier, simultaneous measurement of chemical concentrations and ventilation rates is required for the calculation of emission factors. Therefore, measurements of ventilation rates were conducted during this study.

Measurements of ventilation rates, utilizing the tracer gas steady state and decay methods, were done at minimum outdoor air supply conditions. The tracer gas technique accounts not only for the outdoor air supplied by each building's HVAC system but also for infiltration due to envelope leakage.

Sulfur hexafluoride (SF_6) was used as the tracer gas. It was released continuously in the outdoor air supply stream of each HVAC system and the release rates were adjusted until concentrations with a variation of 10% or less were achieved in the return air streams. A gas chromatograph equipped with an electron capture detector (Autotrac™, Lagus Applied Technologies) was used to measure concentrations on a real time basis at supply and return air streams of each HVAC system. Also, syringe samples were collected at all the locations where VOC and aldehyde samples were collected throughout the building. Four sets of syringe samples were collected: One set was collected when steady state conditions had been achieved in the building (10% or less variation) and before the tracer gas was turned off (i.e., before the start of the tracer gas decay) and three sets of syringe samples were collected during the decay of the tracer gas (i.e., after the tracer gas was turned off). Syringe samples were analyzed in the field immediately after completion of the VOC sampling at each building. Local tracer gas decay rates were determined based on the syringe samples collected during the tracer gas decay.

In order to compare measured outdoor airflow rates to the design rates, building outdoor airflow rates for each building and each sampling scenario were calculated based on the SF_6 release rates and median steady state concentrations of SF_6 in the return of the HVAC systems. In addition, the percentage of SF_6-derived outdoor airflow rates to the design rates was calculated.

During the 20-month study ventilation measurements were conducted by the CDHS team at each building on three separate occasions for a total of 16 scenarios (ventilation rates were not measured during the pre-occupancy tests of 4-30-03, 4-11-03, and 06-04-03 for Buildings 171, 173, and 174). In addition, building ventilation rates were not measured on 10-29-02 and 06-05-03 for Building 225 by the CDHS team, since the CDHS team and the consultant for the design builder were co-sampling for VOCs and aldehydes during those dates and the consultant also was conducting simultaneous tracer gas ventilation measurements . During the study, 5,764 tracer gas samples were collected at the AHUs via the automatic sampling feature of the Autotrac™. These samples included some overnight samples (collected in 4 of the 9 ventilation measurement occasions in Buildings 171, 172, and 225 as indicated in the footnotes of Tables B7 through B11), during which SF_6 was continuously injected in the HVAC systems overnight. Tracer gas was released overnight in the largest buildings (171 and 225) as well in the auditorium of Building 172 in certain sampling scenarios in order to ensure better mixing conditions prior to the measurements of ventilation taken the following day.

Finally, 640 manual syringe samples were collected and analyzed immediately after the conclusion of each sampling scenario. A median of 46 syringe samples were collected per building scenario (number of syringe samples per building sampling scenario: range 10 to 52, stdev: 10)

3.3 Quality Assurance

The quality assurance program for this study included the following features:

1. Flow rates on the samplers were calibrated prior to testing using a Primary Gas Flow Standard Calibrator (i.e. mini-Buck Calibrator®).
2. Start and stop times were recorded for each pump in the project notebook.
3. Tenax™ tube and pump serial numbers were recorded in the project notebook.
4. Sample media backgrounds: each Tenax™ tube was analyzed prior to field sampling to measure any background contaminants on the tube. For the aldehyde samplers, prior to sample extraction a blank, unexposed sampler was extracted and analyzed to determine the background contributed by the extraction solvent. Aldehyde samplers were stored in the manufacturer's packaging until sampling began.
5. Travel blanks: a travel blank, that is, an unexposed Tenax™ tube or aldehyde sampler traveled with the samplers to and from the field in order to measure any possible contamination due to travel conditions. The travel blanks briefly exposed at the start of sampling were analyzed with their respective set of samples.
6. Duplicate samples: starting with the October 2003 round, two sampling sites had duplicate aldehyde samplers. Every sampling site had duplicate Tenax™ samplers.
7. On two separate sampling occasions (10/29/02 and 6/5/02) side-by-side samples were collected in one building (225) with the IAQ consultant retained by the design/build team in order to ensure that data collected and analyzed by different teams were comparable. This gave the building managers and occupants more credibility to the data submitted by the design/build teams.
8. A minimum of two duplicate syringe samples for tracer gas analysis was collected at each building per sampling scenario.

As was mentioned in Items 6 and 8 above, duplicate samples were collected for all VOC samples and for selected aldehdye and tracer gas samples at each building. The Relative Percent Difference (RPD) between a measured sample value v1 and a duplicate or co-located sample value v2 is defined as follows:

$$\text{RPD} = \frac{Absolute\,|v1 - v2| \times 100\%}{Average(v1, v2)}$$

Where:
v1 = sample measured value
v2= duplicate or co-located sample measured value

The higher the RPD the further apart two duplicate or co-located measurements are.

Section 4. Results and Discussion

The results from a series of measurements conducted from 2002 through 2004 are presented here. The detailed analytical results for VOCs and aldehydes are included in Volume 2 of this report. The discussion of the results included in this report is based on summary tables presented in the Appendices of this Volume. The results of the following tests are discussed:

1. Building 171
    - 4-30-03: Pre-occupancy aldehyde concentrations. No ventilation measurements were conducted.
    - 10-15-03, 03-24-04, and 06-02-04: Post-occupancy #1, #2, and #3 concentrations of VOCs and aldehydes. Ventilation measurements conducted.

2. Building 172
    - 10-10-03: Pre-occupancy concentrations of VOCs and aldehydes. Ventilation measurements conducted with tracer gas.
    - 02-11-04, 03-30-04, and 06-08-04: Post-occupancy #1, #2, and #3 concentrations of VOCs and aldehydes. Ventilation measurements conducted.

3. Building 173
    - 4-11-03: Pre-occupancy concentrations of VOCs and aldehydes. No ventilation measurements were conducted.
    - 10-29-03, 03-03-04, and 04-27-04: Post-occupancy #1, #2, and #3 concentrations of VOCs and aldehydes. Ventilation measurements conducted.

4. Building 174
    - 06-04-03: Pre-occupancy concentrations of VOCs and aldehydes. No ventilation measurements were conducted.
    - 10-07-03, 02-04-04, and 04-21-04: Post-occupancy #1, #2, and #3 concentrations of VOCs and aldehydes. Ventilation measurements conducted.

5. Building 225
    - 02-26-02, 04-02-02, 06-25-02, and 06-28-02: Pre-occupancy #1 (before furniture), #2 (after furniture), #3 (1 week before occupancy), and #4 (3 days before occupancy) concentrations of VOCs and aldehydes. Ventilation measurements conducted. All data provided by Indoor Environmental Engineering with VOC and aldehyde analyses by Berkeley Analytical Associates..
    - 10-29-02 and 06-05-03: Post-occupancy #1 and #2. Concentrations of VOCs and aldehydes sampled side-by-side with Indoor Environmental Engineering. Ventilation measurements conducted by Indoor Environmental Engineering with VOC and aldehyde analysis by Berkeley Analytical Associates.
    - 10-23-03, 03-10-04, and 05-19-04: Post-occupancy #3, #4, and #5 concentrations of VOCs and aldehydes. Ventilation measurements conducted.

4.1 Ventilation Measurement Results

4.1.1 Discussion of Ventilation Measurements

Table B1 (Appendix B) shows the design data for all 5 buildings[9]. Tables B2 to B6 show the local air change rates for all locations and sampling scenarios for all 5 buildings based on the tracer gas decay method. Tables B7 to B11 show the SF_6 release rates and steady state concentrations right before the SF_6 release was stopped. Table 2 below shows the standard deviations of tracer gas local steady state concentrations just prior to the tracer gas being turned off. Standard deviations varied between 0.9 and 9.1 (only in 4 of the 15 total sampling scenarios the standard deviations were above 3.0) It is worth noting that during three sampling scenarios of the two large buildings (171 and 225) tracer gas was released in these buildings overnight starting the evening prior to the morning of the sampling. Despite the longer tracer gas release times, mixing as measured by the standard deviations of Table 2 was not affected.

Table 2. Standard Deviations of Local Steady State Tracer Gas Concentrations Prior to Decay

	171			172				173			174		225		
	10/15/03	3/24/04	6/2/04	10-10-03	2/11/04	3/30/04	6/8/04	10/29/03	3/3/04	4/27/04	2/4/04	4/21/04	10/23/03	3/10/04	5/19/04
N	8	10	10	9	11	11	11	12	12	12	11	12	10	10	9
Overnight tracer release		x	x												x
STDEV	5.1	4.8	9.1	2.8	2.0	2.8	2.4	0.9	1.1	0.9	1.9	1.1	2.8	6.0	4.1

Table 3 below summarizes the air change rates calculated based on the tracer gas decay and steady state methods as percent above or below design values. The data indicate that the air change rates in 3 of the 16 sampling scenarios when using the decay method and in 5 of the 15 sampling scenarios when using the steady state method were below the design airflows by 5 to 45%. It should be noted that the SF_6-derived outdoor airflow rates also include infiltration – the design outdoor airflow rates do not include infiltration.

[9] The designers for buildings 171-174 provided the minimum required ventilation rate by the California Title 24 (15 cfm per person) whereas, the designers of Building 225 provided 25 cfm per occupant. All five buildings met or exceeded the energy goals of the state for this project (30% better than the 1999 California Title 24), but Building 225 offered more innovative features such as underfloor air and lower ambient lighting supplemented by task lighting, thus enabling the designers to “trade” higher ventilation rates for better energy features elsewhere.

Using an arbitrary value of 20% as an estimate of field measurement errors, the number of local ach (measured with syringe samples during the decay of the tracer gas), which were 20% or more below each building's design rate, was calculated and is shown in Table B12. For the three smaller buildings (172, 173, and 174) the percent of locations below design varied between 0 and 3.4%. These percentages were much higher at the two large buildings (171 and 225). For Building 171 the total percentage was 45 and for Building 225 (Floors 2 through 6) it was 50% indicating that in the larger buildings there were more areas with ventilation rates below the design values.

Table 3. Percent of Tracer-Based Measured Air Change Rates of Building Median[10] (Decay Method) and Median AHU (Steady State Method) for All Buildings Above (indicated by "+") or Below (indicated by "-") Design

	171			172				173			174			225		
	10/15/03	**3/24/04**	**6/2/04**	**10/10/03**	**2/11/04**	**3/30/04**	**6/8/04**	**10/29/03**	**3/3/04**	**4/27/04**	**10/7/03**	**2/4/04**	**4/21/04**	**10/23/03**	**3/10/04**	**5/19/04**
Design ach	0.6			0.6				0.6			0.6			1.1		
% above/below design based on measured bldg median decay	0	0	-17	+50	+50	+83	+17	+100	+17	+50	+50	0	0	-18	+27	-45
% above/below design based on measured AHU median steady state	+8	-5	-13		+12	+36	+108	+53	-36	+8	+46	-19	+23	+53	+26	-17

4.1.2 Quality Assurance

During the study, 640 syringe samples were collected, 35 of which were duplicates (i.e., duplicate samples were collected in 6% of the cases). As shown in Table G3 (Appendix G), the median RPD was 0.5 (range 0 to 9.8, stdev: 2.2).

4.2 Volatile Organic Compound and Aldehyde Measurement Results

Volume 2 of this report lists the results for all the measurements conducted as described in Section 2.1 of this report. Target chemicals as discussed in Section 2.1 and listed on Table A1 that were below the quantitation limits for all locations per building for a particular sampling date

[10] Building median for the decay method is the median of the local and AHU return ACHs. Building median for the steady state method is the median of the ACHs derived from the AHU returns.

are not reported in these tables (the LOQ of each target chemical is shown in Table A1).

Given the large amount of data generated as a result of this study, the analyses and discussion are focused to specific questions of interest to the State and the USEPA. There are additional analyses that can be performed at a later time, but such additional analyses, although of great interest, fall outside the scope of this study and report.

In this study, eight building- and occupant-related chemicals were identified. The building-related chemicals are: acetaldehyde, caprolactam, formaldehyde, naphthalene, and nonanal. The occupant-related chemicals are: benzaldehyde, decamethylcyclopentasiloxane (d-5) and d-limonene. Table 4 summarizes the findings for these chemicals. The following sections are focused on one or more of these chemicals.

Table 4. Concentration Statistics for Building- and Occupant-Related Chemicals

	Median	Stdev	N	Min	Max
Acetaldehyde	6.7	2.7	265	0.5	18
Benzaldehyde	1.3	0.9	242	0.6	6.6
Caprolactam	5.3	4.7	248	0.9	38
Decamethylcyclopentasiloxane	24	25	241	1.1	140
d-Limonene	5.2	9.9	247	0.6	72
Formaldehyde	19	12	265	0.4	81
Naphthalene	0.5	1.2	248	0.0	17
Nonanal	4.2	4.8	257	1.0	29

4.2.1 Evaluation of Implementation of Section 1350 at the CAEEC

The Section 01350 testing protocol was used to evaluate and select most of the interior finishing materials and products. The list of chemicals in this protocol was also used to evaluate the quality of the indoor air after completion of construction and before occupancy and several times after occupancy.

Tables E1 through E5 (Appendix E) list summaries of concentration data of target chemicals for all 5 buildings per sampling scenario. In order to visualize how successfully the concentration criteria of Section 01350 were met, Table C1 (Appendix C) lists the number of locations that exceeded these criteria. As can be seen by Table C1, the concentration targets set forth by this project were met in the majority of the locations. Acetaldehyde and formaldehyde targets were not met in numerous locations of more than one building. These results are consistent with our previously published study on building material emissions[11].

[11] L. Alevantis. 2003. Building Material Emissions Study. California Department of Health Services. Final Report, submitted to the California Integrated Management Board through the Public Health Institute. Available at: http://www.ciwmb.ca.gov/greenbuilding/Specs/Section01350/METStudy.htm

4.2.2 Comparison of Measured Post-Occupancy Concentrations at the CAEEC to those Measured at the USEPA's BASE Study of 100 Occupied Buildings[12].

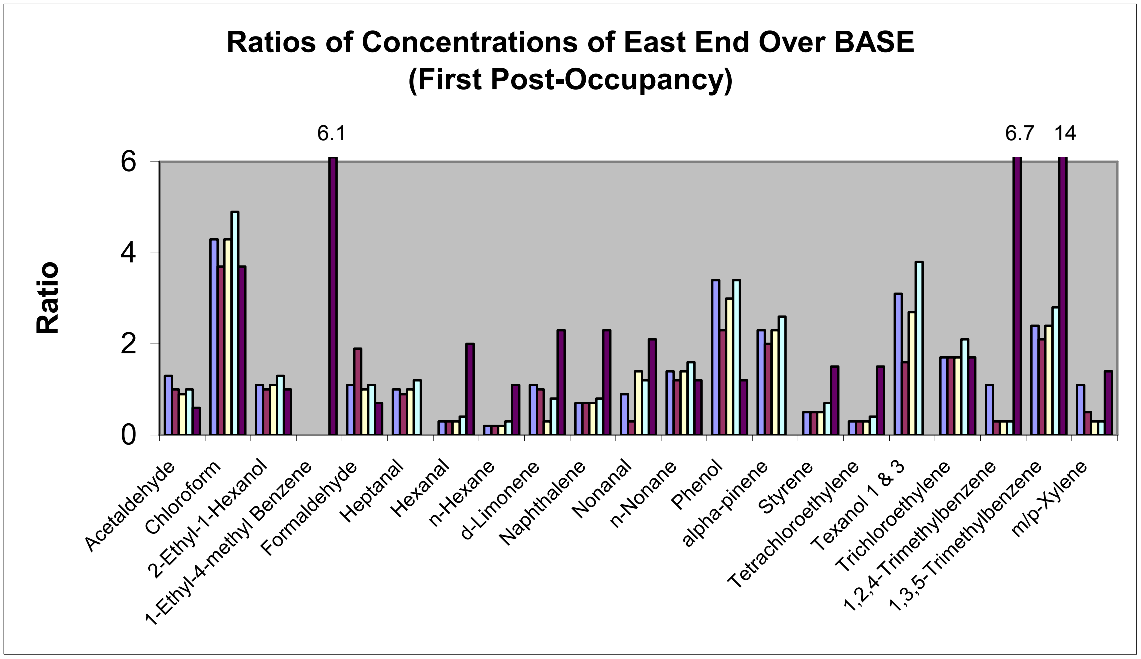
The BASE study was conducted under contract with the USEPA to collect extensive indoor air quality data from 100 randomly selected public and commercial office buildings in 37 cities in 25 States from mid to late 90s . The information collected provided baseline IAQ data and symptom incidence in randomly-selected office buildings without highly publicized indoor air quality issues, i.e., the study was designed to obtain normative data.

Comparisons between the CAEEC and BASE studies would have been most useful based on emission factors. However, the emission factors from the BASE study were not available, so the comparisons presented in this report are limited to actual measured concentrations from both studies without accounting for the ventilation rates. Since ventilation rates can differ substantially from building to building, the errors resulting from comparing only concentrations can be considerable (for example in the case of the CAEEC the ratios of the maximum to the minimum outdoor airflow rates was as high as 4.7). Higher ventilation rates result in lower concentrations and the opposite is true for lower ventilation rates.

It is also noted that the indoor VOCs present in the BASE buildings would generally be dominated by occupant-related chemicals because of the older age of these buildings, rather than building-related chemicals typically found during the first few months of occupancy of a new building such as the CAEEC.

There were 38 chemicals common to the CAEEC and the USEPA BASE studies (see Table A2 – Appendix A). Tables C3 and C4 (Appendix C) show summaries of comparisons of the CAEEC data to the BASE data for: (a) the first sampling scenarios at the CAEEC after occupancy; and (b) the last sampling scenarios at the CAEEC. Comparisons are based on the ratios of the 50 and 95 percentile concentrations for each of the two studies. It should be noted that the BASE study data used here were collected either by canister or on sorbents while all the CAEEC data were based on samples collected on sorbents. Furthermore, there were some significant differences between BASE VOC data from sorbents and from canisters. Figure 1 below shows the 50th percentile ratios for the first and last sampling after occupancy, respectively for all chemicals with concentration ratios of 1.0 and higher between the CAEEC and the BASE studies.

[12] http://www.epa.gov/iaq/base/base_publications.html



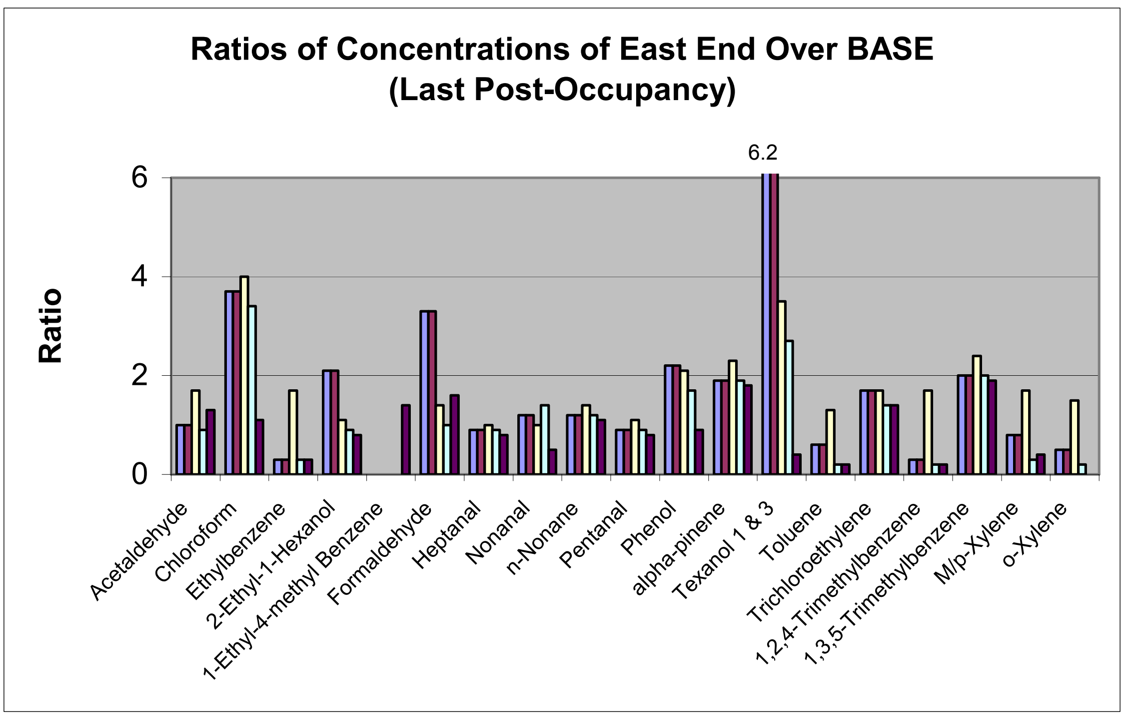


Figure 1. 50th Percentile Ratios of Median Concentrations of the CAEEC Over BASE for the First and Last Post-Occupancy Measurements of the CAEEC (ratios 1.0 >=0[13] shown)

[13] Due to the large number of chemicals common to the BASE and CAEEC studies (38 common chemicals) and the fact that a number of chemicals had ratios less than 1.0 in all buildings, only those chemicals with ratios 1.0 and above in one or more buildings are shown graphically. Some chemicals had ratios of 1.0 or higher in certain buildings and less than 1.0 in others; in these cases all the ratios (i.e., both above and below 1.0) for such chemicals are shown

Overall, concentrations of the common chemicals measured at the CAEEC were comparable to those reported in the BASE study with only few chemicals at the CAEEC being higher than the BASE study, indicating that careful selection of building materials provides indoor air concentrations of most chemicals comparable to existing buildings, thus reducing exposures to high levels of numerous chemicals usually associated with new buildings. This is particularly noteworthy since the CAEEC buildings were new when the VOC measurements were made and the BASE study buildings were not. Chemicals at the CAEEC with concentrations higher than twice those measured at the BASE study included chloroform, 1-ethyl-4-methyl benzene, phenol, alpha-pinene, texanol 1&3, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene. Below we discuss each of these chemicals:

1. Chloroform generally was below the reporting limit except for one site on one visit when it was actually quite high; it may have been a special cleaning event.
2. 1-ethyl-4-benzene, 1,2,4-trimethylbenzene, and 1,3,5-trimethylbenzene were all very high at one site (the childcare center at Building 225 where linoleum flooring was installed) and these concentrations probably skewed the averages.
3. a-pinene is related to cleaning and air freshening activities.
4. Phenol is used in numerous products.
5. Texanol 1 & 3 is found largely in paints and adhesives; it is emitted from painted surfaces for quite a while. We theorize that the higher concentrations of texanol at the CAEEC were due to the newness of the paint in these buildings as opposed to the buildings in the BASE study which were at least few years old.

4.2.3 Variation of Emission Factors Over time of Target Chemicals

One of the goals of this study was to measure the behavior of the building- and occupant-related chemicals over time. However, very few chemicals could be traced to a unique source – for most chemicals, it was extremely difficult to pinpoint their source(s).

Eight building- and occupant-related chemicals were identified. These are: (a) building-related chemicals: acetaldehyde, caprolactam, formaldehyde, naphthalene, and nonanal; and (b) occupant-related chemicals: benzaldehyde, d-5 and d-limonene. One building-related compound (caprolactam) and one occupant-related compound (d-5) were clearly emitted from identifiable unique sources and, therefore, analyses of pre- and post-occupancy variations were focused on these two compounds.

In order to illustrate the variation of the emission factors of some target chemicals over time, one location per building was selected (at middle level for Buildings 171-174; upper level for Building 225 since very early pre-occupancy, pre-and post-furniture data were collected at that location) and the emission factors of selected target chemicals were plotted in Figures F1 through F6 (Appendix F) for all the sampled dates.

It was anticipated that the building-related chemicals would decay with time, whereas, occupant related compounds would increase after occupants moved in.

In the case of the occupancy-related chemical d-5, a chemical used in personal care products, such as perfumes and deodorants, and in dry cleaning, 58 to 90-fold increases were observed between median pre- and post-occupancy emission factors (see Table D2 – Appendix D). Therefore there was a clearly identifiable increase in the emissions of this chemical.

In the case of the building-related chemical caprolactam, a chemical found in carpets and other Nylon 6 products, the expected decay in emission factors was observed in Building 225 (Figure F2 and Table D5 – Appendices F and D) – in the other four buildings since hallway carpeting was replaced shortly after occupancy, an increase in emission factors followed by a decrease was observed as expected. The emission factor in one building 7 months after the pre-occupancy sampling was 45% of the pre-occupancy emission factor and in another building this percentage was only 3% 27 months after the pre-occupancy sampling. As anticipated, there was a clear decrease in the emissions of this chemical

In the case of the predominantly building-related chemical formaldehyde, fluctuation in the emission factors was observed in all 5 buildings indicating variation in occupant-related activities and/or indoor chemistry byproducts. It also noted that emission factors of Buildings 225 and 172 were the highest of the 5 buildings. Since Buildings 172 and 225 had office furniture systems from the same manufacturer, it is likely that the increased formaldehyde levels were due to varying emissions from the panels that contained formaldehyde-emitting acoustical boards (since the indoor temperature and humidity levels of all 5 buildings were similar, formaldehyde differences attributable to these factors were eliminated). In contrast, Buildings 171, 173, and 174 where formaldehyde concentrations were lower, had office furniture systems from a different manufacturer.

Emission factors of acetaldehyde, d-limonene, and nonanal also fluctuated throughout the study (see Figures F1, F4, and F6 – Appendix F) indicating that with the exception of some signature chemicals as discussed above, accurate source determination is extremely difficult in occupied buildings. Emission factors of benzaldehyde and naphthalene were generally very low and therefore were not plotted. A major shortcoming of this study relative to its potential is the lack of data on cleaning and maintenance activities, and, possibly, touch up activities or the introduction of other building materials, furnishings, or finishes after the initial occupancy.

Given that the construction of all 5 buildings was fairly similar, the standard deviations of emission factors for the target chemicals were examined to see which ones had the highest values. In most locations the largest variation as measured by the standard deviation of calculated post-occupancy median emission factors was that of d-5 (see Table C2 – Appendix C). As anticipated, this indicates varying occupancies at the sampled locations and varying quantities of perfumes and other d5 sources. The next highest values were those of d-limonene, formaldehyde, and in few instances, caprolactam. The high standard deviation of d-limonene indicates varying cleaning activities with so-called “green” cleaning products. High standard deviations for caprolactam in certain sampling scenarios of Buildings 171, 172, 173, and 174 can be due to hallway carpet replacement during the early phases of post-occupancy. High standard deviations of emission factors for formaldehyde indicate that formaldehyde was present due to factors other than the building itself, since all sampled locations had similar building materials and furniture within the same building. Variation in formaldehyde emission factors can be associated with indoor air chemistry by-products generated by occupant activities such as cleaning.

4.2.4 Comparison of Calculated Emission Factors of a Building-Related Chemical (Caprolactam) Based on Measured Concentrations and Ventilation Rates to those Derived from Small Chamber Carpet Testing

One of the goals of this study was to determine the correlation between emissions of target chemicals in indoor environments and the emissions derived from small chamber tests. As was mentioned earlier, a major shortcoming of this study was the lack of data on cleaning and maintenance activities, and touch up or other introduction of building materials, furnishings, or finishes before and after the initial occupancy. In addition, the fact that there are multiple sources for most chemicals, makes it even more difficult to estimate the contribution of each source to the same chemical.

Therefore, the analysis was focused on one unique signature chemical that is emitted from Nylon 6 fibers. This chemical is caprolactam and it is unique to non-SBR latex backed carpeting. Caprolactam has also been detected in the fabric of panels of office systems furniture; however, testing of workstations submitted by the two manufacturers who supplied furniture to this complex, did not reveal presence of this chemical (at least not at sufficiently high concentrations to trigger its reporting as an abundant compound).

Since emission factors were calculated for each measured chemical in the indoor environment based on measured concentrations, local ventilation rates and building dimensions, these calculated emission factors were compared to those reported[14] by the laboratories that did small chamber testing of carpeting prior to its selection and installation.

Since concentration data and local ventilation data were available for only 2 of the 5 buildings, the analyses are focused on these two buildings (Buildings 172 and 225). Both builders used carpeting from the same manufacturer; however, in Building 225 carpet tiles were used throughout the building, whereas in the other 4 buildings, although broadloom was installed initially throughout these buildings, few months after occupancy the hallway carpeting was replaced with carpet tiles from the same manufacturer.

As can be seen from the Block 225 data below (Tables 5 and 6), the median pre-occupancy measured emission factor was about 1.5 times <u>higher</u> than the chamber-based emission factors. On the contrary, in the case of Building 172, the median pre-occupancy measured emission factor was about 2 times <u>lower</u> than the chamber-based emission factors. In both buildings, median post-occupancy emissions factors (25 months after occupancy for 225 and 8

---

[14] For each laboratory-analyzed sample an emission factor (EF) is calculated for each target compound at steady state conditions using the following equation:

$$EF = \frac{Q \bullet (C - C_o)}{A}$$

where:
EF = emission factor [$\mu g/m^2 \cdot h$]
Q = mini-chamber airflow rate [m^3/h]
C = mini-chamber concentration of the compound [$\mu g/m^3$]
Co = background mini-chamber concentration of the compound [$\mu g/m^3$]
A = exposed area of the material in the mini-chamber [m^2]

months after occupancy for 172) were several times lower than the chamber-based emission factors (20 times lower for 225 and 3 times lower for 172).

It is noted that the pre-occupancy testing at Building 225 was done shortly after carpeting was installed on the floor where air sampling occurred, whereas, pre-occupancy testing in Building 172 was done several months after construction was completed (approximately 6 to 8 months - it was the last building to be occupied).

Therefore, based on one chemical, measurements in two buildings, and chamber-based emission data for two carpets, emissions of this chemical shortly after carpet installation correlated to the chamber-derived emissions within a factor of 2. This chemical decays considerably several months after installation. This finding is consistent with existing literature, i.e., that the emissions of most chemicals decay exponentially with time. For most chemicals, the power law model can predict reasonably well the temporal emissions profile of a certain chemical. However, unpublished work related to the decay of caprolactam shows that the decay of this chemical does not follow the power law model (at least the first few weeks after manufacturing).

The rather large excursion found immediately prior to occupancy should be noted. This excursion may be attributable to carpet cleaning and the water solubility of the compound. Finally, it should be noted that emission factors decreased considerably between pre-occupancy and the last sampling scenario. In the case of Building 172, the caprolactam emission factor 7 months after the pre-occupancy sampling, was 45% of the pre-occupancy caprolactam emission factor. In the case of Building 225 with a considerably longer period (27 months) between the preoccupancy sampling and the last round of sampling, the emission factor was three percent of the pre-occupancy value.

Table 5. Small Chamber Carpet Emission Factors

Building #	Emission Factors as Reported by Testing Laboratory
171-174	Carpet (broadloom?) only: 61 μg/m^2-hr (10 days conditioning followed by 96 hr testing)
	Carpet assembly (broadloom type "0" and adhesive on stainless steel tray): 83 μg/m^2-hr (5 days of conditioning followed by 48 hrs of testing)
	Carpet assembly (broadloom type "2" and adhesive on stainless steel tray): 77 μg/m^2-hr (5 days of conditioning followed by 48 hrs of testing)
	Carpet assembly (broadloom type "9" and adhesive on stainless steel tray): 94 μg/m^2-hr (5 days of conditioning followed by 48 hrs of testing)
	Carpet assembly (broadloom ? and adhesive on stainless steel tray): 83 μg/m^2-hr (5 days of conditioning followed by 48 hrs of testing)
225	Carpet tile only: 88.3 μg/m^2-hr (10 days conditioning followed by 96 hr testing)
	Carpet assembly (tile and adhesive on stainless steel tray): 73 μg/m^2-hr (5 days of conditioning followed by 48 hrs of testing)

Table 6. Pre- and Post-Occupancy Emission Factors (µg/m²-hr) in the Indoor Environment		
Building #	**Pre-Occupancy**	**Last Post-Occupancy**
172	10/10/03	6/8/04
	Median 46 µg/m²-hr (range: 7 to 110, Stdev=32) (N= 9 indoor locations sampled)	Median 21 µg/m²-hr (range: 0 to 34, Stdev=9.7) (N= 14 indoor locations sampled)
225	2/26/02	5/19/04
	Median 120 µg/m²-hr (range: 96 to 140, Stdev=34) (N=2 both on the 6th floor)	Median 3.6 µg/m²-hr (range: 0 to 7, Stdev=2.7) (N=6)

4.2.5 Comparison of Measured Concentrations of an Occupant-Related Chemical [Decamethylcyclopentasiloxane (d-5)] to those Reported by Weschler et al[15,16,17].

D-5 is an odorless, colorless liquid used as an ingredient in a number of personal health and beauty products, such as deodorants, antiperspirants, cosmetics, shampoos, and body lotions. It is also used as a dry cleaning solvent and in industrial cleaning[18]. Weschler et al also note that d-5 is a byproduct in certain silicone-based caulks and lubricants but that personal care products is the dominant source of this chemical in the 70 buildings they studied. D-5 has been used as a marker of occupancy. In the past, health effects of this chemical have not been considered since it is a fairly unreactive compound. However, more recently, the USEPA has indicated that cancer studies on d-5 "indicate that there may be a cancer hazard associated with D5". At this point a risk assessment has not been conducted and the USEPA "is not in a position to characterize potential health risks to human health".

On a separate, non-published extensive literature review conducted by the California Office of Environmental Health Hazard Assessment (OEHHA) for establishing a chronic reference exposure limit (CREL) for d-5 (chronic REL is a level at or below which adverse noncancer health effects would not be expected to occur in even sensitive populations) a concentration of 700 $\mu g/m^3$ was suggested.

Tables 7 and 8 below summarize all the d-5 data collected over the 20 month CAEEC study. Pre-occupancy concentrations were very low (median 1.3 to 1.7, stdev 0 to 1.9) but increased considerably after occupancy (median 14 to 34, stdev 18 to 32). Concentrations as high as 140 µg/m³ were measured. The concentrations measured in the CAEEC study were comparable to those reported by Weshcler et al[19]. The highest concentrations measured were

[15] Weschler, C. J., H. C. Shields, and D. Rainer, Concentrations of volatile organic compounds at a building with health and comfort complaints, Am. Ind. Hyg. Assoc. J., 51, 261-268, 1990.
[16] Shields, H. C. and C. J. Weschler, Volatile organic compounds measured at a telephone switching center from 5/30/85 - 12/6/88: A detailed case study, J. Air Waste Manage. Assoc., 42, 792-804, 1992
[17] Shields, H. C., D. M. Fleischer, and C. J. Weschler, Comparisons among VOCs measured in three types of U.S. commercial buildings with different occupant densities, Indoor Air, 6, 2-17, 1996
[18] US EPA, Siloxane D5 in Drycleaning Applications: Fact Sheet. Office of Pollution Prevention and Toxics. December 2005.
[19] Weschler et al reported the following indoor d-5 concentrations in the 3 articles cited earlier:

1. Complaint building with low air exchange and high occupant density -- less than 6 L/s/occupant

well below any existing or proposed health guidelines. The contribution of sources other than occupants themselves to d-5 concentrations appear to be insignificant based on measured pre-occupancy concentrations.

Emission factors could only be calculated for one preoccupancy sampling (Building 172) where the median value was zero (pre-occupancy concentrations for d-5 were not reported in the consultant's reports because it was below detection). It should be noted that pre-occupancy concentrations of d-5 were of the same order of magnitude for Buildings 173 and 174 as for 172. After occupancy, median emission factors were between 58 and 90. Therefore, d-5 is an excellent unique indicator of occupancy.

Table 7. Median d-5 Concentrations

Building	Pre-Occupancy						Post Occupancy (all samples)					
	Median	Min	Max	95%	N	Stdev	Median	Min	Max	95%	N	Stdev
	(μg/m³)						(μg/m³)					
171							35	8.9	93	83	40	20
172	1.5	1.5	4.3	2.8	12	0.8	27	4.9	140	120	42	32
173	1.7	1.3	7.6	5.3	9	2.0	29	3.5	81	76	42	19
174	1.3	1.2	1.3	1.3	13	0	29	1.3	130	79	39	27
225							18	1.1	90	62	44	18

Table 8. Median d-5 Emission Factors

Building	Pre-Occupancy						Post Occupancy (all samples)					
	Median	Min	Max	95%	N	Stdev	Median	Min	Max	95%	N	Stdev
	(μg/m²-hr)						(μg/m²-hr)					
171							76	19	240	176	40	46
172	0	0	13	5.7	12	3.7	90	14	710	270	42	130
173							86	20	220	210	41	58
174							58	0	300	190	38	62
225							65	0.0	530	210	43	95

---

28 μg/m³ -- Building 2, 4th floor
79 μg/m³ -- Building 3, 1st floor
34 μg/m³ -- building exhaust

2. Well-ventilated telephone switching office. The highest level was measured during a period of renovation on the 1st floor when there were many people doing the various tasks.
0.8 to 14 μg/m³
3. 7.0 μg/m³ -- geometric mean of 50 switching offices, low occupant density (geometric standard deviation: 2.8)
4. 26.1 μg/m³ -- geometric mean of 9 data center, medium occupant density, low air exchange rates (geometric standard deviation: 2.4)
5. 39.6 μg/m³ -- geometric mean of 11 administrative offices, high occupant density, moderate air exchange rates (geometric standard deviation: 2.4) (there were 4 facilities with concentrations greater than 100 μg/m³ and one administrative office with a concentration greater than 200 μg/m³.

4.2.6 Analytical Procedure Variations (inter and intra laboratory)

As was described in Section 3.3 under this study's quality assurance program, duplicate samples were collected during all scenarios and, in addition, side-by-side samples were collected in one building with the IAQ consultant retained by one of the two design/build teams. Below are the results of these analyses.

4.2.6.1 Inter-Laboratory Variations

As was noted in Sections 3.3 and 4.2 all sampling sites had duplicate Tenax™ samplers and starting with the October 2003 round, two sampling sites per building had duplicate DNPH samplers (270 Tenax™ samplers, 270 duplicate Tenax™ samplers, 270 DNPH samplers, and 30 duplicate DNPH samplers).

Median RPD for all 105 chemicals was 0 (15,365 observations, stdev: 18, range: 0-200). It is noted that a large number of duplicates with high RPDs was due to the fact that for those duplicates the measured concentrations were close to the limit of quantitation (LOQ) and as a result in numerous cases one sample was below the LOQ (in which case ½ of the LOQ was used) and its duplicate sample in most cases was slightly higher than the LOQ, and therefore the RPD was unrealistically high in these cases. Further analyses of the RPDs is planned.

Table G1 (appendix G) lists the median RPDs of those chemicals with values greater than 0. Median RPDs of individual chemicals ranged from 0 to 13. Choosing an arbitrary RPD of 20 to account for analytical laboratory variations, the percentage of observations with a median RPD of 20 or higher was 8.7 (see summary Table 9 below - of the 15,365 observations, 1339 had RPDs of 20 or more).

Table 9. Duplicate Observations with RPD>20

Chemical	N	%
2-Butoxyethanol	51	21
Butyraldehyde	7	23
Propionaldehyde	8	27
Caprolactam	50	20
d-Limonene	52	21
Texanol 1 & 3	64	27
m/p-Xylene	69	28
Decamethylcyclopentasiloxane	59	24
3-Methyl Butanal	5	38
Toluene	72	29
Nonanal	103	42

4.2.6.2 Intra-Laboratory Variations

On two separate sampling occasions (10/29/02 and 6/5/02) side-by-side samples were collected in one building with the IAQ consultant retained by the construction company. The RPDs for the 8 target chemicals are presented in Table G2 (Appendix G). Median RPDs of individual chemicals ranged from 24 to 160 (individual RPDs ranged from 0 to 160).

The variation presented above (both intra and inter laboratory) need to be accounted for: (a) when air sampling in buildings is conducted to determine whether or not to occupy a building based on specific concentration targets, or (b) in the case of low-emitting building material certification programs. Since such variations do exist, it is critical that duplicate samples are collected always and that both samples are analyzed. When RPDs exceed the laboratory's pre-determined number, such as 20%, both samples should be discarded. Caution should be exercised when the concentrations sampled are close to the RPDs. In such case, unrealistically high RPDs may result.

4.2.7 Comparison of the Occupant Survey Results for Blocks 225 and 172 with the Measured VOC and Aldehyde Concentrations

One of the goals of this study was to compare our findings to those reported by a different research group conducting occupant surveys in two of the five buildings. Since the final report of this research study has not been issued yet, only the background, study design, and preliminary findings of this study are discussed.

4.2.7.1 Background

As was noted earlier, the CAEEC was the first sustainable office building complex that the State of California ever built. One of the five buildings (225) was designed with an underfloor air distribution system (UFAD) (except the first floor). Given that the requirement of the State for all 5 buildings was to exceed the State's energy code by 30%, the additional energy savings offered by the UFAD alone could not justify for its installation. When the designers and consultants looked into the "soft savings" of this ventilation system, such as occupant comfort and savings resulting from being able to reconfigure the floor space for changing occupant needs (referred to as "churn"), very little information existed in the literature to justify the additional cost of installing the UFAD. The State's Department of Finance agreed to approve this expenditure with the requirement that the State conduct a study to compare the performance of Building 225 to one of the other four buildings that had conventional overhead air distribution system (Building 172). The results of this study were to be used to determine whether the State of California would build more buildings with the UFAD.

As a result the CBE was commissioned by the State of California to compare both the positive and negative impacts of the UFAD versus the overhead air distribution system for a range of building performance metrics, including:

1. Energy use
2. Indoor environmental quality
3. Occupant satisfaction, comfort, and productivity
4. First cost
5. Operating/churn/life-cycle costs

4.2.7.2 Study Design

A web-based questionnaire was administered shortly before the occupants of Buildings 225 and 172 moved from the former buildings. Limited environmental measurements were taken (i.e., temperature and humidity). The web-based questionnaire was repeated approximately 6 months after the occupants moved into the new buildings.

A number of complications and roadblocks occurred that has resulted in delaying issuing the final report of this study. Some of these complications include:

1. Buildings 225 and 172 were going to be occupied by the same State department (Department of Education). This would have made it easier to compare 225 to the control building since similar functions would have been performed at both buildings. However, at the last minute, the Department of Education decided not to occupy Building 172. This caused a delay of about one year. In the end, the State department occupying the other three buildings (Department of Health Services) also occupied Building 172.
2. A number of balancing issues with Building 225's UFAD further delayed getting accurate post-occupancy data.
3. Finally, collection of energy data required installation of additional monitoring equipment.

4.2.7.3 Preliminary Findings

The occupants of Building 225 with the UFAD were more satisfied with the air quality, temperature, and air movement of their new building than with their previous one. This is an interesting finding given that formaldehyde levels in 225 were higher than in 171, 173, and 174. Similarly, the occupants of 172 were satisfied with their building despite the fact that 172 had higher formaldehyde concentrations compared to the other four buildings.

Further analyses of the CBE and VOC/aldehdye/ventilation measurement data are anticipated in the future. CBE's final report is anticipated in December 2006.

Section 5. Conclusions and Lessons Learned

5.1 Conclusions

1. This study has shown that requiring emissions testing from manufacturers appears to have helped achieve better than average indoor air quality at the CAEEC. The concentration targets established for this project were not exceeded in the majority of the locations. Concentrations of the common chemicals measured at the CAEEC were comparable to those reported in the BASE study with only few chemicals at the CAEEC being higher than the BASE study. Therefore, as expected, careful selection of building materials during a building's design appears to result in lower concentrations of VOCs during the initial months of a newly-constructed building. However, comparisons of concentrations without normalizing for building age and ventilation rates provide only limited information.

2. One of the goals of this study was to measure the behavior of the building- and occupant-related chemicals over time. While this was accomplished, very few chemicals could be traced to a unique source – for most chemicals, it was extremely difficult to pinpoint their source(s) since few chemicals have clearly unique sources.

   Only one building-related compound (caprolactam) and one occupant-related compound (d-5) studied were clearly identifiable from unique sources. In the case of caprolactam, there was a distinct decrease over time in its emissions, and in the case of d-5, there was a clear increase over time in its emissions. Emission factors of some of the other target chemicals (i.e., acetaldehyde, benzaldehyde, naphthalene, d-limonene, and nonanal) fluctuated throughout the study. Therefore, temporal changes of emission factors of building- and occupant- related chemical sources do occur as expected but the rate of change can vary greatly across buildings, even for the same chemical.

   Post-occupancy local emission factors of some of the target chemicals were fairly uniform within each building, whereas, others differed substantially from building median values. Chemicals with highly variable local emission factors were: d-5, d-limonene, caprolactam (in certain sampling occasions), and formaldehyde. In the case of caprolactam the variations in 4 buildings (171-174) are explained by hallway carpet replacement during the early phases of post-occupancy. However, the variations in the emission factors for formaldehyde indicate locally higher levels of this chemical possibly due indoor air chemistry by-products generated from occupant activities such as cleaning. Therefore, concentrations of occupant-related chemicals are more likely to show high variations within the same building than building-related chemicals that tend to be more uniformly mixed within a building.

3. One of the goals of this study was to determine the correlation between emissions of target chemicals in indoor environments and the emission data from small chamber tests. This correlation analysis was done for one chemical (caprolactam) and it was found that emissions of this chemical in the indoor environment correlated to the chamber-derived emissions within a factor of 2. Therefore, estimating air concentrations of a chemical with a unique identifiable source based on chamber-derived emission factors may only give a rough approximation of indoor concentration shortly after the

source is installed (Section 01350 calculations are based on a 14-day post-installation timeframe). Since there are multiple sources for most chemicals, it is very difficult to estimate the contribution of each source to the concentrations of the same chemical.

5.2 Lessons Learned

1. A major shortcoming of this study relative to its potential was the lack of data on cleaning and maintenance activities, and, possibly, touch up or other introduction of building materials, furnishings, or finishes after the initial occupancy. Collection of emissions data from cleaning and maintenance products was beyond the scope of this study, but it would likely have been very useful to have had collected these data. In regards to touch up activities and the introduction of new building materials and/or furnishings, given that there are lot of these activities taking place just prior to building occupancy, it is very difficult to collect accurate information on this issue.

2. Reliance on a building's ventilation system to replicate air change rates from one sampling session to the next under the same settings of the outdoor air controls may lead to incorrect assumptions and, therefore, inaccurate results. Therefore, it is critical to measure ventilation rates concurrently with contaminant measurements in order to be able to interpret the measured concentrations.

3. Emissions testing of building material samples by their manufacturer does not necessarily guarantee that materials of similar chemical profile would be delivered and installed in a building. Therefore, third-party certification programs with random samplings or other verification procedures are needed.

4. Accurate characterization of indoor air chemical concentrations requires numerous samples and ventilation measurements at several locations over an extended period of time. Many variables need to be considered and controlled in the building, or accounted for in the data analyses.

5. Analytical procedure and ventilation rate variations need to be accounted for, especially in low-emitting building material certification programs or when air sampling in buildings is conducted to determine whether concentrations targets have been met. It is important that duplicate samples are collected in each location and that samples exceeding a pre-determined variability be discarded. It is also important to relate concentration targets to a specific outdoor air ventilation rate or design value.

APPENDIX A - LIST OF TARGET CHEMICALS

Table A1. List of Target Chemicals

	Compound Name	CAS Number	MW	Calibration	LOQ (µg/m³)	Aldehyde-DNPH Analysis	CREL (µg/m³)	ARB (TAC) listed	Prop. 65 listed	Odor Threshold (µg/m³)	Other Limits (µg/m³)
1	Acetaldehyde	75-07-0	44.1	Yes	11		9	Yes	Yes	340	
2	Acetic Acid	64-19-7	60.1	No	3			No	No	360	
3	Acetone	67-64-1	58.1	Yes	13	Yes		No	No	> 1000	
4	Acetophenone	98-86-2	120.2	No	2			Yes	No	> 1000	
5	Benzaldehyde	100-52-7	106.1	Yes[20]	3	Yes		No	No	190	
6	Benzene	71-43-2	78.1	Yes	2		60	Yes	Yes	> 1000	
7	Benzoic Acid	65-85-0	122.1	No	3			No	No	N/A	
8	Butanoic Acid	107-92-6	88.1	No	3			No	No	14	
9	2-Butoxyethanol	111-76-2	118.2	Yes[21]	2			Yes	No	> 1000	20[22]
10	2-(2-Butoxyethoxy)-ethanol	112-34-5	162.3	Yes	3			Yes	No	N/A	
11	1-Butoxy-2-Propanol	5131-66-8	132.2	No	3			No	No	N/A	
12	n-Butyl Acetate	123-86-4	116.2	No	3			No	No	930	
13	Butylated Hydroxytoluene	128-37-0	220.4	No	3			No	No	N/A	
14	n-Butyl-1-butanamine	111-92-2	129.2	No	3			No	No	N/A	
15	Butylcyclohexane	1678-93-9	140.3	Yes	3			No	No	N/A	
16	Butyraldehyde	123-73-9	72.1	Yes	13	Yes		No	No	28	
17	Caprolactam	105-60-2	113.2	Yes	3			Yes	No	N/A	100[23]
18	Chloroform	67-66-3	119.4	Yes	3		300	Yes	Yes	> 1000	

[20] Benzaldehyde was added in October 2003.
[21] 2-Butoxyethanol was added October 2003.
[22] CREL is 20μg/m^3 from the TAC list (www.arb.ca.gov/toxics/tac/factshts/glycleth.pdf).
[23] Interim State of California concentration limit is 100 μg/m^3

Table A1. List of Target Chemicals

	Compound Name	CAS Number	MW	Calibration	LOQ (µg/m^3)	Aldehyde-DNPH Analysis	CREL (µg/m^3)	ARB (TAC) listed	Prop. 65 listed	Odor Threshold (µg/m^3)	Other Limits (µg/m^3)
19	Cumene	98-82-8	120.2	Yes[24]	2			Yes	No	120	
20	Cyclohexane	110-82-7	84.2	No	3			Yes	No	> 1000	
21	Cyclohexanone	108-94-1	98.2	Yes	3	Yes		No	No	> 1000	
22	Decamethylcyclopentasiloxane	541-02-6	370.8	Yes[25]	3			No	No	N/A	
23	Decanal	112-31-2	156.3	Yes[26]	3	Yes		No	No	5.9	
24	n-Decane	124-18-5	142.3	Yes	3			No	No	> 1000	
25	1,4-Dichlorobenzene	106-46-7	147.01	No	2		800	No	No	300	
26	cis-1,3-Dimethylcyclopentane	2532-58-3	98.2	No	3			No	No	N/A	
27	trans-1,3-Dimethylcyclopentane	1759-58-6	98.2	No	3			No	No	N/A	
28	2,3-Dimethylpentane	565-59-3	100.2	No	3			No	No	N/A	
29	1,4-Dioxane	123-91-1	88.12	Yes[27]	2		3000	Yes	Yes	> 1000	
30	n-Dodecane	112-40-3	170.3	No	3			No	No	> 1000	
31	2-Ethoxyethanol	110-80-5	90.1	Yes	2		70	Yes	Yes	> 1000	
32	2-(2-Ethoxyethoxy) Ethanol	111-90-0	134.2	No	3			Yes	No	N/A	
33	2-Ethoxyethyl acetate	111-15-9	132.2	Yes	2		300	Yes	Yes	1000	
34	Ethyl Acetate	141-78-6	88.1	No	3			No	No	> 1000	
35	Ethylbenzene	100-41-4	106.2	Yes	2		2000	Yes	Yes	13	
36	Ethylcyclopentane	1640-89-7	98.2	No	3			No	No	N/A	
37	Ethylene Glycol	107-21-1	62.1	Yes	17		400	Yes	No	N/A	
38	Ethyl-3-ethoxypropionate	763-69-9	146.2	No	3			No	No	N/A	
39	2-Ethyl-1-Hexanoic Acid	149-57-5	144.2	Yes	3			No	No	N/A	

[24] Cumene or Isopropylbenzene was added October 2003.
[25] Decamethylcyclopentasiloxane was added June 2004.
[26] Decanal was added in October 2003.
[27] 1,4-Dioxane was added October 2003.

Table A1. List of Target Chemicals

	Compound Name	CAS Number	MW	Calibration	LOQ (µg/m³)	Aldehyde-DNPH Analysis	CREL (µg/m³)	ARB (TAC) listed	Prop. 65 listed	Odor Threshold (µg/m³)	Other Limits (µg/m³)
40	2-Ethyl-1-Hexanol	104-76-7	130.2	Yes	3			No	No	> 1000	
41	1-Ethyl-2-methylbenzene	611-14-3	120.2	No	3			No	No	N/A	
42	1-Ethyl-3-methylbenzene	620-14-4	120.2	No	3			No	No	N/A	
43	1-Ethyl-4-methylbenzene	622-96-8	120.2	No	3			No	No	N/A	
44	Formaldehyde	50-00-0	30.0	Yes	11	Yes	33	Yes	Yes	> 1000	
45	Heptadecane	629-78-7	240.5	No	3			No	No	N/A	
46	Heptanal	111-71-7	114.2	Yes[28]	3	Yes		No	No	23	
47	n-Heptane	142-82-5	100.2	Yes	3			No	No	> 1000	
48	Hexadecane	544-76-3	226.4	No	3			No	No	N/A	
49	Hexamethylcyclotrisiloxane	541-05-9	222.5	No	3			No	No	N/A	
50	Hexanal[29]	66-25-1	100.2	Yes	3			No	No	58	
51	n-Hexane	110-54-3	86.2	Yes	2		7000	Yes	No	> 1000	
52	Hexanoic Acid	142-62-1	116.2	No	3			No	No	60	
53	Indane	496-11-7	118.2	No	3			No	No	N/A	
54	Isopropanol	67-63-0	60.1	Yes	2		7000	Yes	No	> 1000	
55	δ-Limonene	5989-27-5	136.2	Yes[30]	3			No	No	> 1000	
56	Longifolene	475-20-7	204.4	No	3			No	No	N/A	
57	Menthol	89-78-1	156.3	No	3			No	No	270	
58	2-Methoxyethanol	109-86-4	76.1	Yes	5		60	Yes	Yes	> 1000	
59	1-Methoxy-2-Propanol	107-98-2	90.1	No	3			No	No	N/A	
60	m-Methylacetophenone	585-74-0	134.2	No	3			No	No	37	
61	3-Methyl Butanal	590-86-3	86.1	No	3			No	No	8.1	

[28] Heptanal was added in October 2003.
[29] Hexanal was added in October 2003.
[30] δ-Limonene was added February 2004.

Table A1. List of Target Chemicals

	Compound Name	CAS Number	MW	Calibration	LOQ (µg/m³)	Aldehyde-DNPH Analysis	CREL (µg/m³)	ARB (TAC) listed	Prop. 65 listed	Odor Threshold (µg/m³)	Other Limits (µg/m³)
62	3-Methyl-1-butyl acetate	123-92-2	130.2	No	3			No	No	N/A	
63	Methylcyclohexane	108-87-2	98.2	Yes	3			No	No	N/A	
64	Methylene Chloride	75-09-2	84.9	Yes	3		400	Yes	Yes	> 1000	
65	2-Methylhexane	591-76-4	100.2	No	3			No	No	N/A	
66	3-Methylhexane	589-34-4	100.2	No	3			No	No	N/A	
67	6-Methyl-5-hepten-2-one	110-93-0	126.2	No	3			No	No	200	
68	Methyl Isobutyl Ketone	108-10-1	100.2	Yes[31]	2			Yes	No	> 1000	
69	Methyl Methacrylate	80-62-6	100.1	No	3			Yes	No	> 1000	
70	1-Methyl-2-Pyrrolidinone	872-50-4	99.1	Yes	2			No	Yes	N/A	
71	β-Myrcene	123-35-3	136.2	No	3			No	No	N/A	
72	Naphthalene	91-20-3	128.2	Yes	2		9	Yes	Yes	79	
73	N,N-Dibutyl Formamide	761-65-9	157.3	No	3			No	No	N/A	
74	Nonanal	124-19-6	142.2	Yes[32]	3	Yes		No	No	13	
75	n-Nonane	111-84-2	128.3	Yes	3			No	No	> 1000	
76	Nonanoic Acid	112-05-0	158.2	No	3			No	No	13	
77	Octamethylcyclotetrasiloxane	556-67-2	296.6	No	3			No	No	N/A	
78	Octanal	124-13-0	128.2	Yes[33]	3	Yes		No	No	7.2	
79	n-Octane	111-65-9	114.2	Yes[34]	3			No	No	> 1000	
80	Octanoic Acid	124-07-2	144.2	No	3			No	No	23	
81	Pentadecane	629-62-9	212.4	No	3			No	No	N/A	
82	Pentanal	110-62-3	86.1	Yes[35]	3	Yes		No	No	22	

[31] Methyl Isobutyl Ketone was added October 2003.
[32] Nonanal was added in October 2003.
[33] Octanal was added in March 2004.
[34] n-Octane was added in March 2004.
[35] Pentanal was added in March 2004.

Table A1. List of Target Chemicals

	Compound Name	CAS Number	MW	Calibration	LOQ (µg/m³)	Aldehyde-DNPH Analysis	CREL (µg/m³)	ARB (TAC) listed	Prop. 65 listed	Odor Threshold (µg/m³)	Other Limits (µg/m³)
83	2,4-Pentanedione	123-54-6	100.1	No	3			No	No	N/A	
84	Pentanoic Acid	109-52-4	102.1	No	3			No	No	20	
85	Phenol	108-95-2	94.1	Yes	2		200	Yes	No	430	
86	α-Pinene	80-56-8	136.2	Yes[36]	3			No	No	> 1000	
87	β-Pinene	127-91-3	136.2	Yes[37]	3			No	No	N/A	
88	Piperidine	110-89-4	85.1	No	3			No	No	> 1000	
89	1-Piperidinecarboxaldehyde	2591-86-8	113.2	No	3			No	No	N/A	
90	Propionaldehyde	123-38-6	58.1	Yes	13	Yes		Yes	No	65	
91	2-Propoxyethanol	2807-30-9	104.2	No	3			Yes	No	N/A	
92	1-Propoxy-2-Propanol	1569-01-3	118.2	No	3			No	No	N/A	
93	Propylbenzene	103-65-1	120.2	No	3			No	No	N/A	
94	Propylene Glycol	57-55-6	76.1	No	3			No	No	N/A	
95	Styrene	100-42-5	104.2	Yes	2		900	Yes	No	630	
96	Tetrachloroethylene	127-18-4	165.8	Yes	2		35	Yes	Yes	> 1000	
97	Tetradecane	629-59-4	198.4	No	3			No	No	N/A	
98	Texanol 1 & 3	25265-77-4	216.3	Yes[38]	3			No	No	N/A	
99	Toluene	108-88-3	92.1	Yes	2		300	Yes	Yes	> 1000	
100	1,1,1-Trichloroethane	71-55-6	133.4	Yes	2		1000	Yes	No	> 1000	
101	Trichloroethylene	79-01-6	131.4	Yes	2		600	Yes	Yes	> 1000	
102	Tridecane	629-50-5	184.4	No	3			No	No	N/A	
103	1,2,3-Trimethylbenzene	526-73-8	120.2	Yes[39]	3			No	No	N/A	

[36] α-Pinene was added October 2003.
[37] β-Pinene was added October 2003.
[38] Texanol 1 & 3, also known as 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate, was added October 2003.
[39] 1,2,3-trimethylbenzene was added March 2004.

Table A1. List of Target Chemicals

	Compound Name	CAS Number	MW	Calibration	LOQ ($\mu g/m^3$)	Aldehyde-DNPH Analysis	CREL ($\mu g/m^3$)	ARB (TAC) listed	Prop. 65 listed	Odor Threshold ($\mu g/m^3$)	Other Limits ($\mu g/m^3$)
104	1,2,4-Trimethylbenzene	95-63-6	120.2	Yes[40]	3			Yes	Yes	780	
105	1,3,5-Trimethylbenzene	108-67-8	120.2	Yes	3			No	No	> 1000	
106	TVOC as Chlorobenzene-d5	n/a						No	No	N/A	
107	TVOC as Toluene	n/a						No	No	N/A	
108	n-Undecane	1120-21-4	156.3	Yes	3			No	No	> 1000	
109	m/p-Xylene	108-38-3/ 106-42-3	106.2	Yes	2		700	Yes	No	> 1000	
110	o-Xylene	95-47-6	106.2	Yes	2		700	Yes	No	> 1000	

[40] 1,2,4-trimethylbenzene was added October 2003.

Table A2. List of VOCs Common to Both the CAEEC and USEPA's BASE Studies With Results For The BASE Study

Index from Table A1	Compound Name	CAS Number	Median LOQ	Site Frequency Detected (%)	Building Frequency Detected (%)	50	95	AM	ASD	GSD	GSD
1	Acetaldehyde	75-07-0	0.49	100	100	7.2	15	7.8	4	6.7	1.8
3	Acetone	67-64-1	1.73	100	100	30	110	42	32	33	2
6	Benzene	71-43-2	0.35	100	100	3.6	9.1	4.2	2.8	3.5	1.9
9	2-Butoxyethanol	111-76-2	0.66	93	98	5.5	68	12	20	4.9	4
12	n-Butyl Acetate	123-86-4	0.35	92	94	1.5	10	3.1	6	1.5	3.1
13	Butylated Hydroxytoluene	128-37-0	0.33	0	0	0	0	0.17	0	0.17	1
18	Chloroform	67-66-3	0.70	18	29	0.35	1.3	0.59	1	0.44	1.8
24	n-Decane	124-18-5	0.35	99	100	2.9	24	6.3	8.6	3.5	2.8
25	1,4-Dichlorobenzene	106-46-7	0.35	69	77	0.54	13	2.8	8.3	0.7	4.1
30	Dodecane	112-40-3	0.53	99	100	3.5	14	5.4	7.1	3.6	2.3
34	Ethyl Acetate	141-78-6	0.35	96	100	2	7.5	3.7	7.5	2	2.7
35	Ethylbenzene	100-41-4	0.35	99	100	1.5	6.2	2.4	3	1.7	2.3

Table A2. List of VOCs Common to Both the CAEEC and USEPA's BASE Studies With Results For The BASE Study

Index from Table A1	Compound Name	CAS Number	Median LOQ	Site Frequency Detected (%)	Building Frequency Detected (%)	50	95	AM	ASD	GSD	GSD
40	2-Ethyl-1-Hexanol	104-76-7	0.33	95	100	1.2	5.1	1.8	1.9	1.2	2.7
43	1-Ethyl-4-methyl Benzene	622-96-8	0.35	93	96	0.77	4.1	1.3	1.6	0.85	2.4
44	Formaldehyde	50-00-0	0.39	99	100	15	32	16	8.8	13	2.1
46	Heptanal	111-71-7	2.50	5.1	23	1.25	2	2.1	5.2	1.4	1.7
50	Hexanal	66-25-1	0.66	98	100	4.1	12	5.4	3.8	4.2	2.1
51	n-Hexane	110-54-3	0.66	91	98	2.5	12	3.9	3.8	2.4	2.8
54	Isopropanol	67-63-0	4.70	76	100	30	320	73	130	22	5.2
55	d-Limonene	5989-27-5	0.35	98	100	7.1	44	12	18	6.5	3.1
64	Methylene Chloride	75-09-2	2.40	64	81	2.9	16	21	150	3.2	2.9
68	Methyl Isobutyl Ketone	108-10-1	0.35	84	93	1	7.2	2.2	3.6	1.1	3.3
72	Naphthalene	91-20-3	0.35	83	90	0.73	2.6	0.95	1.1	0.63	2.4
74	Nonanal	124-19-6	0.66	100	100	3.6	7.9	4.3	2.7	3.7	1.7
75	n-Nonane	111-84-2	0.35	93	100	0.94	10	2.8	6.1	1.2	3.2

Table A2. List of VOCs Common to Both the CAEEC and USEPA's BASE Studies With Results For The BASE Study											
Index from Table A1	**Compound Name**	**CAS Number**	**Median LOQ**	**Site Frequency Detected (%)**	**Building Frequency Detected (%)**	**50**	**95**	**AM**	**ASD**	**GSD**	**GSD**
82	Pentanal	110-62-3	0.66	90	98	1.2	4	1.6	1.2	1.3	2
85	Phenol	108-95-2	0.33	97	100	1.8	7.3	2.5	2.1	1.7	2.5
86	alpha-pinene	80-56-8	0.35	84	94	0.57	3.1	0.94	1.4	0.59	2.4
95	Styrene	100-42-5	0.35	94	99	0.91	3	1.3	1.2	0.92	2.2
96	Tetrachloroethylene	127-18-4	0.35	96	100	1.5	18	3.8	5.9	1.8	3.3
98	Texanol 1 & 3	25265-77-4	0.66	88	93	2.5	19	5.4	6.5	2.8	3.4
99	Toluene	108-88-3	0.35	100	100	8.7	39	16	37	9.4	2.3
100	1,1,1-Trichloroethane	71-55-6	0.69	99	100	3.1	21	11	47	3.6	2.9
101	Trichloroethylene	79-01-6	0.35	54	66	0.29	2.6	0.76	1.8	0.37	2.6
104	1,2,4-Trimethylbenzene	95-63-6	0.35	98	100	1.9	12	3.3	3.4	2.2	2.4

Table A2. List of VOCs Common to Both the CAEEC and USEPA's BASE Studies With Results For The BASE Study

Index from Table A1	Compound Name	CAS Number	Median LOQ	Site Frequency Detected (%)	Building Frequency Detected (%)	50	95	AM	ASD	GSD	GSD
105	1,3,5-Trimethylbenzene	108-67-8	0.35	84	93	0.54	3.9	1	1.3	0.63	2.5
108	n-Undecane	1120-21-4	0.35	99	100	4	19	6.3	7	4.1	2.5
109	m/p-Xylene	108-38-3/ 106-42-3	0.35	99	100	5.1	24	8.4	9.7	5.7	2.4
110	o-Xylene	95-47-6	0.35	99	100	2.1	8.2	3.1	3.6	2.2	2.2

APPENDIX B - VENTILATION MEASUREMENT RESULTS

Table B1. Building Data								
BUILDING		**FLOOR AREA (ft^2)**	**VOLUME (ft^3)**	**NUMBER OF AHUs**	**DESIGN TOTAL CAPACITY PER AHU (CFM)**	**DESIGN MIN OA PER AHU (CFM)**	**DESIGN ACH (hr^{-1})**	**TOTAL DESIGN MIN OA CFM**
171		392690	5843536	4	70,000	15000	0.62	60000
172		154800	2453838	2	60000	11500	0.60	24500
				1	7600	1500		
173		182030	2898767	2	70000	15000	0.62	30000
174		208950	3224984	2	80000	15700	0.58	31400
225	2 thru 6	251759	3339579	3	55,000	16800	1.0	
	1st floor	25441	333277	1	20000 AC3,4	9200	1.8	
	TOTAL	277200	3672856				1.1	59600

Table B2. BLOCK 171 – Air Change Rates				
	ACH			
LOCATION	(Per AQS study – regression method)[1]	10-15-03	03-24-04	06-02-04
AHU Returns				
AHU 1-1	0.36	0.48	0.48	0.47
AHU 1-2	0.34	0.53	0.53	0.47
AHU 1-3	0.40	0.58	0.55	0.47
AHU 1-4	0.70	0.58	0.53	0.46
AHU Return Median		0.56	0.53	0.47
Floor				
2nd, location 2-1		0.57	0.57	0.50
2nd, location 2-2		0.59	0.49	0.47
3rd, location 3-1		0.44	0.46	0.52
3rd, location 3-2			0.66	0.34
3rd, location 3-3			0.38	0.43
4th, location 4-1		0.65	0.64	0.50
4th, location 4-2		0.59	0.65	0.50
5th, location 5-1	0.45	0.65	0.65	0.56
6th, location 6-1	0.61	0.56	0.59	0.48
6th, location 6-2		0.58	0.59	0.45
Building Median		0.58	0.56	0.47

[1] Data supplied by Air Quality Sciences through Clark Construction Company.

Table B3. BLOCK 172 – Air Change Rates					
LOCATION	**ACH**				
	(Per AQS study – regression method)[1]	**10-10-03**	**02-11-04**	**03-30-04**	**06-08-04**
AHU Returns					
AHU 2-1	0.68	0.67	0.85	1.1	0.71
AHU 2-2	0.69	0.84	0.90	1.1	0.73
AHU 2-3 (auditorium)		0.56	0.70	0.98	0.65
AHU Return Median		0.67	0.85	1.1	0.71
Floor					
1-1 (auditorium)		0.68	0.72	1.4	0.80
1-2		1.6			
2-1		1.0	0.80	0.50	0.71
2-2			0.89	1.2	0.76
3-1		1.3	1.0	1.1	0.73
3-2		0.64	0.89	0.46	0.74
4-1		1.4	0.98	1.3	0.74
4-2			0.92	0.50	0.75
5-1		1.4	0.97	1.3	0.70
5-2		0.94	0.95	0.51	0.73
6-1	0.67 0.66	0.92	0.97	0.52	0.72
6-2			0.97	1.4	0.71
Building Median		0.93	0.91	1.1	0.73

[1] Data supplied by Air Quality Sciences through Clark Construction Company

Table B4. BLOCK 173 – Air Change Rates				
LOCATION	**ACH**			
	Per AQS study – regression method[1]	**10-29-03**	**03-03-04**	**04-27-04**
Return AHU 3-1	0.49	1.3	0.60	0.73
Return AHU 3-2	0.55	1.2	0.75	0.94
AHU Return Median		1.3	0.68	0.84
LOCATION				
1-1		1.6	0.56	0.71
2-1		0.9	0.59	0.67
2-2		1.0	0.72	1.0
3-1		1.0	0.56	0.70
4-1		1.2	0.83	1.05
4-2		1.2		
4-HW			0.61	0.98
5-1		1.1	0.64	0.72
5-2		1.1	0.84	1.0
6-1	0.44	1.1	0.59	1.0
6-2	1.0	1.4	0.87	0.75
7-1		1.2	0.67	0.74
7-2		1.1	0.88	1.0
Building Median		1.2	0.66	0.85

[1] Data supplied by Air Quality Sciences through Clark Construction Company

Table B5. BLOCK 174 – Air Change Rates

LOCATION	ACH			
	Per AQS study – regression method[1]	10-07-03[2]	02-04-04	04-21-04
AHU 4-1	0.52	0.96	0.62	0.59
AHU 4-2	0.58	0.90	0.59	0.59
AHU Return Median		0.93	0.61	0.59
LOCATION				
6th floor	0.44			
7th floor	0.53			
1-1			0.49	0.63
1-2			0.60	0.62
2-1			0.61	0.61
3-1			0.56	0.67
3-2			0.58	0.53
4-1			0.61	0.59
4-2				0.67
5-1			0.47	0.71
5-2			0.53	0.66
6-1			0.58	0.60
7-1			0.61	0.64
7-2			0.61	0.53
Building Median		0.93	0.59	0.62

[1] Data supplied by Air Quality Sciences through Clark Construction
[2] Syringe samples not collected during tracer gas decay. Syringe samples collected only at tracer gas steady state condition.

Table B6. BLOCK 225 – Air Change Rates					
LOCATION	ACH				
	10-29-02[1]	06-05-03[1]	10-23-03	03-10-04	05-19-04
Return AHU 1			0.93	1.1	0.58
Return AHU 2			1.0	1.5	0.65
Return AHU 3			1.0	1.6	0.65
Return AHU 1st floor			0.79	1.3	0.61
AHU Return Median			0.97	1.4	0.63
LOCATION					
1-1	0.7	0.5	0.70	1.4	0.61
1-2 (childcare)	0.7	0.8	0	1.6	0.78
2-1			0.76	1.3	0.64
3-1	0.7	0.7	0.78	1.4	0.60
3-2			0.90	2.0	0.62
4-1	0.7	0.7	0.86	1.5	0.60
4-2			0.95	1.4	0.56
5-1	0.8	0.8			
6-1			1.0	1.4	0.58
6-2	0.9	0.8	0.89	2.1	0.66
Building Median			0.89	1.4	0.61

[1] Data supplied by Indoor Environmental Engineering through Hensel Phelps Construction Company

Table B7. Steady-State Tracer Gas Data for Building 171											
BLDG #	STEADY STATE DATA IN THE AHU SYSTEMS							LOCAL STEADY STATE CONCENTRATIONS MEASURED W/SYRINGES (ppb)			
	AHU #	STEADY STATE CONCENTRATION OF SF_6 IN AHU RETURNS (ppb)			SF_6 FLOW IN AHU SUPPLY AIR (cc/min)						
		10-15-03	03-24-04[41]	06-02-04[42]	10-15-03	03-24-04	06-02-04	Location	10-15-03	03-24-04	06-02-04
171	AHU1	45	34	34	25.2	14.6	12.4	6-1	43	46	46
	AHU2	45	36	35	21.5	14.9	12.5	6-2	43	36	48
	AHU3	39	39	36	15.1	15.2	12.4	5-1	35	36	49
	AHU4	41	38	38	17.4	14.9	14.5	4-1	43	47	47
Median (stdev)		43 (2.8)	37 (2.1)	35 (2.0)	79.2	59.6	51.8	4-2	51	38	41
								3-1	51	37	26
								3-2		35	41
								3-3		39	23
								2-1	44	38	41
								2-2	43	47	46
								Median (stdev)	43 (5.1)	38 (4.8)	44 (9.1)

41 SF_6 started on 3-23-04 (overnight)
42 SF_6 was released overnight

Table B8. Steady-State Tracer Gas Data for Building 172

BLDG #	STEADY STATE DATA IN THE AHU SYSTEMS									LOCAL STEADY STATE CONCENTRATIONS MEASURED W/SYRINGES (ppb				
	AHU #	STEADY STATE CONCENTRATION OF SF_6 IN AHU RETURNS (ppb)				SF_6 FLOW IN AHU SUPPLY AIR (cc/min)								
		10-10-03	02-11-04	03-30-04[43]	06-08-04[44]	10-10-03	02-11-04	03-30-04	06-08-04	Location	10-10-03	02-11-04	03-30-04	06-08-04
172	AHU1	40	41	41	32	12.9	17	12.1	17.4	6-1	38	46	52	45
	AHU2	41	42	36	31	16.1	11.3	23.1	26.55	6-2		50	49	40
	AUDI	42	39	40	35	2	33.3[45]	23.6[46]	20.67[47]	5-1	39	50	48	41
Median (stdev)		41 (1.3)	41 (1.5)	40 (2.5)	32 (2.0)	29.21	31.72	37.63	46.07	5-2	38	46	52	44
										4-1	43	50	50	41
										4-2		46	52	44
										3-1	39	50	49	40
										3-2	38	46	53	45
										2-1	38	48	47	39
										2-2		46	53	44
										1W	43			
										1auditori	45	46	44	39
										Median (stdev)	39 (2.8)	46 (2.0)	50 (2.8)	41 (2.4)

[43] SF_6 was left on overnight at auditorium supply
[44] SF_6 was left on overnight at auditorium supply
[45] 10.28% SF_6
[46] 10.28% SF_6
[47] 10.28% SF_6

Table B9. Steady-State Tracer Gas Data for Building 173

BLDG #	AHU #	STEADY STATE DATA IN THE AHU SYSTEMS: STEADY STATE CONCENTRATION OF SF_6 IN AHU RETURNS (ppb)			SF_6 FLOW IN AHU SUPPLY AIR (cc/min)			LOCAL STEADY STATE CONCENTRATIONS MEASURED W/SYRINGES (ppb)			
		10-29-03	03-03-04	04-27-04	10-29-03	03-03-04	04-27-04	Location	10-29-03	03-03-04	04-27-04
173	AHU1	21	39	24	15.1	11.8	7.0	7-1	21	46	24
	AHU2	22	40	25	13.6	9.5	15.1	7-2	22	44	25
Median (stdev)		22 (21-22; 0.6)	39 (0.49)	24 (0.57)	28.6	21.3	22.1	6-1	23	46	25
								6-2	21	44	23
								5-1	22	46	23
								5-2	23	44	25
								4-1	23	44	25
								4-2	22	46	
								4-3			25
								3-1	22	46	24
								2-1	23	45	23
								2-2	21	43	25
								1-1	21	46	23
								Median (stdev)	22 (0.85)	46 (1.1)	25 (0.94)

Table B10. Steady-State Tracer Gas Data for Building 174

BLDG #	AHU #	STEADY STATE DATA IN THE AHU SYSTEMS: STEADY STATE CONCENTRATION OF SF_6 IN AHU RETURNS (ppb)			SF_6 FLOW IN AHU SUPPLY AIR (cc/min)			LOCAL STEADY STATE CONCENTRATIONS MEASURED W/SYRINGES (ppb			
		10-07-03	02-04-04	04-21-04	10-07-03	02-04-04	04-21-04	Location	10-07-03	02-04-04	04-21-04
174	AHU1	47	37	29	36.6	8.7	16.4	7-1	N/A	38	35
	AHU2	46	37	32	21.8	16.9	14.9	7-2		42	36
Median (stdev)		47 (0.8)	37	30 (2.1)	58.4	25.6	31.3	6-1		37	36
								5-1		40	35
								5-2		38	37
								4-1		41	34
								4-2			35
								3-1		38	37
								3-2		40	36
								2-1		39	36
								1-1		38	34
								1-2		43	34
								Median (stdev)		39 (1.9)	36 (1.1)

Table B11. Steady-State Tracer Gas Data for Building 225

BLDG #	AHU #	STEADY STATE DATA IN THE AHU SYSTEMS: STEADY STATE CONCENTRATION OF SF_6 IN AHU RETURNS (ppb)			SF_6 FLOW IN AHU SUPPLY AIR (cc/min)			LOCAL STEADY STATE CONCENTRATIONS MEASURED W/SYRINGES (ppb			
		10-23-03	03-10-04	05-19-04[48]	10-23-03	03-10-04	05-19-04	Location	10-23-03	03-10-04	05-19-04
225	AHU1	22	29	31	18.4	18	13.3	6-1	26	37	35
	AHU2	24	32	35	12.3	7.8	5.58	6-2	24	29	34
	AHU3	27	28	32	21.7	24	16.3	4-1	26	33	33
	1st floor	25	22	31 & 29	9.6	11.8	8.39	4-2	26	32	34
Median (stdev)		24 (1.9)	29 (4.3)	31 (1.9)	62.0	61.6	43.57	3-1	27	32	34
								3-2	26	29	35
								2-1	26	32	33
								1-1	28	47	41
								1-2	18	30	25
								return AHU 3	26	42, 22, 23	
								Median (stdev)	26 (2.8)	32 (6.0)	34 (4.1)

[48] SF_6 was released in all AHU systems overnight

Table B12. Measured Local Ventilation Rates Below Design								
Location		Building Design ACH (hr^{-1})	Number of Local ACH 20% Or More Below Design (Sample Size)					
			Post-Occupancy					
			#1`	#2	#3	#4	#5	Total % (N)
171		0.62	2 (12)	4 (14)	12 (14)			45 (40)
172		0.60	0 (14)	1 (14)	0 (14)			2.4 (42)
173		0.62	0 (14)	0 (14)	0 (14)			0 (42)
174		0.58	0 (2)	1 (13)	0 (14)			3.4 (29)
225	2 thru 6	1.0	3 (4)	4 (4)	2 (10)	0 (10)	10 (10)	50 (38)
	1	1.8	2 (2)	2 (2)	3 (3)	0 (3)	3 (3)	77 (13)

APPENDIX C - STATISTICAL DATA OF ALL VOC AND ALDEHYDE MEASUREMENTS

Table C1. Number of Locations Exceeding Air Concentrations Goals For Selected Chemicals

Chemical Name	Target ($\mu g/m^3$)	171			172			173			174			225				
		10/15/03	3/24/04	6/2/04	2/11/04	3/30/04	6/8/04	10/29/03	3/3/04	4/27/04	10/7/03	2/4/04	4/21/04	10/29/02	6/5/02	10/23/03	3/10/04	5/19/04
N ⇒		**13**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**15**	**13**	**14**	**15**	**7**	**7**	**14**	**15**	**15**
Acetaldehyde	9	8		12	2	1	1	1		14	2				1	1	1	7
Caprolactam	100																	N=7
Formaldehyde	33				3	10	10								1	1	1	
Naphthalene	9										1							N=7
Nonanal	13					1								1	1			N=7

Table C2. Summary of Standard Deviations of Calculated Emission Factors For Selected Chemicals

Chemical Name	171			172			173			174			225				
	10/15/03	3/24/04	6/2/04	2/11/04	3/30/04	6/8/04	10/29/03	3/3/04	4/27/04	10/7/03	2/4/04	4/21/04	10/29/02	6/5/02	10/23/03	3/10/04	5/19/04
N ⇒	13	15	15	15	15	15	15	15	15	13	14	15	7	7	14	15	15
Acetaldehyde	6.5	2.5	4.6	3.9	12	5	9.8	3.3	4.6	6.3	3.7	3.5	4.5	5.0	7.0	64	5.2
Benzaldehyde	1.4	1	0.9	1.0	6.3	1.2	3.5	0.9	0	2.5	2.1	1.4	5.5	1.9	2.0	9.3	0.7
Caprolactam	9.2	21	9.5	7.6	27	9.7	14	7.2	7.1	20	7.0	5.6	6.8	3.5	10	27	2.7
Decamethylcyclop entasiloxane	24	47	19	47	190	34	60	61	53	33	50	13	30	19	52	420	54
D-Limonene	28	22	3.6	21	47	2.1	15	34	7.1	18	36	8.8	19	13	36	240	20
Formaldehyde	13	7	8.8	36	83	39	25	6.8	7.4	17	11	8.9	4.4	18	31	230	15
Naphthalene	4.7	0.4	0	0	1.8	0	0	0	0	21	0	0.7	0.3	1.7	0	0	0
Nonanal	2.3	5.3	2.7	5.7	19	0	9.9	4.8	3.9	8	4.5	4.3	0	7.4	0	0	1.8

Table C3. Ratios of Concentrations of the 50 and 95 Percentiles of the First Post-Occupancy Concentrations to those Measured in the USEPA's BASE Study[49]											
		171		**172**		**173**		**174**		**225**	
		10/15/03		**2/11/04**		**10/29/03**		**10/7/03**		**10/29/02**	
		50/50	**95/95**	**50/50**	**95/95**	**50/50**	**95/95**	**50/50**	**95/95**	**50/50**	**95/95**
Acetaldehyde	75-07-0	1.3	0.8	1.0	0.6	0.9	0.6	1.0	0.7	0.6	0.4
Acetone	67-64-1	0.3	0.1	0.6	0.2	0.3	0.1	0.3	0.1	0.3	0.1
Benzene	71-43-2	0.2	0.1	0.1	0.1	0.2	0.1	0.2	0.1	1.0	0.5
2-Butoxyethanol	111-76-2	0.4	0.1	0.1	0.0	0.2	0.1	0.3	0.1	0.3	0.1
n-Butyl Acetate	123-86-4			0.8	0.3	0.9	0.2				
Butylated Hydroxytoluene	128-37-0										
Chloroform	67-66-3	4.3	1.2	3.7	1.2	4.3	1.2	4.9	1.4	3.7	1.0
n-Decane	124-18-5	0.4	0.1	0.4	0.1	0.4	0.1	0.5	0.1	1.0	0.2
1,4-Dichlorobenzene	106-46-7										
Dodecane	112-40-3	0.4	0.3	0.3	0.2	0.4	0.4	0.4	0.2		
Ethyl Acetate	141-78-6										
Ethylbenzene	100-41-4	0.8	0.4	0.3	0.2	0.3	0.1	0.4	0.1	1.7	0.7
2-Ethyl-1-Hexanol	104-76-7	1.1	0.3	1.0	0.3	1.1	0.3	1.3	0.3	1.0	0.6
1-Ethyl-4-methyl Benzene	622-96-8									6.1	11.9
Formaldehyde	50-00-0	1.1	0.7	1.9	1.3	1.0	0.7	1.1	0.8	0.7	0.4
Heptanal	111-71-7	1.0	0.7	0.9	0.7	1.0	0.7	1.2	0.8		
Hexanal	66-25-1	0.3	0.2	0.3	0.1	0.3	0.1	0.4	0.1	2.0	0.9
n-Hexane	110-54-3	0.2	0.1	0.2	0.1	0.2	0.1	0.3	0.1	1.1	0.3
Isopropanol	67-63-0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
d-Limonene	5989-27-5	1.1	0.7	1.0	0.4	0.3	0.2	0.8	0.3	2.3	0.5
Methylene Chloride	75-09-2	0.4	0.1	0.4	0.1	0.4	0.1	0.4	0.1	0.3	0.1
Methyl Isobutyl Ketone	108-10-1					0.5	0.2	0.6	0.3	0.5	0.2
Naphthalene	91-20-3	0.7	1.3	0.7	0.2	0.7	0.2	0.8	3.1	2.3	0.7
Nonanal	124-19-6	0.9	0.6	0.3	0.6	1.4	1.0	1.2	0.8	2.1	1.6
n-Nonane	111-84-2	1.4	0.1	1.2	0.1	1.4	0.1	1.6	0.2	1.2	0.1
Pentanal	110-62-3										

[49] Half of the LOQ was used when <LOQ was reported. Also ratios were calculated only for those chemicals that had reported measured concentrations or LOQ.

Table C3. Ratios of Concentrations of the 50 and 95 Percentiles of the First Post-Occupancy Concentrations to those Measured in the USEPA's BASE Study[49]											
		171		**172**		**173**		**174**		**225**	
		10/15/03		**2/11/04**		**10/29/03**		**10/7/03**		**10/29/02**	
		50/50	**95/95**	**50/50**	**95/95**	**50/50**	**95/95**	**50/50**	**95/95**	**50/50**	**95/95**
Phenol	108-95-2	3.4	1.1	2.3	0.7	3.0	1.0	3.4	1.1	1.2	0.6
alpha-pinene	80-56-8	2.3	0.5	2.0	0.5	2.3	0.5	2.6	0.5		
Styrene	100-42-5	0.5	0.2	0.5	0.2	0.5	0.2	0.7	0.2	1.5	0.5
Tetrachloroethylene	127-18-4	0.3	0.0	0.3	0.0	0.3	0.0	0.4	0.0	1.5	0.1
Texanol 1 & 3	25265-77-4	3.1	0.7	1.6	0.3	2.7	0.9	3.8	0.9		
Toluene	108-88-3	0.6	0.2	0.4	0.2	0.2	0.1	0.3	0.1	0.9	0.3
1,1,1-Trichloroethane	71-55-6	0.3	0.0	0.3	0.0	0.3	0.0	0.3	0.1	0.3	0.0
Trichloroethylene	79-01-6	1.7	0.2	1.7	0.2	1.7	0.2	2.1	0.2	1.7	0.2
1,2,4-Trimethylbenzene	95-63-6	1.1	0.3	0.3	0.1	0.3	0.1	0.3	0.1	6.7	6.7
1,3,5-Trimethylbenzene	108-67-8	2.4	0.4	2.1	0.4	2.4	0.4	2.8	0.4	14.3	9.1
n-Undecane	1120-21-4	0.3	0.1	0.3	0.1	0.3	0.1	0.4	0.1	0.7	0.2
m/p-Xylene	108-38-3/106-42-3	1.1	0.4	0.5	0.2	0.3	0.1	0.3	0.1	1.4	0.6
o-Xylene	95-47-6	0.9	0.4	0.2	0.2	0.2	0.1	0.3	0.1	0.0	0.0

Table C4. Ratios of Concentrations of the 50 and 95 Percentiles of the Last Post-Occupancy Concentrations to those Measured in the USEPA's BASE Study[50]

		171		172		173		174		225	
		6/2/04	6/2/04	6/8/04	6/8/04	4/27/04	4/27/04	4/21/04	4/21/04	5/19/04	5/19/04
		50/50	95/95	50/50	95/95	50/50	95/95	50/50	95/95	50/50	95/95
Acetaldehyde	75-07-0	1.4	0.8	1.0	0.6	1.7	1.0	0.9	0.5	1.3	0.7
Acetone	67-64-1	0.6	0.2	0.5	0.2	1.0	0.3	0.4	0.1	0.6	0.2
Benzene	71-43-2	0.1	0.1	0.1	0.1	0.5	0.3	0.1	0.1	0.1	0.1
2-Butoxyethanol	111-76-2	0.8	0.1	0.6	0.1	0.5	0.1	0.3	0.1	0.4	0.1
n-Butyl Acetate	123-86-4					0.9	0.2				
Butylated Hydroxytoluene	128-37-0										
Chloroform	67-66-3	3.7	1.0	3.7	2.8	4.0	1.1	3.4	1.0	1.1	0.3
n-Decane	124-18-5	0.4	0.1	0.4	0.1	0.4	0.1	0.4	0.0	0.3	0.0
1,4-Dichlorobenzene	106-46-7					0.9	0.1				
Dodecane	112-40-3			0.3	0.2	0.4	0.2	0.3	0.1	0.3	0.3
Ethyl Acetate	141-78-6					0.7	0.2				
Ethylbenzene	100-41-4	0.8	0.3	0.3	0.2	1.7	0.5	0.3	0.1	0.3	0.1
2-Ethyl-1-Hexanol	104-76-7	2.3	0.7	2.1	0.7	1.1	0.3	0.9	0.6	0.8	0.2
1-Ethyl-4-methyl Benzene	622-96-8									1.4	1.6
Formaldehyde	50-00-0	1.3	0.7	3.3	1.9	1.4	0.7	1.0	0.5	1.6	0.9
Heptanal	111-71-7	0.9	0.6	0.9	0.6	1.0	0.7	0.9	0.6	0.8	0.5
Hexanal	66-25-1	0.3	0.1	0.3	0.2	0.3	0.1	0.3	0.3	0.2	0.1
n-Hexane	110-54-3	0.5	0.2	0.3	0.2	0.4	0.2	0.2	0.1	0.2	0.0
Isopropanol	67-63-0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
d-Limonene	5989-27-5	0.6	0.1	0.2	0.0	0.8	0.2	0.6	0.3	0.6	0.4
Methylene Chloride	75-09-2	0.3	0.1	0.3	0.1	0.4	0.1	0.3	0.1	0.3	0.1
Methyl Isobutyl Ketone	108-10-1	0.5	0.1	0.5	0.1	0.5	0.2	0.4	0.2	0.4	0.1
Naphthalene	91-20-3	0.7	0.2	0.7	0.2	0.7	0.4	0.5	0.3	0.5	0.2
Nonanal	124-19-6	1.1	0.8	1.2	0.7	1.0	0.7	1.4	1.1	0.5	0.3
n-Nonane	111-84-2	1.2	0.1	1.2	0.1	1.4	0.1	1.2	0.1	1.1	0.1
Pentanal	110-62-3	0.9	0.3	0.9	0.3	1.1	0.3	0.9	0.9	0.8	0.3
Phenol	108-95-2	2.8	0.9	2.2	0.7	2.1	0.6	1.7	0.8	0.9	0.3

[50] Half of the LOQ was used when <LOQ was reported. Also ratios were calculated only for those chemicals that had reported measured concentrations or LOQ

Table C4. Ratios of Concentrations of the 50 and 95 Percentiles of the Last Post-Occupancy Concentrations to those Measured in the USEPA's BASE Study[50]

		171		172		173		174		225	
		6/2/04	6/2/04	6/8/04	6/8/04	4/27/04	4/27/04	4/21/04	4/21/04	5/19/04	5/19/04
		50/50	95/95	50/50	95/95	50/50	95/95	50/50	95/95	50/50	95/95
alpha-pinene	80-56-8	1.9	0.4	1.9	0.4	2.3	0.4	1.9	0.4	1.8	0.3
Styrene	100-42-5	0.5	0.2	0.5	0.2	0.5	0.4	0.4	0.1	0.4	0.1
Tetrachloroethylene	127-18-4	0.3	0.0	0.3	0.0	0.8	0.1	0.8	0.1	0.3	0.0
Texanol 1 & 3	25265-77-4	6.9	1.6	6.2	1.1	3.5	0.8	2.7	1.1	0.4	0.1
Toluene	108-88-3	0.8	0.3	0.6	0.2	1.3	0.4	0.2	0.2	0.2	0.1
1,1,1-Trichloroethane	71-55-6	0.3	0.0	0.3	0.0	0.3	0.0	0.2	0.0	0.2	0.0
Trichloroethylene	79-01-6	1.7	0.2	1.7	0.2	1.7	0.2	1.4	0.2	1.4	0.2
1,2,4-Trimethylbenzene	95-63-6	0.7	0.2	0.3	0.1	1.7	0.3	0.2	0.1	0.2	0.2
1,3,5-Trimethylbenzene	108-67-8	2.0	0.3	2.0	0.3	2.4	0.3	2.0	0.3	1.9	0.9
n-Undecane	1120-21-4	0.3	0.1	0.3	0.1	0.3	0.1	0.3	0.1	0.3	0.1
m/p-Xylene	108-38-3/106-42-3	1.2	0.4	0.8	0.2	1.7	0.4	0.3	0.1	0.4	0.1
o-Xylene	95-47-6	0.9	0.3	0.5	0.2	1.5	0.5	0.2	0.2	0.0	0.0

APPENDIX D - SUMMARY OF POST-OCCUPANCY EMISSION FACTORS

Table D1. Summary of Statistical Data of Calculated Post-Occupancy Emissions Factors in Building 171 for Target Chemicals

Chemical Name	10/15/03 (N=12)				3/24/04 (N=14)				6/2/04 (N=14)			
	Median µg/m^2-hr	STDEV	95%	Range µg/m^2-hr	Median µg/m^2-hr	STDEV	95%	Range µg/m^2-hr	Median µg/m^2-hr	STDEV	95%	Range µg/m^2-hr
Acetaldehyde	15	6.5	22	0, 24	16	2.5	19	11,20	14	4.6	18	0.6, 20
Benzaldehyde	2.6	1.4	3.7	0, 3.9	5.6	1	7	4.1,7.5	2.7	0.9	3.8	1, 4.2
Caprolactam	16	9.2	24	0, 26	14	21	63	0, 73	13	9.5	29	0,31
Decamethylcyclopentasiloxane	63	24	84	20, 87	120	47	210	77, 240	60	19	93	42, 110
D-Limonene	20	28	81	7.9, 100	31	22	68	5.6, 69	7	3.6	13	3, 17
Formaldehyde	30	13	46	0, 49	30	7	40	17, 44	30	8.8	34	0, 35
Naphthalene	0	4.7	7.3	0, 16	1.9	0.4	2.6	1.4, 3	0	0	0	0, 0
Nonanal	7.3	2.3	10	4.1, 12	12	5.3	23	5.7, 24	7.4	2.7	12	3.7, 14

Table D2. Summary of Statistical Data of Post-Occupancy Calculated Emissions Factors in Building 172 for Target Chemicals

Chemical Name	2/11/04 (N=14)				3/30/04 (N=14)				6/8/04 (N=14)			
	Median µg/m^2-hr	**STDEV**	**95%**	**Range** µg/m^2-hr	**Median** µg/m^2-hr	**STDEV**	**95%**	**Range** µg/m^2-hr	**Median** µg/m^2-hr	**STDEV**	**95%**	**Range** µg/m^2-hr
Acetaldehyde	18	3.9	24	12, 27	16	12	37	0, 50	13	5	19	0, 20
Benzaldehyde	1.2	1.0	3.2	0, 3.6	12	6.3	24	5.1, 25	1.6	1.2	3.3	0, 4.7
Caprolactam	13	7.6	24	0, 29	23	27	74	4.1, 99	21	9.7	34	0, 34
Decamethylcyclopentasiloxane	76	47	190	49, 210	150	190	620	30, 710	60	34	100	14, 130
D-Limonene	24	21	72	8.5, 77	22	47	95	8.4, 200	3.1	2.1	6.4	0.5, 6.9
Formaldehyde	94	36	160	45, 170	120	83	270	6.5, 360	130	39	170	48, 190
Naphthalene	0	0	0	0, 0	3.8	1.8	5.7	0, 6.2	0	0	0	0, 0
Nonanal	3.4	5.7	14	0, 23	28	19	68	12. 74	0	0	0	0, 0

Table D3. Summary of Statistical Data of Post-Occupancy Calculated Emissions Factors in Building 173 for Target Chemicals

Chemical Name	10/29/03 (N=14)				3/3/04 (N=14)				4/27/04 (N=13)			
	Median μg/m²-hr	STDEV	95%	Range μg/m²-hr	Median μg/m²-hr	STDEV	95%	Range μg/m²-hr	Median μg/m²-hr	STDEV	95%	Range μg/m²-hr
Acetaldehyde	17	9.8	33	8.5, 51	9.5	3.3	14	2.5, 17	25	4.6	32	16, 33
Benzaldehyde	4.3	3.5	11	1.8, 14	0.6	0.9	1.7	0, 3.4	0	0	0	0
Caprolactam	34	14	49	0, 62	8.8	7.2	20	0, 28	19	7.1	31	7.3, 32
Decamethylcyclopentasiloxane	94	60	220	20, 220	72	61	190	24, 220	82	53	200	38, 200
D-Limonene	11	15	45	0, 53	34	34	100	5.1, 130	21	7.1	30	12, 34
Formaldehyde	47	25	89	28, 130	25	6.8	33	11, 40	43	7.4	54	32, 61
Naphthalene	0	0	0	0	0	0	0	0	0	0	0	0
Nonanal	25	9.9	36	7.4, 39	5.6	4.8	17	1.2, 17	14	3.9		8.5, 22

Table D4. Summary of Statistical Data of Post-Occupancy Calculated Emissions Factors in Building 174 for Target Chemicals

Chemical Name	10/7/03 (N=12)				2/4/04 (N=13)				4/21/04 (N=13)			
	Median µg/m²-hr	STDEV	95%	Range µg/m²-hr	Median µg/m²-hr	STDEV	95%	Range µg/m²-hr	Median µg/m²-hr	STDEV	95%	Range µg/m²-hr
Acetaldehyde	13	6.3	25	4.7, 27	9.9	3.7	16	4.7, 17	11	3.5	13	0, 14
Benzaldehyde	3.4	2.5	8.6	0.8, 8.6	1.4	2.1	6.4	0, 6.5	5.4	1.4	7.9	4.2, 9.6
Caprolactam	34	20	63	0, 76	12	7.0	22	0, 24	11	5.6	22	4.8, 23
Decamethylcyclopentasiloxane	40	33	100	0, 120	66	50	160	0, 170	64	13	240	20, 300
D-Limonene	25	18	60	8.3, 66	44	36	110	18, 160	9.8	8.8	27	6.9, 40
Formaldehyde	43	17	75	21, 77	30	11	49	15, 55	29	8.9	34	0, 35
Naphthalene	0	21	34	0, 72	0	0	0	0	1.8	0.7	2.2	0, 2.3
Nonanal	18	8	25	0, 29	4.7	4.5	16	2.9, 19	7	4.3	16	3.8, 20

Table D5. Summary of Statistical Data of Post-Occupancy Calculated Emissions Factors in Building 225 for Target Chemicals

Chemical Name	10/29/02 (N=6)				6/5/03 (N=6)				10/23/03 (N=13)				3/10/04 (N=13)				5/19/04 (N=6)			
	Median µg/m²-hr	STDEV	95%	Range µg/m²-hr	Median µg/m²-hr	STDEV	95%	Range µg/m²-hr	Median µg/m²-hr	STDEV	95%	Range µg/m²-hr	Median µg/m²-hr	STDEV	95%	Range µg/m²-hr	Median µg/m²-hr	STDEV	95%	Range µg/m²-hr
Acetaldehyde	6.8	4.5	14	3.3 15	9.9	5.0	17	6.2 19	15	7.0	30	9.1 39	28	21	64	8.6 96	19	5.2	24	7.5 25
	N=5																N=13			
Benzaldehyde	5.5	5.5	13	0 14	1.3	1.9	4	0 4.6	0.8	2.0	5.3	0 6.7	3.4	3.3	9.3	0 12	2	0.7	2.4	0.7 2.5
Caprolactam	11	6.8	19	0 19	8.1	3.5	9.4	0 9.6	8.2	10	27	0 34	14	9.0	27	0 34	3.6	2.7	6.9	0 7.0
Decamethylcyclopentasiloxane	62	30	78	0 80	25	19	52	10 58	48	52	150	21 210	130	130	420	47 530	58	54	150	31 180
									N=12											
D-Limonene	49	19	73	26 74	10	13	34	5.7 41	27	36	100	9.2 130	46	110	240	12 420	11	20	47	6.1 57
									N=12											
Formaldehyde	29	4.4	34	25 34	52	18	76	33 83	74	31	120	33 140	100	78	230	29 330	53	15	63	20 65
																	N=13			
Naphthalene	0.4	0.3	0.85	0.1 1.0	0	1.7	3	0 4.1	0	0	0	0	0	0	0	0	0	0	0	0
Nonanal	0	0	0	0	3.8	7.4	17	0.5 21	0	0	0	0	0	0	0	0	5	1.8	7.3	2.9 7.6

APPENDIX E - SUMMARY OF ALL CONCENTRATION DATA

Table E1. Summary of Statistical Data of Post-Occupancy Measured Concentrations in Building 171 for Target Chemicals

Chemical Name	10/15/03 (N=13)				3/24/04 (N=15)				6/2/04 (N=15)			
	Median μg/m^3	95%	STDEV	Range μg/m^3	Median μg/m^3	95%	STDEV	Range μg/m^3	Median μg/m^3	95%	STDEV	Range μg/m^3
Acetaldehyde	9.6	12	3.5	0.6, 13	7.2	8.1	0.9	5.2, 8.4	10	13	2.3	3.5, 14
Benzaldehyde	1.3	1.4	0.1	1.2, 1.4	2.4	2.9	0.5	1.1, 3	1.1	1.2	0	1.1, 1.2
Caprolactam	6.6	11	4	1.1, 12	6.9	31	11	0.9, 38	6.5	19	5.8	1, 21
Decamethylcyclopentasiloxane	26	35	9.3	8.9, 37	52	91	20	34, 93	30	55	11	23, 55
D-Limonene	8.0	32	11	3.3, 39	16	31	9.4	2.4, 35	4	6.1	1.8	1.1, 7.6
Formaldehyde	16	6.1	6.1	0.4, 23	16	18	2.4	9.4, 19	20	22	4.2	5.2, 22
Naphthalene	0.5	3.4	1.8	0.5, 6.9	0.4	1.0	0.3	0.4, 1.2	0.5	0.5	0	0.5, 0.5
Nonanal	3.4	4.6	1.4	1.2, 5	5.3	9.9	2.6	2.4, 12	4.0	6.3	1.5	1.1, 7.5

Table E2. Summary of Statistical Data of Post-Occupancy Measured Concentrations in Building 172 for Target Chemicals

Chemical Name	2/11/04 (N=15)				3/30/04 (N=15)				6/8/04 (N=15)			
	Median µg/m^3	95%	STDEV	Range µg/m^3	Median µg/m^3	95%	STDEV	Range µg/m^3	Median µg/m^3	95%	STDEV	Range µg/m^3
Acetaldehyde	7.2	9.2	1.1	5.3, 9.4	6.8	10	2.7	0.5, 12	7.2	9.1	1.3	5.1, 9.3
Benzaldehyde	1.2	1.4	0.2	1.1, 1.8	2.9	4.4	0.8	1.1, 4.4	1.2	1.2	0.1	1.1, 1.3
Caprolactam	3.4	6.6	2.0	1, 7.8	8.5	16	5.4	1, 22	7.4	12	3.2	1, 12
Decamethylcyclopentasiloxane	23	50	12	13, 53	51	130	43	7.6, 140	20	34	11	4.9, 43
D-Limonene	7.0	19	5.5	1.1, 20	6.1	24	10	1.1, 43	1.1	1.2	0.2	0.6, 1.2
Formaldehyde	28	43	8.8	17, 47	46	73	21	3.3, 81	50	60	14	20, 68
Naphthalene	0.5	0.6	0.1	0.4, 0.7	0.7	1.2	0.4	0.4, 1.7	0.5	0.5	0.1	0, 0.5
Nonanal	1.2	4.4	1.9	1.1, 8.1	8.4	13	3.3	3, 16	4.4	5.4	1.2	1.1, 5.9

Table E3. Summary of Statistical Data of Post-Occupancy Measured Concentrations in Building 173 for Target Chemicals

Chemical Name	10/29/03 (N=15)				3/3/04 (N=15)				4/27/04 (N=15)			
	Median µg/m^3	95%	STDEV	Range µg/m^3	Median µg/m^3	95%	STDEV	Range µg/m^3	Median µg/m^3	95%	STDEV	Range µg/m^3
Acetaldehyde	6.2	9.0	1.8	3.9, 12	5.8	7.5	1.3	2.8, 7.8	13	15	1.5	9.9, 15
Benzaldehyde	1.3	1.9	0.4	1.3, 2.7	1.2	1.2	0	1.1, 1.2	3.1	3.5	0.6	1.2, 3.5
Caprolactam	7.1	10	2.3	1.1, 11	3.6	6.3	2.2	1, 9.5	6.2	8.4	2.1	2.3, 9.1
Decamethylcyclopentasiloxane	22	46	13	3.5, 56	30	79	23	12, 81	31	75	18	17, 76
D-Limonene	2.0	10	3.1	1.3, 10	13	34	12	1.2, 44	5.5	11	3.0	2.7, 12
Formaldehyde	15	23	4.6	11, 30	13	16	2.9	6.2, 17	21	24	2.1	17, 25
Naphthalene	0.5	0.5	0	0.5,0.5	0.5	0.5	0	0.5, 0.5	0.5	1	0.3	0.5, 1.0
Nonanal	5.0	7.6	2.2	1.3, 8.1	1.9	5.1	1.4	1.1, 5.7	3.7	5.5	1.0	2.6, 5.8

Table E4. Summary of Statistical Data of Post-Occupancy Measured Concentrations in Building 174 for Target Chemicals												
Chemical Name	**10/7/03 (N=13)**				**2/4/04 (N=14)**				**4/21/04 (N=15)**			
	Median µg/m^3	**95%**	**STDEV**	**Range** µg/m^3	**Median** µg/m^3	**95%**	**STDEV**	**Range** µg/m^3	**Median** µg/m^3	**95%**	**STDEV**	**Range** µg/m^3
Acetaldehyde	7.1	10	1.6	3.8, 11	6.5	8.4	1.5	3.7, 8.6	6.4	8.0	1.8	0.5, 8.4
Benzaldehyde	1.5	1.6	0.1	1.3, 1.6	1.1	2.7	0.6	1.1, 2.7	232	3.0	0.8	1.1, 4
Caprolactam	8.6	16	4.8	1.2, 19	5	9.0	2.5	1.3, 10	4.7	11	3.0	1, 12
Decamethylcyclopentasiloxane	13	30	8.5	1.3, 33	31	73	22	1.5, 76	40	100	32	18, 130
D-Limonene	6	15	4.8	1.5, 16	18	44	15	8.9, 66	4.5	12	4.3	2.9, 20
Formaldehyde	17	25	4.4	11, 25	15	23	4.5	9.9, 25	15	16	3.6	2.1, 17
Naphthalene	0.6	7.9	4.7	0.5, 17	0.5	0.6	0.1	0.4, 0.6	0.4	0.9	0.2	0.4, 0.9
Nonanal	4.4	6.3	1.7	1.3, 7.1	1.5	6.4	2.0	1.1, 7.7	5.1	8.4	1.7	3.8, 11

Table E5. Summary of Statistical Data of Post-Occupancy Measured Concentrations in Building 225 for Target Chemicals

Chemical Name	10/29/02 (N=7)				6/5/03 (N=7)				10/23/03 (N=14)				3/10/04 (N=15)				5/19/04 (N=7)			
	Median µg/m^3	95%	STDEV	Range µg/m^3	Median µg/m^3	95%	STDEV	Range µg/m^3	Median µg/m^3	95%	STDEV	Range µg/m^3	Median µg/m^3	95%	STDEV	Range µg/m^3	Median µg/m^3	95%	STDEV	Range µg/m^3
Acetaldehyde	4.3	6.3	1.3	2.8, 6.7	5.1	9.3	2.5	3.6 10	6.2	9.7	1.8	4.5 11	6.5	12	3.5	2.9 18	9	11	1.9	4.9 11
																	N=15			
Benzaldehyde	4.4	6.4	2.3	1.1 6.6	1.3	1.3	0	1.3 1.3	1.3	1.9	0.3	1.2 2.3	1.2	1.4	0.2	1 1.7	1	1.1	0.2	0.6 1.1
Caprolactam	3.6	5.9	1.8	1 6.1	2.8	3.4	0.8	1.1 3.5	2.4	8.1	2.7	1.1 9.6	2.1	4.7	1.4	0.9 5.8	1.6	2.8	0.8	0.9 2.8
Decamethylcyclopentasiloxane	21	23	8.6	1.1 23	8.2	22	8.6	2.9 26	14	41	15	3.3 60	22	72	23	8.9 90	24	57	20	14 66
									N=13											
D-Limonene	16	22	4.9	9.4 23	3.3	14	6.2	1.3 18	8.1	29	10	2.9 39	8.0	38	18	2.6 72	46	18	7.2	2 21
									N=13											
Formaldehyde	11	14	1.7	9.9 14	21	36	9.7	14 40	24	35	7.7	15 39	19	40	13	7.9 60	25	27	5.8	11 29
																	N=15			
Naphthalene	1.7	1.9	0.1	1.6 1.9	0.5	1.5	0.5	0.5 1.8	0.5	0.8	0.1	0.5 0.9	0.5	0.6	0.1	0.4 0.7	0.4	0.4	0.1	0.3 0.4
Nonanal	7.6	13	4.6	1.1 14	5.7	12	3.4	4.7 14	1.3	4.9	1.5	1.2 6.1	1.3	4.4	1.4	1 5.2	2.0	2.8	0.8	1 2.8

APPENDIX F - GRAPHS OF EMISSION FACTORS FOR SELECTED CHEMICALS

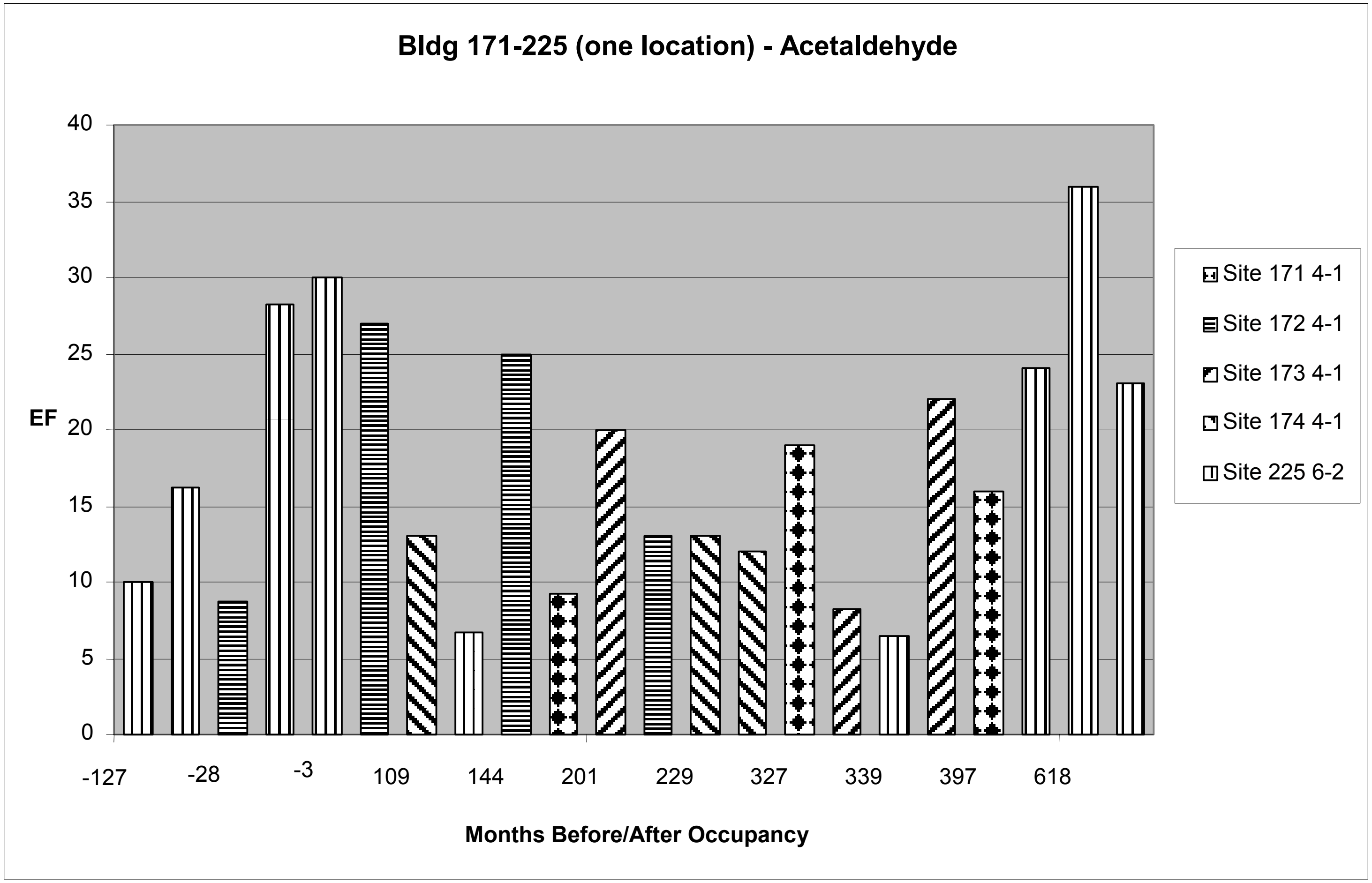


Figure F1. Pre- and Post- Occupancy Emission Factors of Acetaldehyde for a Selected Location Per Building

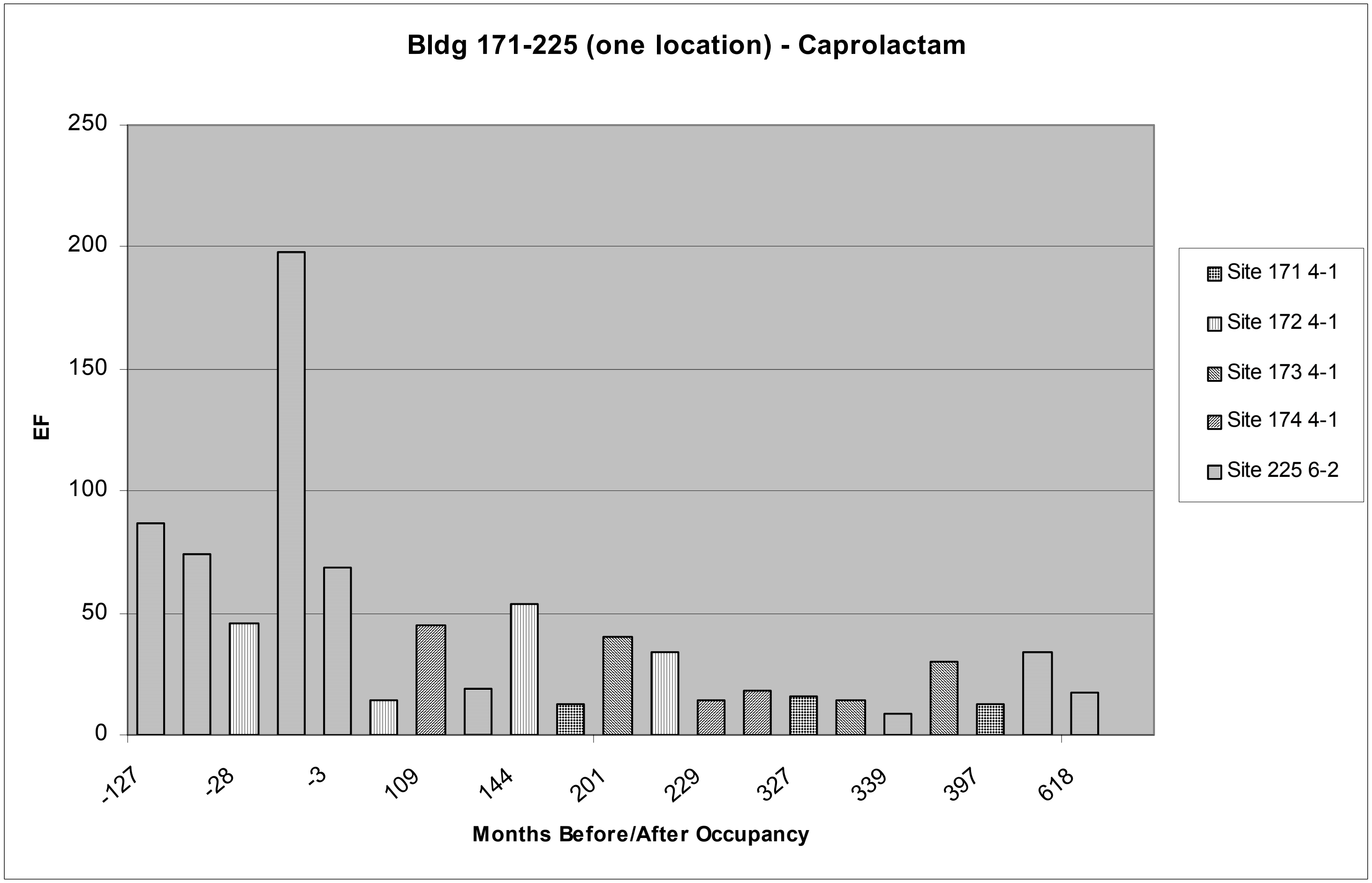


Figure F2. Pre- and Post- Occupancy Emission Factors of Caprolactam for a Selected Location Per Building

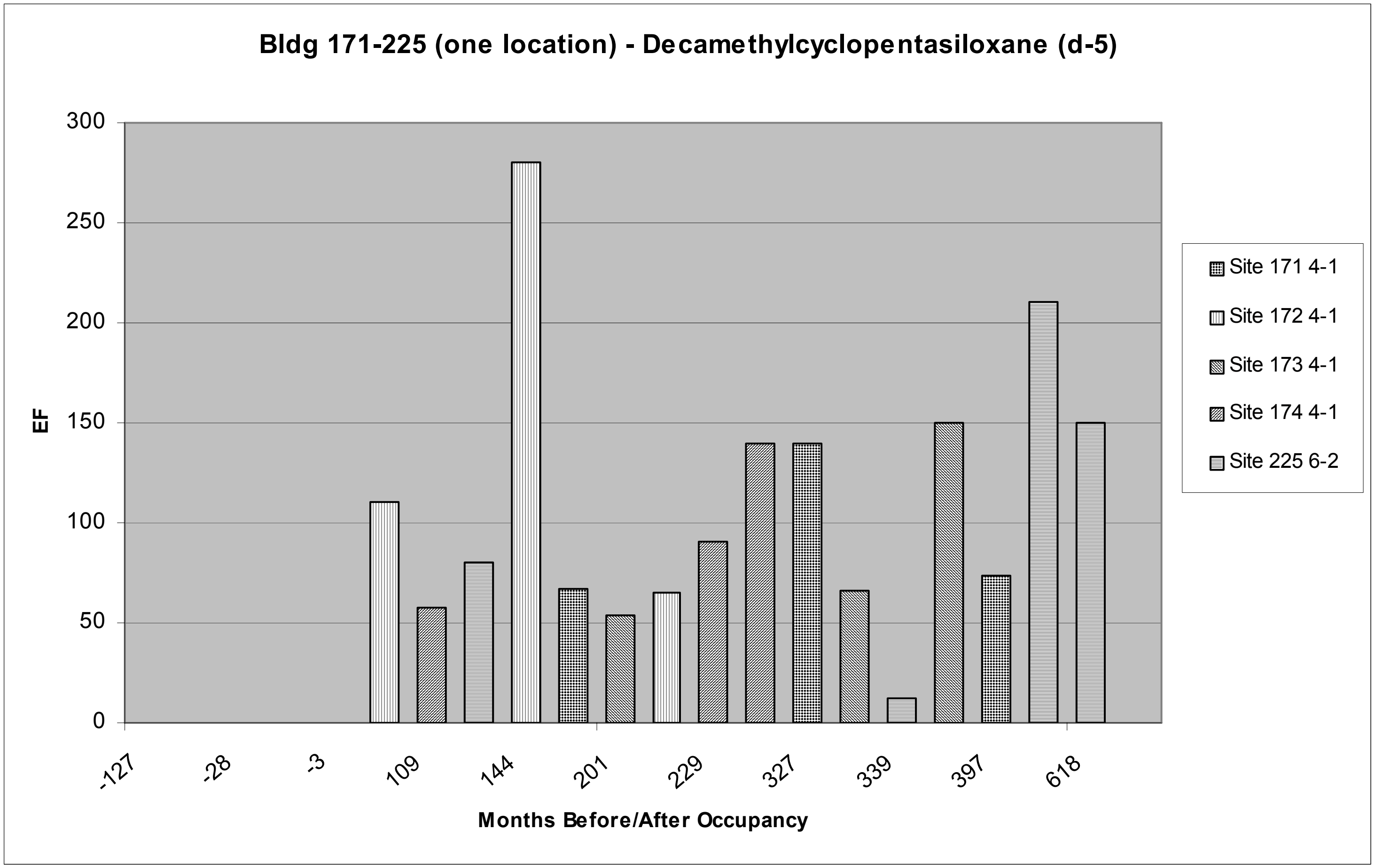


Figure F3. Pre- and Post- Occupancy Emission Factors of d-5 for a Selected Location Per Building

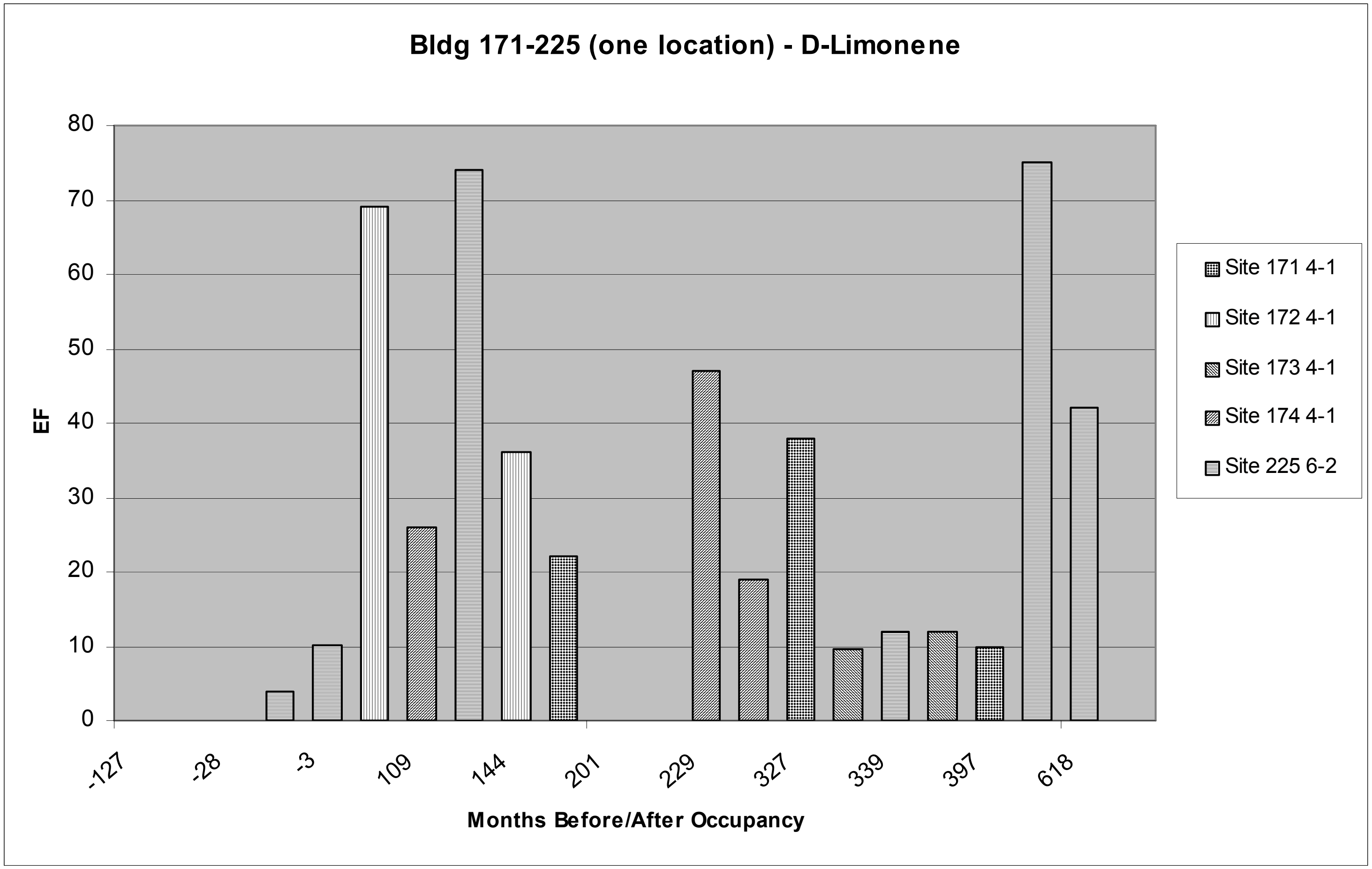


Figure F4. Pre- and Post- Occupancy Emission Factors of d-Limonene for a Selected Location Per Building

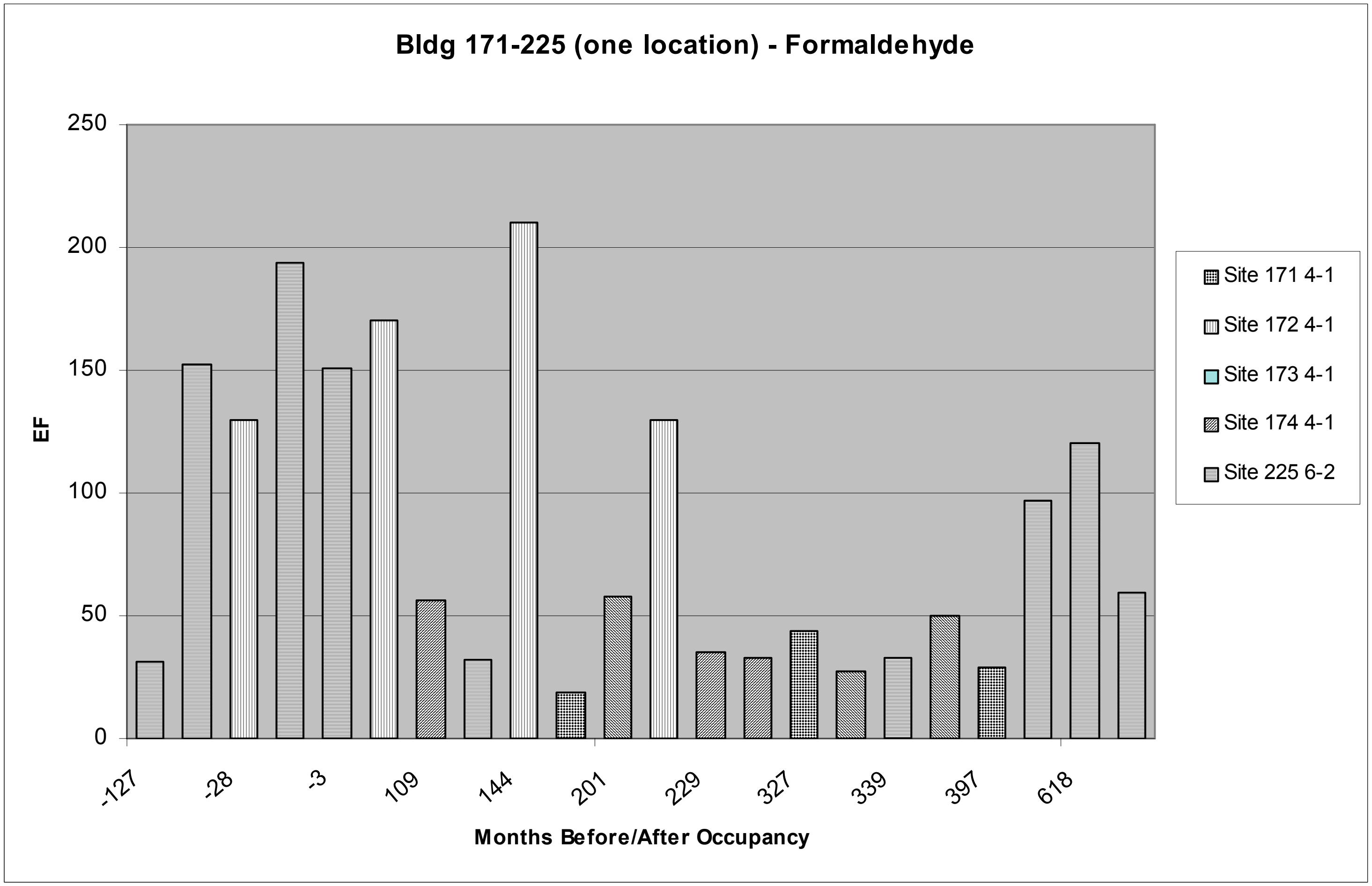


Figure F5. Pre- and Post- Occupancy Emission Factors of Formaldehyde for a Selected Location Per Building

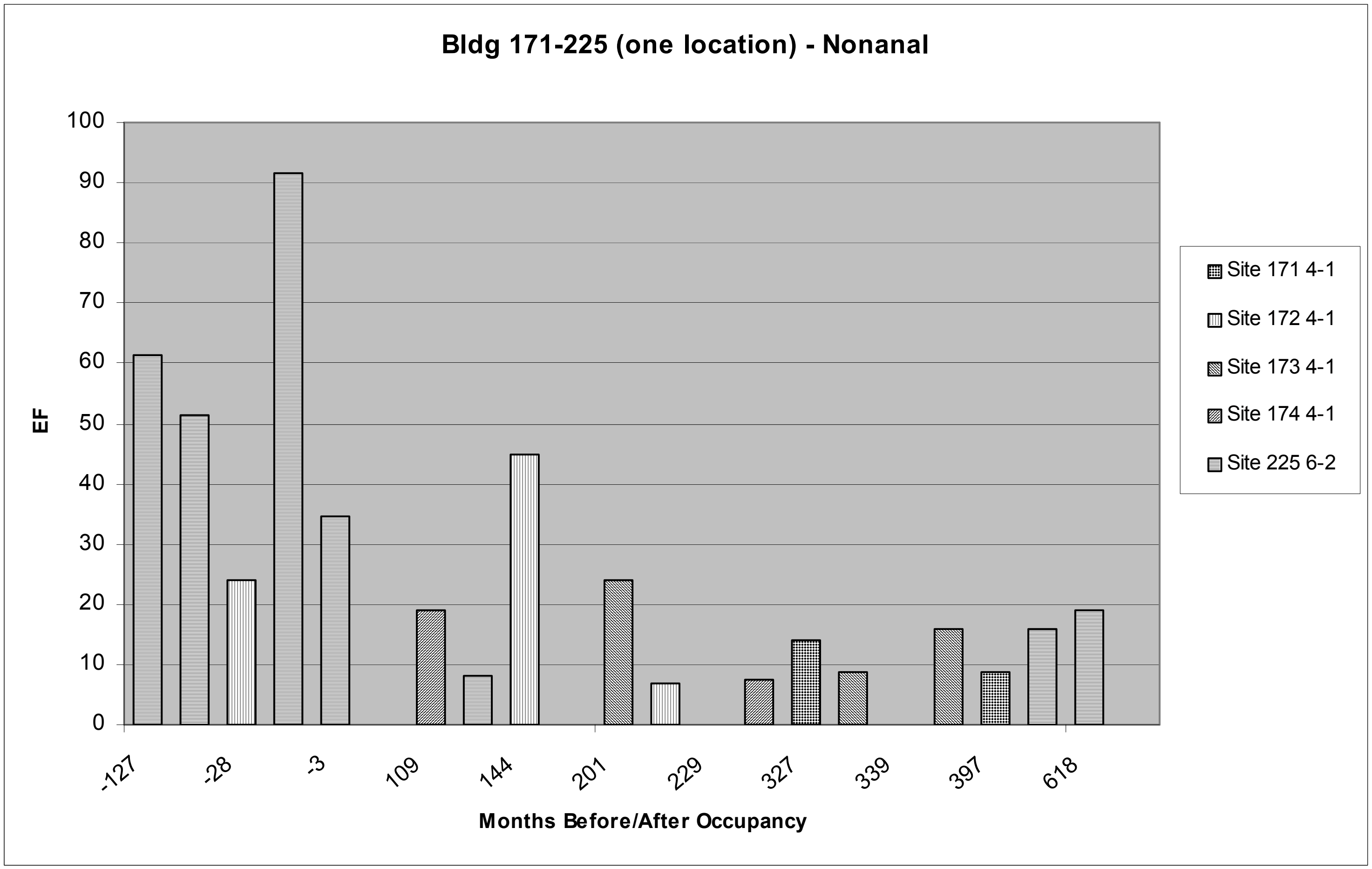


Figure F6. Pre- and Post- Occupancy Emission Factors of Nonanal for a Selected Location Per Building

APPENDIX G - QUALITY ASSURANCE

Table G1. Summary of Median Relative Percent Differences (RPD) For VOC And Aldehyde Duplicates Higher Than 0									
								Observations with RPD>20	
Chemical			**Median RPD >0**	**STDEV**	**N**	**MIN**	**MAX**	**N**	**%**
2-Butoxyethanol	111-76-2	q	0.8	20.2	247	0	130	51	21
Butyraldehyde	123-73-9	q	1.1	50.9	30	0	200	7	23
Acetone	67-64-1	q	3.7	6.0	30	0	25	1	3
Propionaldehyde	123-38-6	q	4.0	39.1	30	0	200	8	27
Formaldehyde	50-00-0	q	4.0	8.9	30	0.3	48	1	3
Caprolactam	105-60-2	q	5.5	20.1	247	0	200	50	20
Acetaldehyde	75-07-0	q	6.0	6.5	30	0.2	24	2	7
d-Limonene	5989-27-5	u	6.2	25.9	246	0	190	52	21
Phenol	108-95-2	q	6.5	29.9	247	0	200	42	17
Texanol 1 & 3	25265-77-4	q	9.6	27.1	240	0	200	64	27
m/p-Xylene	108-38-3/106-42-3	q	9.7	20.0	246	0	120	69	28
Decamethylcyclopentasiloxane	541-02-6	u	9.7	20.6	246	0	140	59	24
3-Methyl Butanal	590-86-3	u	10.0	16.8	13	0	50	5	38
Toluene	108-88-3	q	11.5	20.2	246	0	120	72	29
Nonanal	124-19-6	q	13.0	39.2	247	0	200	103	42
TVOC as Chlorobenzene-d5	n/a	n/a	13.0	25.0	247	0	180	82	33
TVOC as Toluene	n/a	n/a	14.0	25.7	247	0	190	89	36
TOTAL ALL DUPLICATE SAMPLES & ALL 105 CHEMICALS					15365	0	200	1339	

Table G2. Summary of Relative Percent Differences (RPD) Of Side-by-Side Sampling by Two Different Sampling Teams For Selected Chemicals (5 locations co-sampled) for Two Separate Sampling Occasions

	10/29/02				6/5/02			
Chemical Name	**Median**	**Stdev**	**Min**	**Max**	**Median**	**Stdev**	**Min**	**Max**
Acetaldehyde	48.6	21.5	3.0	51.7	48.4	29.8	4.6	82.2
Benzaldehyde								
Caprolactam	38.3	19.8	25.5	69.4	36.7	21.1	18.2	66.7
Decamethylcyclopentasiloxane	37.1	28.8	4.9	64.3	110.1	30.7	56.7	120.9
D-Limonene	104.6	24.4	73.0	125.0	68.2	37.6	24.3	99.3
Formaldehyde	55.6	24.8	0.0	58.1	24.0	25.5	0.0	55.6
Naphthalene	157.9	20.9	120.0	161.9	160.0		160.0	160.0
Nonanal	60.0	49.5	9.2	102.7	25.9	17.1	14.5	59.3

Table G3. Summary of Relative Percent Differences (RPD) Of All Duplicate Syringe Tracer Gas (SF_6) Samples

171		172		173		174		225	
Date	**RPD**	**Date**	**RPD**	**Date**	**RPD**	**Date**	**RPD**	**Date**	**RPD**
10/15/2003	4.1	10/10/2003	1.9	10/29/2003	0.4	2/04/04	0.8	10/23/2003	0
	6.9		9.8		3.3		0	3/10/2004	0
3/24/2004	0.4	2/11/04	1.7	3/3/2004	2.0	4/21/2004	0.9		5.3
	0.4		0.1	4/27/2004	0.5		1.7		0.8
	0.0	3/30/2004	0.4		2.8		0.5	5/19/2004	0
	0.3		0.0		0.4		0.8		0.7
6/2/2004	0.2								2.5
	0.3								
	0.0								0.4