Investigation and Validation of Multiple Lines of Evidence to Assess Vapor Intrusion at Vandenberg Air Force Base, CA for US Air Force School of Aerospace Medicine (USAFSAM/OE) at Brooks City-Base, TX

Final Report – Volume 1

August 28, 2009

Submitted to:
Department of the Air Force
USAFSAM/OE
Attention: Mr. Steven Strausbauch (COR)
2513 Kennedy Circle
Brooks City-Base, TX 78235-5116

Prepared by:

Tetra Tech, Inc.
301 Mentor Dr., Suite A
Santa Barbara, CA 93110

Tetra Tech, Inc.
3746 Mount Diablo Blvd # 300
Lafayette, CA 94549

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Tetra Tech, Inc. (Tetra Tech) has been contracted by the United States Air Force (USAF), HSW/PKAH to conduct an investigation of multiple lines of evidence (MLE) used in assessing risk associated with the vapor intrusion (VI) pathway. To that end, research has been conducted at four Air Force installations where VI is suspected: 1) Cape Canaveral Air Force Station (CCAFS), 2) Travis Air Force Base (AFB), 3) former Kelly AFB, and 4) Vandenberg AFB. The purpose of the investigations was to evaluate a variety of parameters related to VI in order to develop a better understanding of the processes that lead to a complete VI pathway, and ultimately, to develop tools for use by the Air Force in assessing VI at other installations.

The air exchange rate (AER) of a building is critical in determining whether VI may result in unacceptable concentrations of volatiles in indoor air. A building with relatively high rates of VI may never develop high indoor air concentrations if the AER is high, as the vapors will be continually flushed out of the building and replaced with ambient air. Conversely, a building with very low AER could be subject to significant buildup of indoor air concentrations, even with a relatively low concentration source or low rate of intrusion. Commonly used methods of measuring AERs tend to be somewhat cumbersome and costly; however, during the investigations at CCAFS, Travis AFB, and former Kelly AFB, a relatively simple and cost-effective method for determining AERs was developed and used (Tetra Tech 2009a, 2009b, 2009c). The method consists of releasing a known quantity of helium (He) inside a building and then measuring the helium concentration in the air over time as it dissipates. A formula is then applied to the results to calculate the building AER.

The purpose of experiments conducted at Vandenberg AFB and presented and discussed in this report, was to conduct side by side comparisons of this new method with an existing published method, with the objective of validating the new method as a tool for use at other sites. A modified version of American Society for Testing and Materials (ASTM) Method E741-00 was used to obtain an independent estimate of the AER at Building 1833 while simultaneously deploying the helium method developed for this program. The ASTM method involves the release of a tracer gas into a building at a constant, known rate, and then measuring the equilibrium concentration in the building air. A formula is then applied to calculate the AER.

Building 1833 at Vandenberg AFB was selected for these experiments based on its suitability and logistical considerations. The criteria for selecting a building were that it be a commercial/industrial building with an area on the order of 1,000 to 5,000 square feet, and available for conducting these experiments: Building 1833 matched these criteria, and it’s proximity to Tetra Tech’s Santa Barbara, California office made it a logistically favorable option.

2 SITE BACKGROUND INFORMATION

2.1 Site Background Information

Building 1833 is located on Tethys Road, in a relatively remote area of Vandenberg AFB, California, approximately two miles northwest of the intersection of Rancho and Umbra Roads and three miles north of the Vandenberg AFB Airfield (Figure 2-1). Meteorological data from the period of the experiments were gathered from a weather station known as Tower 59, located approximately 1.3 miles northeast of Building 1833.

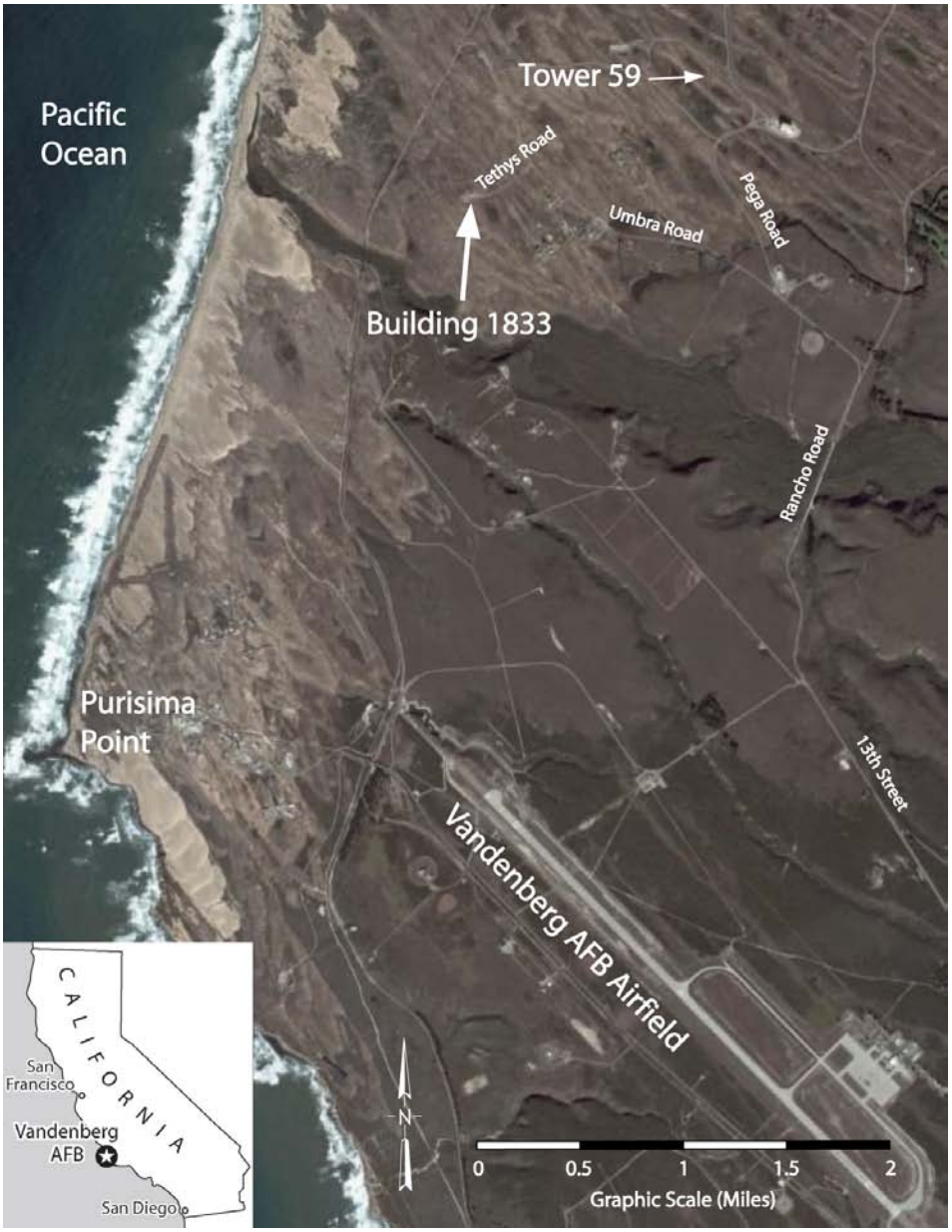

Figure 2-1
Location of Building 1833 at Vandenberg AFB. Source: Google Earth (2009).

Building 1833 consists of a large missile assembly room (service bay) with an office area located on the north side of the building (Figure 2-2). The AER experiments were conducted only in the office area (tan shading in Figure 2-2) and the service bay was sealed off from the office area while the experiments were being conducted.

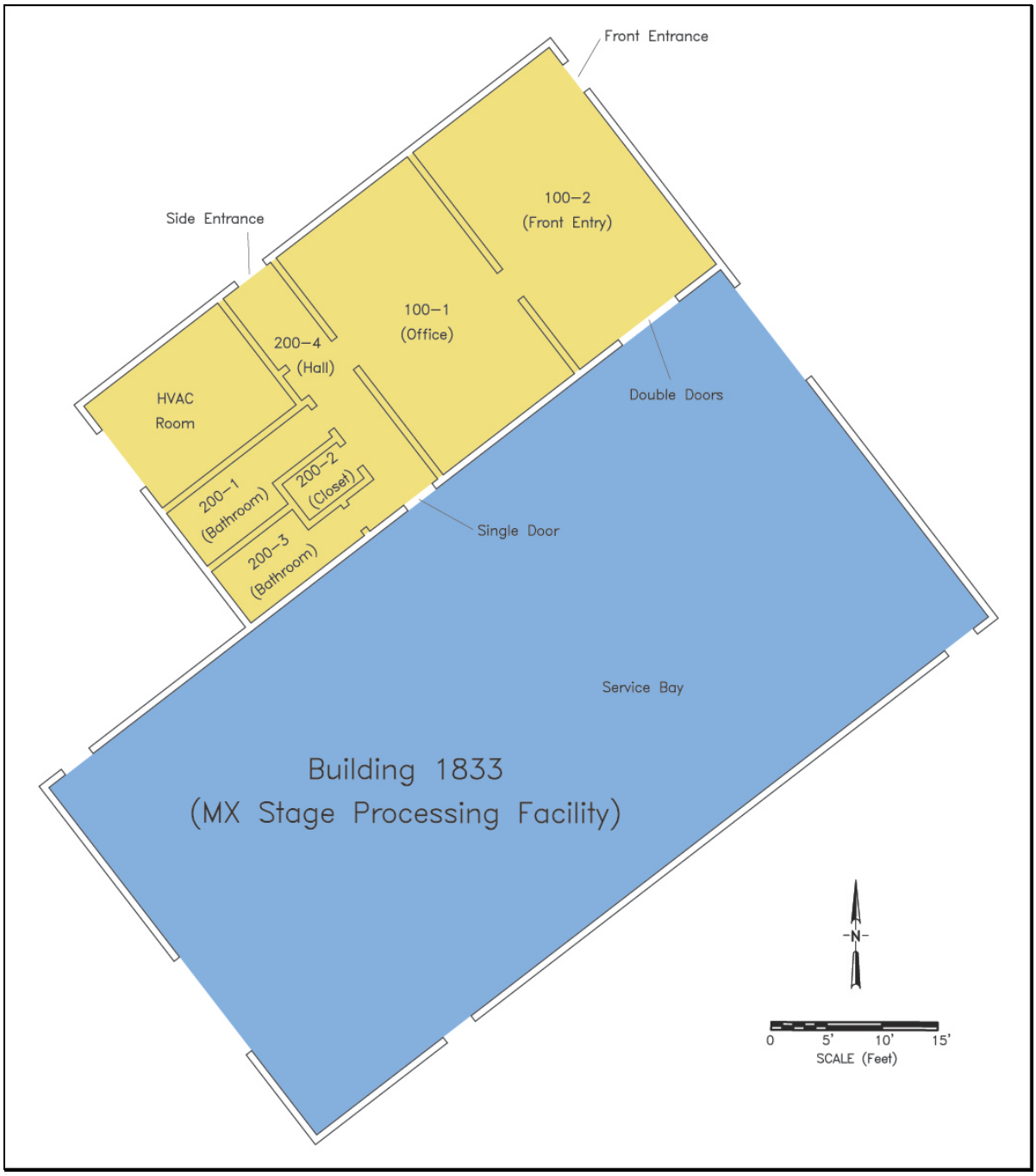

Figure 2-2
Floor Plan of Building 1833 at Vandenberg AFB.

3 MULTIPLE LINES OF EVIDENCE FIELD INVESTIGATION

The experiments were conducted from 15 through 17 June 2009. A variety of samples were collected during the field investigation for on-site and off-site analysis, in order to develop a comprehensive dataset for the comparison of AER experiments. The following sections detail the field activities.

3.1 Building Description and Indoor Volume Estimates

The office area of building 1833 is a single story slab-on-grade structure. An HVAC system located in a room in the western corner of the building services the entire building (Figure 3-1). The HVAC room has no internal connections to the rest of the building (i.e., doors or passageways), other than the HVAC ducting.

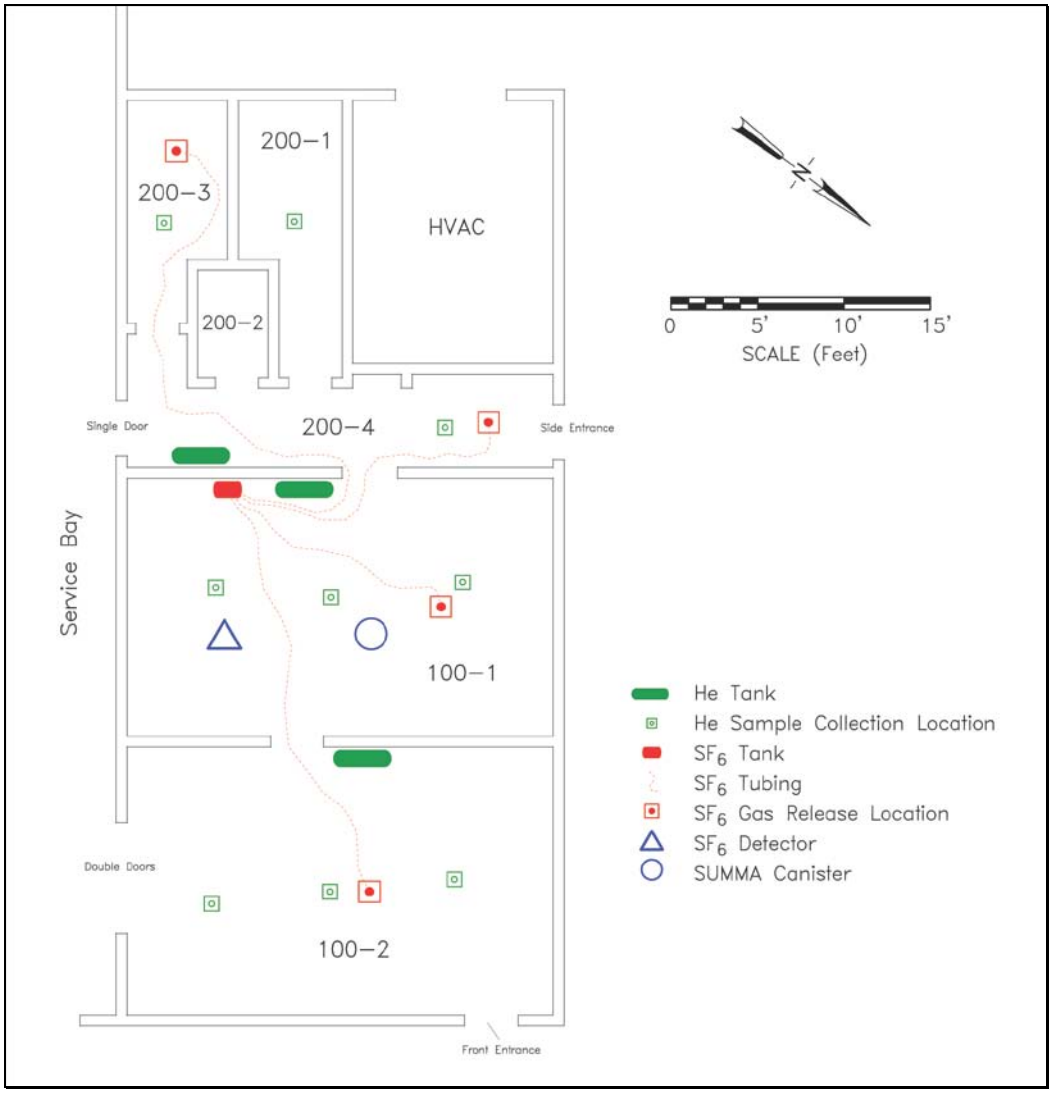

Figure 3-1
Floorplan of Building 1833 office area illustrating components of the AER experiments.

Building 1833 has no windows and only two doors to the outside. Structurally, the building appeared sound with no visible cracks in the walls. As shown on Figure 3-1, one single door and a double door lead to the adjoining service bay. During the experiments, field personnel noticed a constant flux of air flowing under these doors from the office area into the service bay. As such, these locations were identified as significant contributors to the building's AER. Figure 3-2 through Figure 3-5 are photographs of the outside and inside of Building 1833.

Figure 3-2
Photograph showing the north corner of Building 1833 with the slotted doors of the HVAC room visible on the right. Also visible are the front entrance, the side entrance next to the HVAC room, and the large service bay. The external structure to the left of the front door houses a generator used for heating. Three roof vents are visible.

Figure 3-3
Photograph showing room 100-1 (office) looking towards the north, with field personnel crouched next to the SF6 gas detector. The intake port was suspended from the ceiling at a height of approximately 3 feet. The cylinders left of the door leading into the hall contained SF6 gas (silver) and helium gas (orange). Nylaflow tubing was attached to the SF6 gas cylinder and run to four separate locations throughout the office area to enhance distribution of the tracer gas (see Figure 3-1).

A B

Figure 3-4
(A) Photograph showing the SF6 gas source with two-stage pressure regulator, flow meter, and manifolded Nylaflow tubing that lead to various release points in the office area. (B) Close-up view of the variable flow meter used to calibrate the tracer gas release rate, showing a stainless steel float within a graduated flow tube.

Figure 3-5
Photograph taken in room 100-2 (front entry) looking towards the southeast at the double doors leading into the service bay. The doors have been completely sealed using duct tape for the second AER experiment, in which the AER in the office area was deliberately changed from normal conditions.

On 15 June 2009, detailed measurements were taken of each room in order to assess the indoor volume of Building 1833. Indoor volume estimates are presented in Table 3-1. Each room was essentially empty, with only minor ducting and piping.

Table 3-1
Summary table of indoor volumes for Building 1833.

Room containing	Length (in)	Width (in)	Height (in)	Volume (ft^3)
100-1 (office)	280	168	107	2,913
100-2 (front entry)	279	172	107	2,971
200-1 (bathroom)	Various	Various	96	534
200-2 (closet)	72	48	96	192
200-3 (bathroom)	Various	Various	96	537
200-4 (hall)	280	48	96	747
Total Volume without HVAC Room and Service Bay				**7,894**

3.2 Experimental Design

Two separate comparison experiments were conducted at Building 1833, one on 16 June 2009 and the second on 17 June 2009. The original plan called for conducting the experiment first with the HVAC system off and then again with it on, the objective being to conduct the

experiment under two different AER conditions. However, the HVAC blower was found to be malfunctioning, and could not be repaired in time for the experiments; therefore, as an alternative approach, the first experiment was conducted as planned with the building in its condition as-found, with the HVAC off, and the second experiment was conducted with various locations where air could flow in or out of the building, such as around doors, sealed with duct tape to reduce the AER. The objective of this approach was to run the experiment under two different AERs and thereby provide a more robust comparison of the two methods.

Table 3-2
Summary of Field Activities

15 June 2009	• Multiple attempts to turn on HVAC system fail • Indoor volume measurements of office area taken • Steady flow of SF6 tracer gas into office area initiated at 1645 • Continuous logging of SF6 concentrations in Room 100-1 initiated at 1740
16 June 2009	• Helium gas from three 109-cubic-foot cylinders released into office area at 0830 • Indoor air samples for off-site laboratory analysis for He collected subsequently over course of 6 hours • Two discrete indoor air samples collected for off-site laboratory analysis of SF6 at 12:30 and 14:30 • Hand-held He and SF6 detectors carried through office area periodically to collect readings from each room • SUMMA canister deployed in Room 100-1 at 1100 to collect time integrated sample for SF6 analysis • Attempts by Vandenberg AFB personnel to repair HVAC system fail • SUMMA canister closed at 1500 • First experiment completed • Gaps in side entrance to office area and doors leading into adjoining large assembly room sealed with duct tape at 1530
17 June 2009	• Helium gas from three 109-cubic-foot cylinders released into office area at 0830 • Indoor air samples for off-site laboratory analysis for He collected subsequently over course of 5 hours; during each sample collection, a second integrated sample was simultaneously collected in a Tedlar bag and analyzed on-site with hand-held He detector • Three discrete indoor air samples collected for off-site laboratory analysis of SF6 at 0940, 1125, and 1350. • Hand-held He and SF6 detectors carried through office area periodically to collect readings from each room • Second experiment completed • Site cleaned up and restored to condition as found

3.2.1 SF6 Tracer Gas Release

The release of SF6 tracer gas into Building 1833 for the ASTM method was started on the afternoon of 15 June 2009 and continued for the duration of both experiments. Beginning the SF6 release the afternoon of 15 June allowed time for the gas to reach equilibrium in the building prior to the start of the first experiment on the morning of 16 June.

In accordance with ASTM Method E741-00, a pre-determined release rate was selected based on estimates of the building volume and anticipated AER. For this investigation, the tracer gas was a 2.0 percent mixture of SF6 with pure nitrogen as the balance gas. The release was started at 1645 on 15 June 2009. The arrangement for SF6 tracer gas release consisted of a 28-cubic-foot (cf) cylinder, a two-stage pressure regulator that allowed the pressure to be decreased to approximately 2 pounds per square inch (psi), and a flow meter that ensured a constant flow rate of approximately 100 milliliters per minute (ml/min), which equates to approximately 2 ml/min

of SF6 tracer gas (see Figure 3-4B for a close up of the variable flow meter). A series of four manifolded, ¼-inch diameter Nylaflow tubing lengths were attached to the flow meter and run to four locations throughout the office area to promote homogenization of the tracer gas throughout the office area (Figure 3-1). Additionally, four oscillating desk fans were placed throughout the rooms to further enhance mixing of both the helium and SF6 tracer gases. The system was checked for leaks using a MIIRAN SapphIRe hand-held gas analyzer calibrated to detect SF6 gas. The arrangement is shown in Figure 3-3 and Figure 3-4.

Throughout the duration of the experiments, the MIIRAN SapphIRe gas analyzer continuously logged the SF6 concentration in Room 100-1 at 10-minute intervals at the location shown on Figure 3-1. The instrument was set to continually monitor the SF6 concentration and to log the average concentration over each 10-minute interval. Periodically, field personnel took the analyzer to each room to measure the SF6 concentrations in the individual rooms.

3.2.2 Helium Gas Release

The He source for each release (Experiment 1 and Experiment 2) was three 109-cf cylinders of 99 percent pure He, which were placed in the two largest rooms (100-1 and 100-2) and the hall (200-4) Figure 3-1). The valves were fully opened simultaneously by the field crew and the tanks allowed to empty into the building. Each cylinder emptied in approximately 1 minute. The cylinders were weighed before and after release for verification of the mass of helium released.

3.3 Experiment 1

The first experiment was conducted on 16 June 2009. It was assumed that the SF6 tracer gas had attained equilibrium overnight. At 0830, the He was released into the building. Indoor air samples were collected in Tedlar bags for He analysis at 15, 30, 60, 120, 240, and 360 minutes after the release. In addition, indoor air samples were collected in Tedlar bags for SF6 analysis at 240 and 360 minutes after release of the He (i.e. at the same time as the last two samples for HE analysis). All of the samples were collected by drawing indoor air from throughout the building into a 60-ml disposable syringe and expelling it into a Tedlar bag in order to obtain a sample that was representative of the entire building space. Each sample consisted of 150 ml from rooms 100-1and100-2 and 50 ml from rooms 200-1, 200-3, and 200-4 for a total of 450 ml (Figure 3-1).

In addition, a time-integrated indoor air sample for SF6 analysis was collected from Room 100-1 in a SUMMA canister placed at the location shown in Figure 3-1. The canister was open for a period of four hours, from 1100 to 1500.

All of the samples were submitted to Air Toxics, Ltd., located in Folsom, California, for analysis. ASTM method D-1946 was used for analysis of He and an Air Toxics standard operating procedure gas chromatography method was used for analysis of SF6.

3.4 Experiment 2

The second experiment was conducted on 17 June 2009. The original plan specified that the HVAC should be turned on for this experiment in order to alter the AER of the building. However, attempts by Vandenberg AFB personnel to fix the malfunctioning system were unsuccessful. Therefore, the decision was made to completely seal off all gaps in the doors with duct tape and thereby alter the AER by reducing the air flow. The He was released into the building at 0830. Because the He had dissipated faster than expected during Experiment 1, the

decision was made to collect He samples at shorter intervals for the second experiment. Indoor air samples were collected in Tedlar bags for He analysis at 15, 30, 45, 60, 90, 120, 150, 180, 240, and 300 minutes after the release. In addition, indoor air samples were collected in Tedlar bags for SF6 analysis at 70, 175, and 320 minutes after release of the He. All of the samples were collected as described for Experiment 1.

For Experiment 2, samples for He analysis were collected in duplicate. One sample was submitted to Air Toxics for analysis via ASTM method D-1946. The second sample was measured on-site using a Radiodetector MGD 2000 hand-held helium monitor to assess the potential for conducting the AER measurements on-site using a hand-held instrument rather than off-site laboratory analysis.

3.5 Experimental Results

3.5.1 Meteorology During Sampling Period

Previous investigations conducted at CCAFS, former Kelly AFB, and Travis AFB were conducted using multiple lines of evidence, including AER, which were dependent on various meteorological parameters (e.g., barometric pressure, temperature, etc). However, during the focused AER investigation presented herein, only wind speed and direction were considered, as these would influence the pressure differential between the inside of Building 1833 and the outside, thus affecting the AER. The data were collected from a weather station known as Tower 59, located approximately 1.3 miles northeast of Building 1833 (Figure 2-1). As shown in Figure 3-6, wind speed fluctuated significantly between 0 and 5 meters per second (m/s) during the first day of the investigation, increased to between 5 and 7 m/s throughout the night and early morning of the second day of the investigation, and decreased to between 3 and 4 m/s during the experiment conducted on the second day. The wind generally came from the northwest.

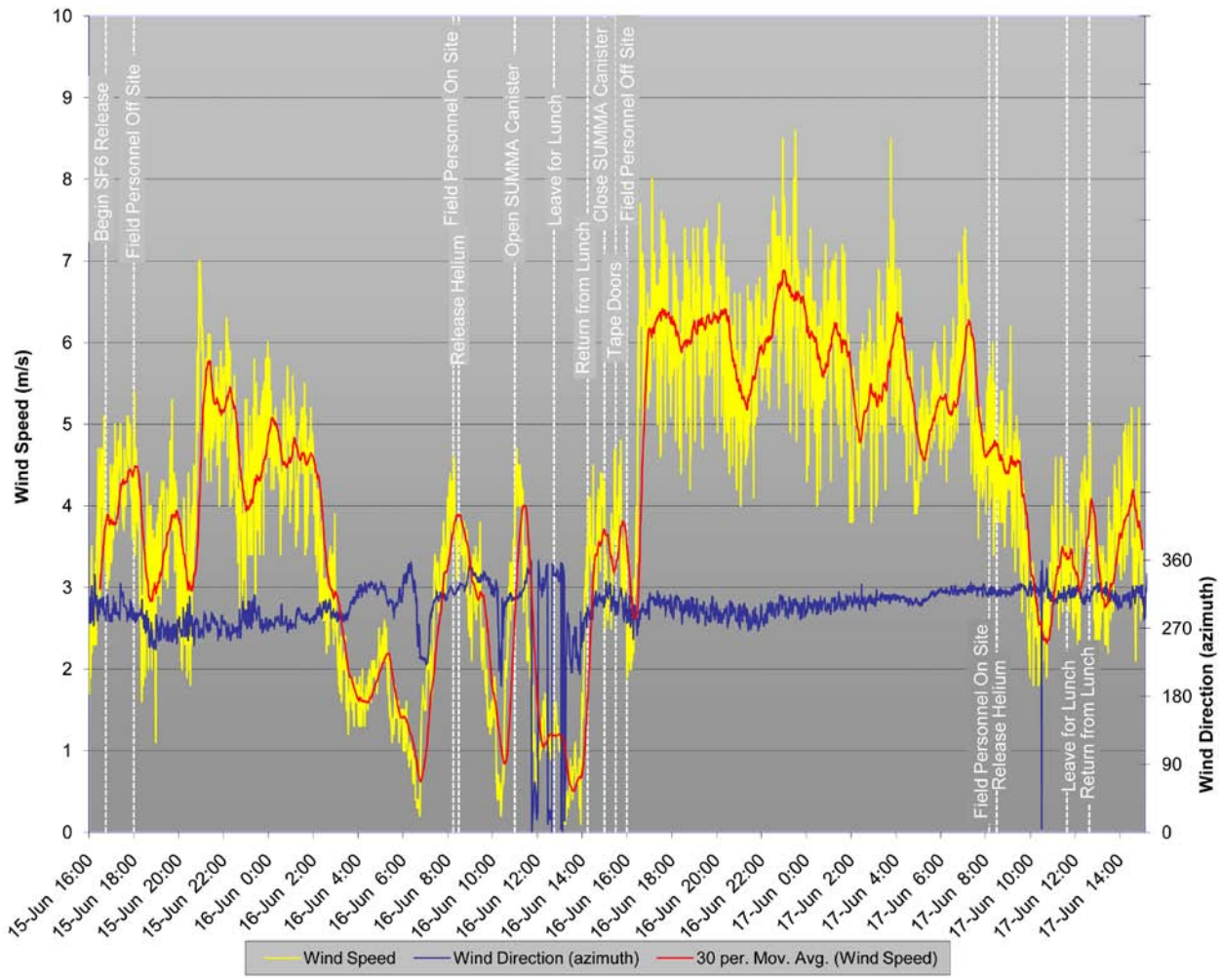

Figure 3-6
Plot of wind speed in meters per second and direction in azumuthal degrees from north at a location approximately 1.3 miles northeast of Building 1833 during the investigation. Redline represents the moving 30-point average windspeed.

3.5.2 Experiment 1 Data

Off-site laboratory analysis for SF6 and helium analyses was performed by Air Toxics. Samples He15, He30, He60, He120, He240, and He360 were collected for off-site analysis of He by ASTM method D-1946. Samples SF6-1, SF6-2, and 1833-SM were collected for off-site analysis of SF6 by method ATL GC APP#08 (an Air Toxic's method). Analytical results are presented in Table 3-3.

Table 3-3
Helium and Sulfurhexafluoride Results Summary
Experiment 1, 16 June 2009
Building 1833
Vandenberg AFB, California

Collection Time	He Sample ID	Laboratory Determined He Concentration (%)	SF6 Sample ID	Laboratory Determined SF6 Concentration (ppbv)
0845	He15	1.8	-	-
0900	He30	1.0	-	-
0930	He60	0.41	-	-
1030	He120	ND	-	-
1230	He240	ND	SF6-1	290
1430	He360	ND	SF6-2	360
1100-1500	-	-	1833-SM	340

Definitions:
He - helium
ND - not detected
ppbv - part per billion by volume
SF6 - sulfurhexafluoride

Notes:
Sample analyses performed by Air Toxics Ltd.
Reporting limit for He is 0.050 percent.
Reporting limit for SF6 is 0.50 ppbv.

On-site analyses of SF6 and helium were conducted by field personnel using the MIIRAN SapphIRe gas analyzer calibrated to detect SF6 in parts per billion (ppb) and the Radiodetector MGD2000 calibrated to detect helium gas in parts per million (ppm). He and SF6 concentrations determined using the hand-held on-site instruments are presented in Table 3-4.

Table 3-4
Helium and Sulfurhexafluoride On-Site Measurements
Experiment 1, 16 June 2009
Building 1833
Vandenberg AFB, California

	Room				
Time	**100-1**	**100-2**	**200-3**	**200-1**	**200-1**
Helium (ppm)					
9:00	6,600	10,700	1,245	750	2,650
9:30	7,325	8,325	3,275	2,650	4,675
10:30	5,925	5,825	5,500	5,375	5,650
12:30	ND	ND	ND	ND	ND
14:15	ND	ND	ND	ND	ND
SF6 (ppb)					
8:35	530	464	675	240	375
9:35	401	391	615	135	350
10:40	210	279	480	90	260
11:45	255	282	520	100	265
14:15	315	270	510	173	291

Definitions:
ppb - parts per billion
ppm - parts per million

Note:
Results shown for each room

3.5.3 Experiment 2 Data

Off-site laboratory analysis for SF6 and helium analyses was performed by Air Toxics. Samples He15, He30, He45, He60, He90, He120, He150, He180, He240, and He360 were collected for off-site analysis of He by ASTM method D-1946. Samples SF6#1, SF6#2, SF6#3 were collected for off-site analysis of SF6 by method ATL GC APP#08 (an Air Toxics' method). Analytical results are presented in Table 3-5. A time-integrated sample for SF6 analysis was not collected for the second experiment.

Table 3-5
Helium and Sulfurhexafluoride Results Summary
Experiment 2, 17 June 2009
Building 1833
Vandenberg AFB, California

Collection Time	He Sample ID	Laboratory Determined He Concentration (%)	Hand-held Meter Determined He Concentration (%)	SF6 Sample ID	Laboratory Determined SF6 Concentration (ppbv)
0845	He+15	1.9	1.59	-	-
0900	He+30	1.4	1.13	-	-
0915	He+45	0.95	1.05	-	-
0930	He+60	0.67	1.08	-	-
0940	-	-		SF6#1	530
1000	He+90	0.37	0.76	-	-
1030	He+120	0.23	0.41	-	-
1100	He+150	0.15	0.21	-	-
1125	-	-		SF6#2	820
1130	He+180	0.11	0.15	-	-
1230	He+240	0.053	0.08	-	-
1330	He+300	ND	ND	-	-
1350	-	-	-	SF6#3	540

Definitions:
He - helium
ND - not detected
ppbv - part per billion by volume
SF6 - sulfurhexafluoride

Notes:
Sample analyses performed by Air Toxics Ltd.
Reporting limit for He is 0.050 percent.
Reporting limit for SF6 is 0.50 ppbv.

As on the previous day, on-site analyses of SF6 and helium were conducted by field personnel using hand-held analyzers, and as discussed in Section 3.4, Tedlar bag samples for He analysis were collected in duplicate, with one sample sent to Air Toxics for off-site analysis and the second bag analyzed on site using the hand-held instrument. Results from this effort are presented in Table 3-6. Results of the on-site He measurements of the Tedlar bag samples are also presented in Table 3-5 for comparison to the laboratory data.

Table 3-6
Helium and Sulfurhexafluoride Results Summary
Experiment 2, 17 June 2009
Building 1833
Vandenberg AFB, California

Time	Room					Bag[1]
	100-1	100-2	200-3	200-1	200-1	
Helium (ppm)						
8:45	18,975	20,000	15,650	14,250	13,800	15,850
9:00	10,350	7,200	7,650	5,875	7,450	11,250
9:15	9,725	7,800	6,850	5,475	7,875	10,500
9:30	10,175	8,550	8,050	6,800	8,750	10,750
10:00	7,550	7,500	5,825	5,150	6,125	7,575
10:30	4,200	4,275	3,000	2,475	3,350	4,100
11:00	2,475	2,850	1,675	1,600	1,850	2,125
11:30	1,700	1,900	1,025	900	1,100	1,475
12:30	1,025	1,075	750	700	700	800
13:30	175	200	50	0	0	0
SF6 (ppb)						
8:10	621	481	1,200	390	604	-
8:55	491	433	1,000	440	560	-
9:20	530	435	1,075	400	540	-
10:15	558	530	1,080	370	560	-
11:05	685	662	1,030	490	690	-
12:45	945	921	1,140	595	795	-
13:45	-	460	800	333	474	-

Definitions:
ppb - parts per billion
ppm - parts per million

Notes:
1 - measurement from Tedlar bag
Results shown for each room

3.5.4 Continuous SF6 Monitoring

In addition to collecting measurements of both He and SF6 in each room, continuous logging of SF6 was conducted in Room 100-1 throughout the duration of the investigation. Results from this effort are presented on Figure 3-7. Figure 3-7 also includes the off-site laboratory data for SF6 analysis. The time integrated sample (SUMMA canister) contained SF6 at a concentration slightly higher than the readings from the logger, which is attributable to the SUMMA canister's proximity to an SF6 gas release location (Figure 3-1). The Tedlar bag sample data are similar to the logged data (Figure 3-7).

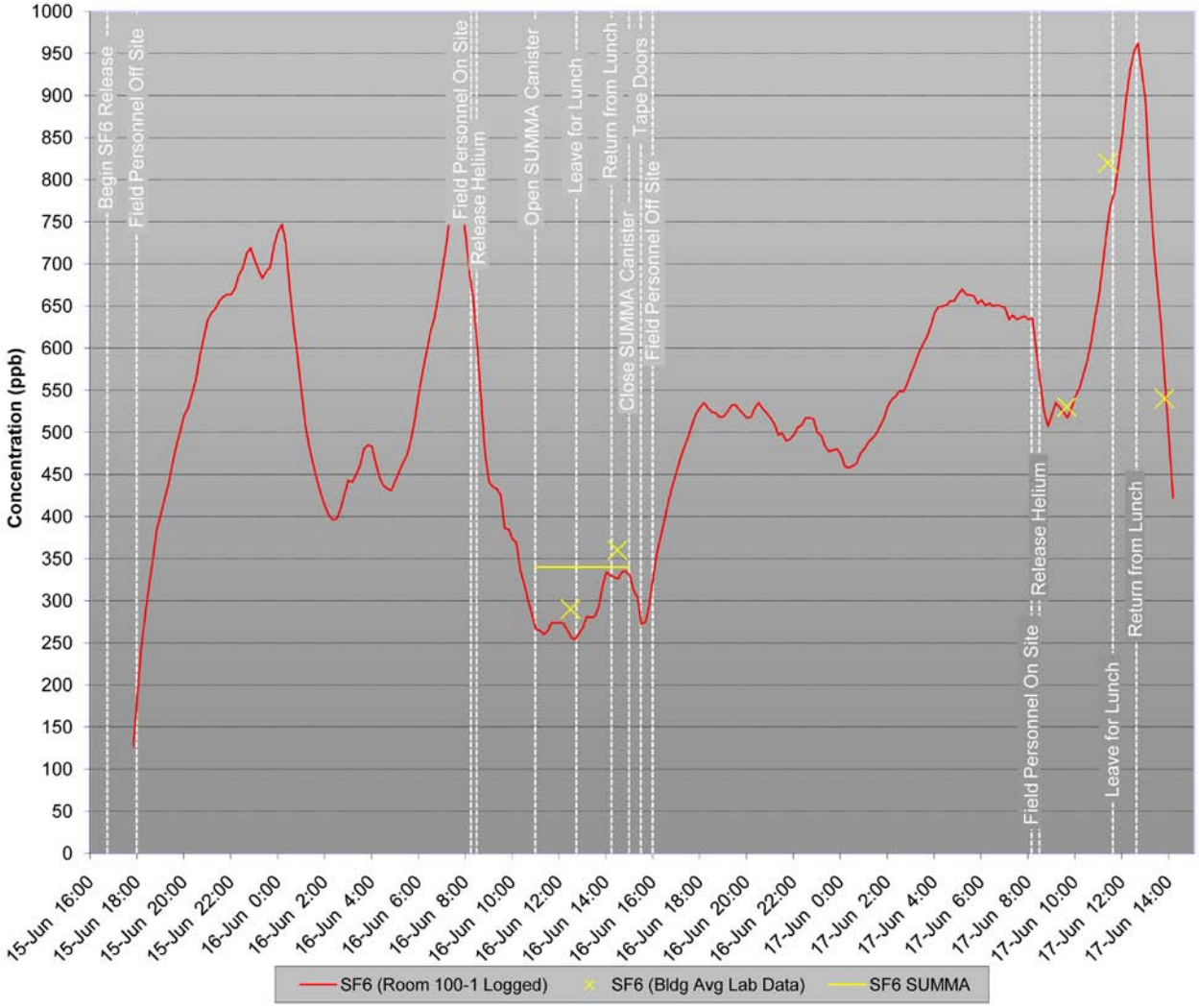

Figure 3-7
Plot of SF6 concentration in Room 100-1 over the course of the investigation as determined using MIIRAN SapphIRe (red line). Yellow crosses indicate concentrations determined by off-site laboratory from Tedlar bag samples. Yellow line indicates concentration determined by off-site laboratory from SUMMA canister.

3.6 QA/QC Considerations

Chain-of-Custody documentation and laboratory data reports are presented in Appendix A. All on-site and off-site laboratory analyses and data validation were performed in accordance with Appendix B. No data quality discrepancies were encountered.

4 AIR EXCHANGE RATE (AER) CALCULATIONS

Air exchange rate analyses were determined for Building 1833 using the following two approaches:

- A known mass of helium was instantaneously released into the building, and periodically samples of air containing helium were collected.
- A known constant rate of SF_6 was released into the building and both continuous and discrete samples were collected.

The theoretical basis of the methods is shown in Appendix C.

The first sets of results are based on He releases, and are shown in Figure 4-1 and Table 4-1. The results in Figure 4-1 depict a least squares best fit analysis approach, which produces one estimate for each set of daily data. The AERs are the highest of the four sites analyzed during this project:

- 52.7/day for 16 June 2009 with the building "as-is"
- 36.4/day for 17 June 2009 with the building more closed up by using duct tape to seal selected air exchange pathways

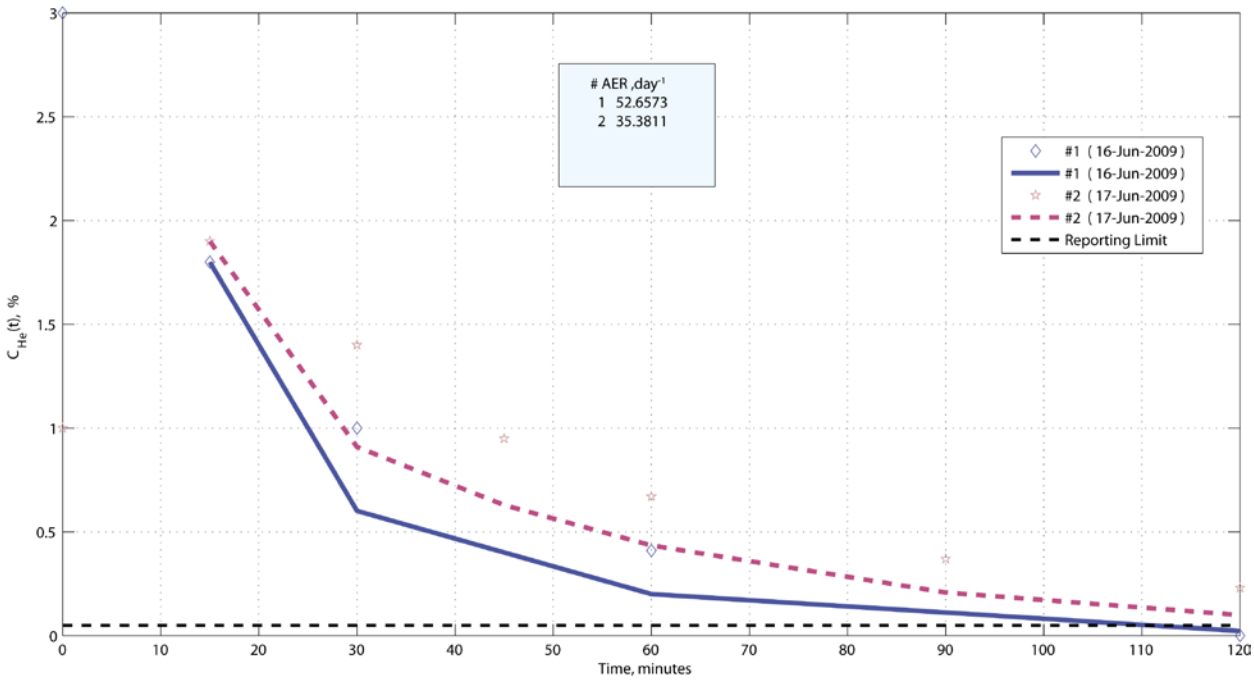

Figure 4-1
Analysis of Air Exchange Rate (AER) Using Instantaneously Released He Analyzed in an Off-site Laboratory.

Table 4-1
Air Exchange Rates by Sub-intervals of time based on discrete samples of helium (the RL=0.05%)

Sample Collection Time	Sample ID	Time From Release, min	He (%)	AER, 1/day
June 16, 2009				
8:45	He+15	15	1.8	-
09:00	He+30	30	1.0	56.4
09:30	He+60	60	0.41	42.8
10:30	He+120	120	<RL	-
12:30	He+240	240	<RL	-
14:30	He+360	360	<RL	-
				Average: 49.6/day
June 17, 2009				
8:45	He+15	15	1.9	-
9:00	He+30	30	1.4	29.3
9:15	He+45	45	0.95	37.2
9:30	He+60	60	0.67	33.5
10:00	He+90	90	0.37	28.5
10:30	He+120	120	0.23	22.8
11:00	He+150	150	0.15	20.5
11:30	He+180	180	0.11	14.9
12:30	He+240	240	0.053	17.5
13:00	He+300	300	<RL	-
				Average: 25.5/day

The second approach to calculating AER using He was to divide the sampling period into intervals and determine AER for each interval. This was done to better see if there were correlations between meteorological conditions and AER. These results are shown in Table 4-1, again for each day.

For the first day (June 16, 2009) only two sub-interval AERs were calculated, since the helium dissipated more quickly than expected. For the second day, samples were collected more frequently and more sub-interval AERs were calculated.

Table 4-2 summarizes the whole-building laboratory results for SF_6, and the calculated AERs using those data.

Table 4-2
AERs calculated using SF_6 data (SF_6 releases began at 16:45, 15 June 2009)

Sample Collection Time	Sample ID	SF_6 (ppbv)	AER (1/day)	Reliability
June 16, 2009				
12:30	SF6-1	290	44.5	High
14:30	SF6-2	360	35.8	High
11:00-15:00 (integrated)	1833-SM	340	37.9	Moderate
June 17, 2009				
9:40	SFG#1	540	23.9	High
11:25	SF6#2	820	15.7	Low
13:50	SF6#3	540	23.9	Low

The air exchange rates shown in Table 4-2 were made based on SF_6 that was released continuously beginning nearly 20 hours before sampling started.

Figure 4-2 compares helium concentrations calculated using an offsite laboratory and then using a hand-held instrument. Data collection began 15 minutes after release, and continued until 240 minutes after release (the reporting level was attained then).

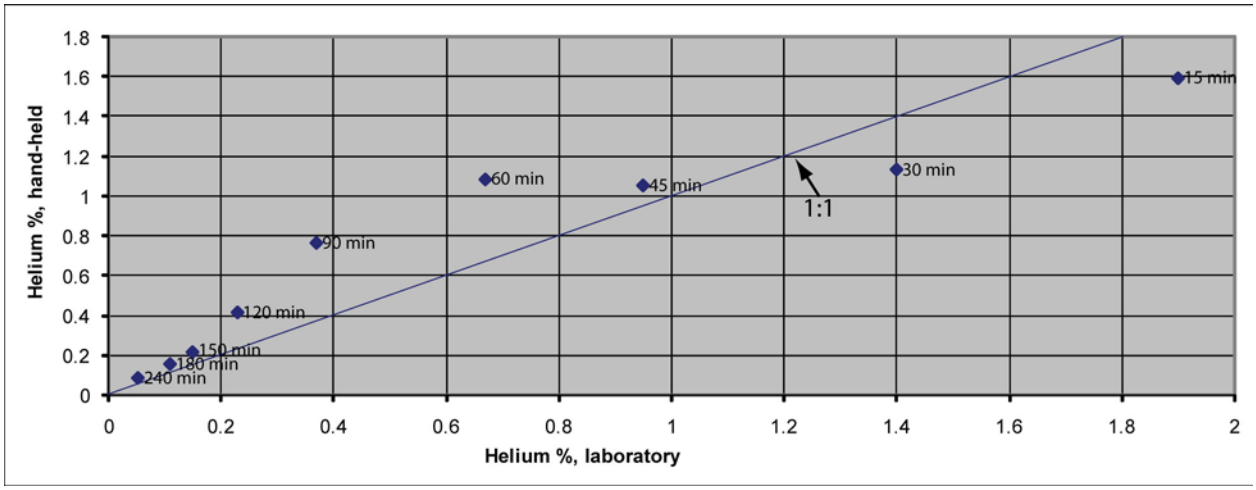

Figure 4-2
Comparison of Laboratory Helium concentrations vs. Hand-held measurements (Times shown adjacent to data points are referenced to minutes after helium release. The helium was released at 8:30 AM on 17 June 2009.)

The data obtained using the hand-held instrument were used to calculate the least squares air exchange rate, and results are shown in Figure 4-3. The 1:1 line is shown that indicates perfect agreement

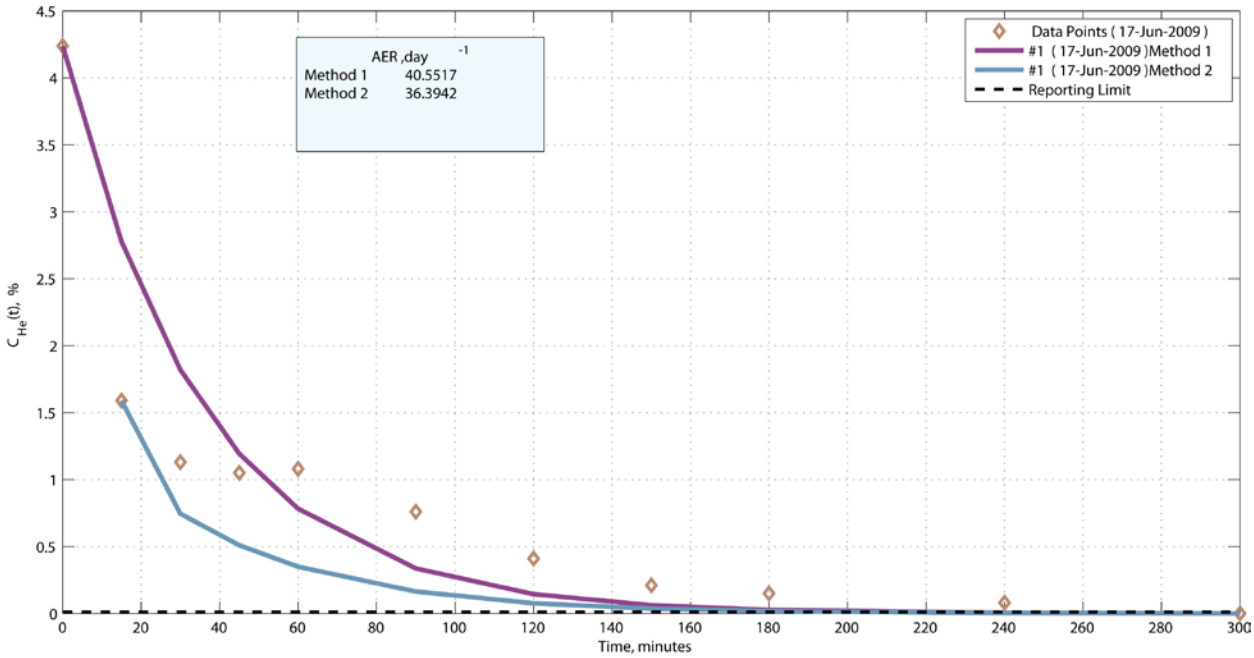

Figure 4-3
Analysis of air Exchange Rate (AER) Using Instantaneously Released He Collected by a Handheld Instrument. (Method 1 and 2)

5 DISCUSSION AND RESULTS

The air exchange rates calculated using a least-squares technique and analyzed using either an off-site laboratory or a handheld instrument showed remarkable agreement (see Figure 4-1 and Figure 4-3). Comparing results of the June 17th tests, it was found that:

- The air exchange rate was 36/day using an off-site laboratory to quantify helium concentrations
- The air exchange rate, using a handheld instrument to sample helium, ranged between 36-41/day.

This agreement was good despite the fact that comparative concentrations did not always fall on the 1:1 line (Figure 4-2), and illustrates the advantage of using a least-squares technique.

Figure 5-1 compares air exchange rates calculated by the helium air exchange method and by the SF_6 method.

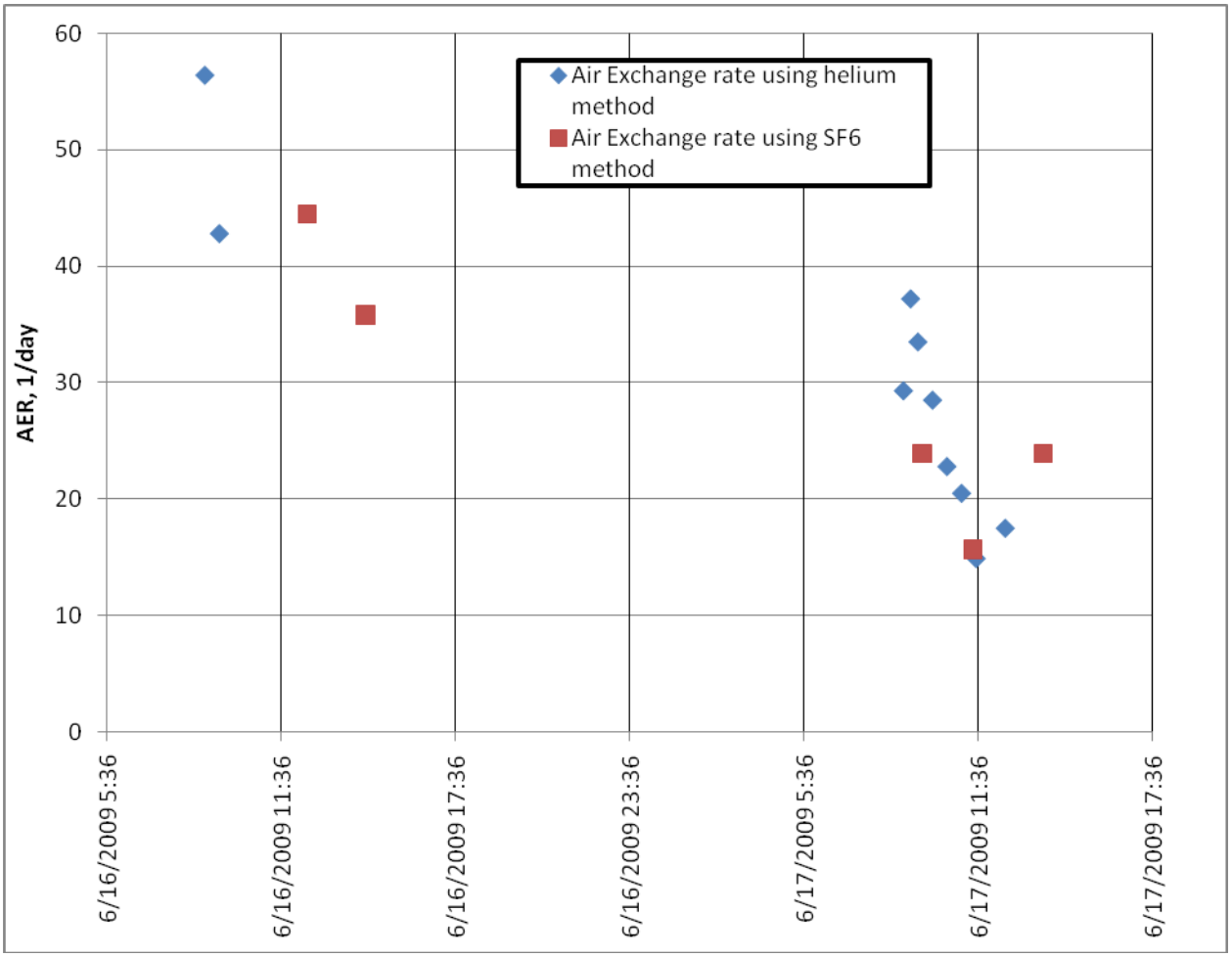

Figure 5-1
Comparison of air exchange rates calculated by two different methods

All data used in this analyses were quantified using an off-site laboratory. There is general agreement between methods, but it is difficult to make quantitative comparisons since the helium and SF_6 data were generally collected at slightly different times, and because of rapidly fluctuating wind speeds (see Figure 3-6).

Figure 5-2 is the same as Figure 5-1 except 30 minute moving-average winds speeds and 4 hour moving-average wind speeds are included. The helium method used a time interval of approximately 30 minutes. The 4-hour wind speeds were added as a comparison. The results indicate that while air exchange rates are changing rapidly, as is the wind speed, no definitive correlation was evident.

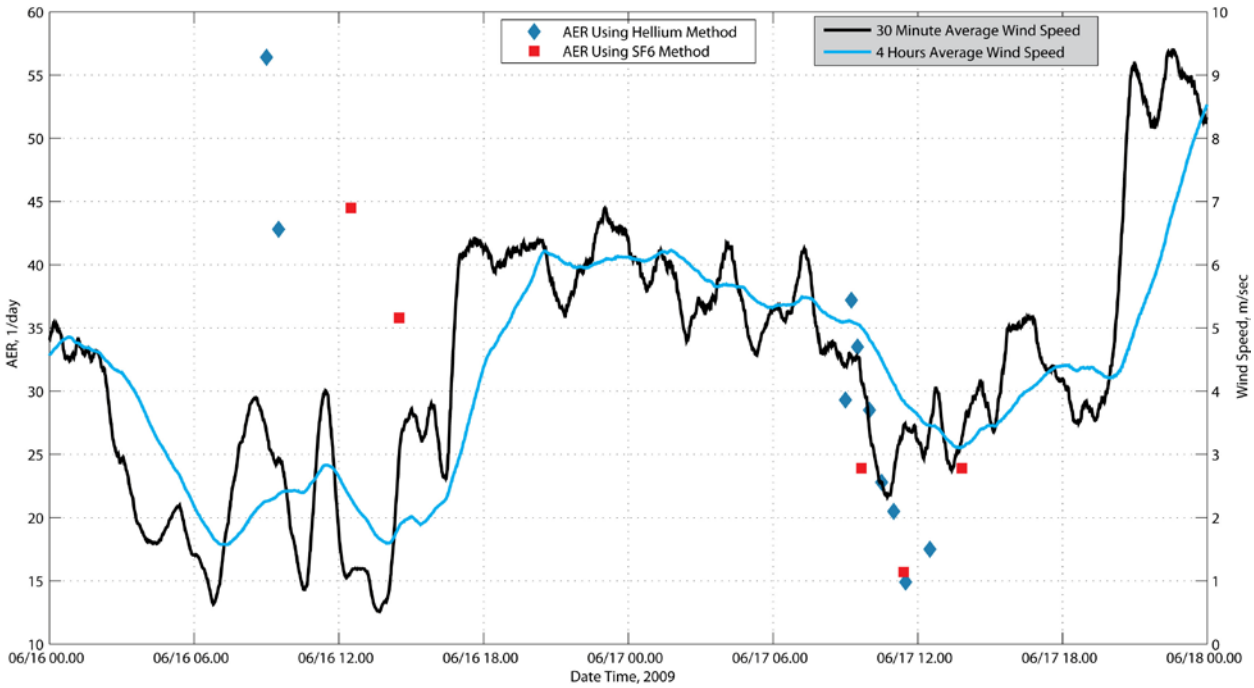

Figure 5-2
Wind speeds superimposed on Air Exchange Rates

Figure 5-3 is similar to Figure 5-1, except a continuous series of calculated air exchange rates are shown. These compare well against the SF_6 method, and lightly less well for the helium method.

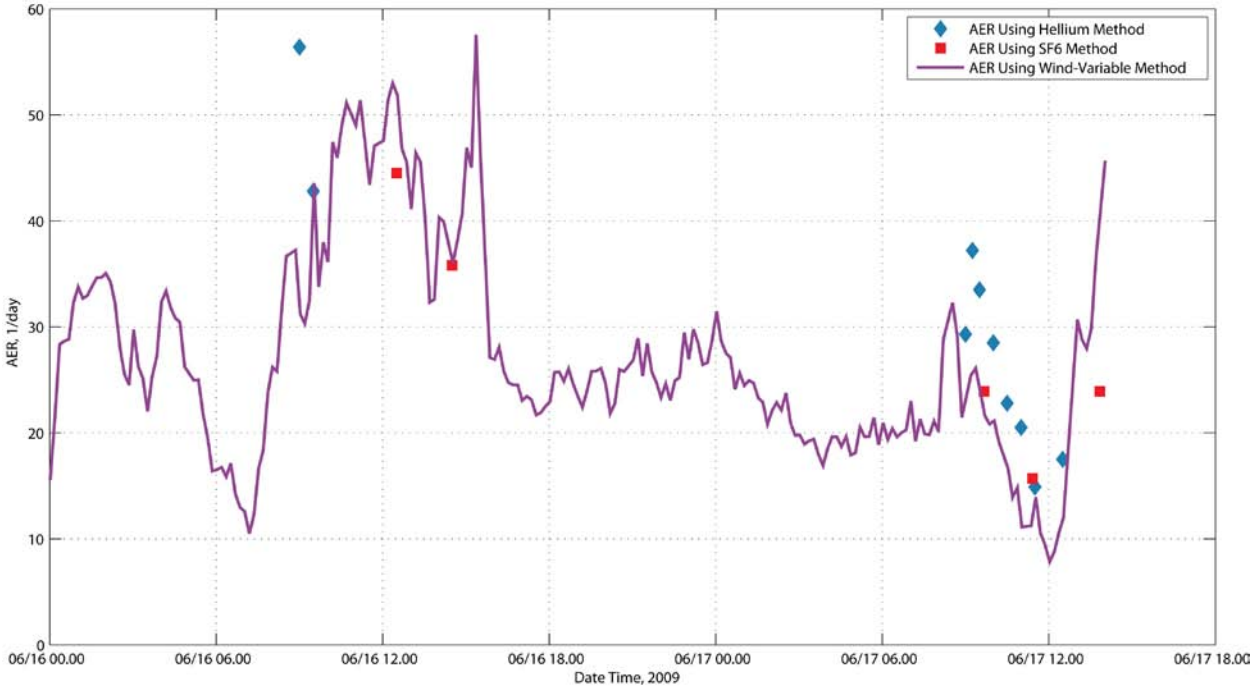

Figure 5-3
Continuous and discrete air exchange rates

6 CONCLUSIONS

1. Air exchange rates (AERs) were calculated using helium and SF_6. Several techniques to analyze the results were developed and are discussed below.

2. Using instantaneously released helium, air exchange rates were calculated in the same fashion as at the previous three sites. The AERs at VAFB were higher than at all other sites. On day 1 (June 16, 2009) the AER, calculated by a least-squares method, was approximately 52/day.On day 2 (June 17, 2009) AER were somewhat lower (typically 36/day), and the decrease was likely due to the fact that several air exchange pathways were sealed

3. On July 17, 2009 a handheld instrument was used to collect helium samples, and the AER calculated from this method was 36/day, practically the same as calculated using laboratory quantified data.

4. A constant release of SF_6, a standard method used to determine AERs, was sustained for the entire field event, and the results were compared to those from the helium method. The results were generally comparable, but because the SF_6 data and helium data were collected at slightly different times, and because the wind speed was so variable, detailed comparisons of the data were not performed.

5. To take advantage of the variable wind speed, a new algorithm for AER calculation was developed that provided continuous predictions of AER. When these predictions were compared against the helium data, the comparison was generally good, adding credibility to the helium method.

7 REFERENCES

Johnson, P.C.; Ettinger, R.A. (1991) Heuristic model for predicting the intrusion rate of contaminant vapors into buildings. *Environmental Science & Technology* Vol. 25, p 1445-1452

Mills, William B.; Liu, Sally; Rigby, Mark C.; and Brenner, David (2007) time-Variable Simulation of Soil Vapor Intrusion into a Building with a Combined Crawl Space and Basement. *Environmental Science & Technology* Vol. 41, No. 14., p 4993-5001

Tetra Tech, Inc. (2009a) Investigation and Validation of Multiple Lines of Evidence to Assess Vapor Intrusion at Cape Canaveral Air Force Station, FL for US Air Force School of Aerospace Medicine (USAFSAM/OE at Brooks City-Base, TX

Tetra Tech, Inc. (2009b) Investigation and Validation of Multiple Lines of Evidence to Assess Vapor Intrusion at Kelly Air Force Base, TX for US Air Force School of Aerospace Medicine (USAFSAM/OE at Brooks City-Base, TX

Tetra Tech, Inc. (2009c) Investigation and Validation of Multiple Lines of Evidence to Assess Vapor Intrusion at Travis Air Force Base, CA