LBID-2491

The Berkeley Hood:

An Operational Envelope Study - 2002

Report Date: 1 December 2003

Test Dates: March – October 2002

Authors:

Geoffrey C. Bell, PE;

Peter Matthes

Team Members:

Dale Sartor P.E., Principal Investigator

Geoffrey C. Bell P.E., Project Head and Inventor

Peter Matthes, Student Intern

Dr. Helmut Feustel, Inventor and Consultant

1 December 2003

CEC DISCLAIMER

DOE DISCLAIMER

Table of Contents

Abstract

A new laboratory device, the Berkeley hood, uses a patented push/pull "air divider" design to provide containment of contaminants. Contaminants are removed, or "pulled" from the hood's interior with a conventional exhaust air system. Uniquely, enhanced containment is provided with supply fans that gently "push" air into the hood's interior with low turbulence intensity. Different quantities of supply airflow "push" influence containment performance. Over 100 test runs were performed with different amounts of supply airflow. Consequently, a basic understanding of an "operational envelope", bounded by an acceptable range of supply airflow, was developed.

Chapter I. Executive Summary

Section 1.01 Study Objectives

(a) Overview

This study's primary objective was to increase understanding of the Berkeley Hood's enhanced containment performance capabilities that relate to its unique supply airflow systems.

(b) Conventional Fume Hoods

Fume hoods are ventilated enclosures used in laboratories where hazardous materials are handled. This enclosure has an operable sash that is positioned to protect the user and to allow experiment manipulation. An exhaust air system is connected to the fume hood that draws room air through the hood's operable sash area and ejects the potentially contaminated air outside the laboratory, typically above the lab's roof. Thus, air flow is induced at the sash or "face" of the hood, which is referred to as the hood's "face velocity." Fume hoods are intended to operate 24 hours per day, seven days a week to ensure that hazards generated inside the hood are contained and removed. The basic design of a fume hood that relies on an induced face velocity has not changed appreciably in over 30 years.

(c) The Berkeley Hood

Researchers at Lawrence Berkeley National Laboratory are developing a new, innovative fume hood. The "Berkeley hood" design introduces supply air from the room at the face of a fume hood in conjunction with the conventional exhaust air system. This directed, "push-pull" airflow system creates an "air divider" with low-turbulence intensity that gently pushes air into the hood. Push is provided by three supply plena with individual fans at this stage of development. Pull is provide by the hood's exhaust fan.

The Berkeley hood's air-divider design provides a curvilinear, directed airflow that is not perpendicular to the hood's face. Consequently, using traditional face velocity, as a performance indicator, is inappropriate. Therefore, tracer gas containment, which is a quantitative measure of hood leakage, is used as the performance indicator for the Berkeley hood.

(d) Operational Envelope Definition

An operating Berkeley hood uses three distinct supply input plenums; top, front, and lower to create the containment air divider (see Figure 2.03.1). Logically, each supply plenum's airflow (push) impacts the hood's ability to contain for a particular exhaust flow rate (pull). The question is; "To what degree is the containment influenced by each supply's input, individually and in combination?"

To answer this question, the range (maximum to minimum) of operation for each supply's volume flow rate needs to be determined, individually and in combination, that maintains containment performance. For defining the work performed during this study, these ranges delineate the hood's "operational envelope." The locus of these supply flow rates forms a boundary of an envelope between "passing" and "failing" containment operation. Pictorially, this boundary can be visualized as a surface in three-dimensional space. See Section 3.01 and Figure 3.01.1

(e) Study Constraints

Ideally, an operational envelope study of the Berkeley hood, as described herein, would present a complete depiction of the entire range of supply flows that provide acceptable containment performance, for a given exhaust airflow rate. Simply stated, the operational envelope includes all of the various supply fan flow settings that cause the hood to contain contaminants. Fan settings that cause containment failure are "outside" the operational envelope and settings that maintain containment are within the envelope. Further, the exhaust airflow rate would be varied to "generate" additional envelopes. Time and cost become deciding factors determining how far to "pursue" an ideal envelope study.

Realistically, the "testing matrix" that three independent variables produces is very complex, or "deep." For example, if each supply rate is adjusted in five percent increments, 8,000 potential combinations are possible. Testing containment requires about two hours. Therefore, about 16,000 person-hours would be necessary just to complete the test runs. Additionally, the depth of this testing matrix increases significantly if the hood's exhaust flow rate is also varied. For example, if five different exhaust flow rates were studied, a total of 40,000 test runs would be necessary equaling 80,000 person-hours. Therefore due to budgetary and time constraints, this operational envelope study includes a limited number test runs that were anticipated to provide high levels of insight.

Section 1.02 Preliminary Considerations

(a) Initial Setup

The Berkeley hood is a constant volume device, i.e., once installed, the total volume of exhaust is fixed. Prior research has indicated that the present design "contains" with an exhaust airflow as low as 30 percent of a conventional hood operating at a face velocity of 100 feet per minute (FPM). Demonstration installations of the Berkeley hood are being installed at an equivalent flow of 50 percent of a conventional hood. For this study, an exhaust airflow equal to 40 percent was used for all evaluations. This choice positions testing between the two values.

(b) Test Method and Thresholds

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers

(ASHRAE) provides a test method for Laboratory hoods in their *Method of Testing Performance of Laboratory Fume Hoods* 110-1995. Relevant tests from the ASHRAE method were used throughout this operational envelope study. These tests included: quantitative containment tests with a mannequin using tracer gas (SF_6), sash traverse tests using SF_6, and both large and small-volume smoke tests. Smoke tests are an efficient "first test" since they provide a visual indicator, which is easily observable.

In the case of quantitative tracer gas (SF_6) tests, thresholds values used for determining "containment loss" for a "pass" or "fail" are from the Laboratory Ventilation Standard Z9.5-2003 produced by the American National Standards Institute and the American Industrial Hygienists Association (ANSI/AIHA). Ratings can be provided for a hood at three levels of installation:

- *"As manufactured"*—initial test of performance in a highly controlled/idealized setting commonly at the manufacturer's facility. A release rate of SF6 tracer gas of 4.0 liters per minute must not be detected at an average concentration of greater than 0.05 ppm over a five minute test run, also stated as 4.0-AM-0.05.

- *"As installed"*—testing is completed in the actual, fully operating facility, potentially more difficult conditions than the manufacturers' facility. A release rate of SF6 tracer gas of 4.0 liters per minute must not be detected at an average concentration of greater than 0.10 ppm over a five minute test run, also stated as 4.0-AI-0.10.

- *"As used"*—testing is performed by adding a hood operator's experimental equipment, a.k.a., "clutter", to the "as installed" hood, making the test conditions even more difficult. A release rate of SF6 tracer gas of 4.0 liters per minute must not be detected at an average concentration of greater than 0.10 ppm over a five minute test run, also stated as 4.0-AU-0.10.

(c) Putting "Failure" into Perspective

The primary purpose of the study is to cause the Berkeley hood to "fail." The frequency that this term appears throughout the document can be disconcerting, but this is the goal of the work. Therefore, to construe that the hood is a failure is not a correct conclusion that one may draw from the work. Therefore, noting a "failure" point only defines the "edge" of the operational envelope and does not indicate that the hood does not work, only "when" the hood does not work. In addition, the term is used when supply airflow rates were zeroed to simulate "failure" of a plenum supply system.

Section 1.03 Primary Conclusions

Primary conclusions follow:

- The Berkeley hood has a broad range of supply plenum airflows where containment is maintained.
- Containment is maintained at very low supply plenum "push-rates."

- Consistent containment was achieved with push-rates between 35 and 80 percent of total exhaust flow.
- Optimum push-rate seems to be approximately 60 percent of total exhaust flow.
- Occasional containment loss was noted when push volume was 80 - 85 percent of total exhaust.
- A push volume of greater than 85 percent can cause containment loss.
- A single supply plenum airflow "failure" does not necessarily result in loss of containment.
- In some cases, multiple supply plenum airflow "failures" do not result in loss of containment.
- Large volume smoke escapes when supply volume equaled, or exceeded, 100 percent exhaust volume, indicating a failure to contain.

Section 1.04 Secondary Results

Secondary findings include:

- Containment tests were performed with singular and multiple supply plenum(s) inoperative. At small push-rates, operating only the lower plenum yields better containment readings than running only the top, or front plenums. This indicates that the lower plenum may be more effective than the other plena when push-rates are low.

- An open-sash traverse test is important for noting containment loss at the hood's work surface. The ASHRAE 110-1995 "sash traverse test" requires moving the tracer gas detector's probe around the entire circumference of the sash opening (with the sash raised) at a distance of one inch inside the opening at a rate of three inches per second.

  In a conventional hood, airflow in this region has a high degree of turbulence that can cause the hood to spill. In the case of the Berkeley hood, airflow in this region has a low degree of turbulence that enhances overall hood containment. Numerous traverse tests were performed that clearly showed the effectiveness the push-pull system and especially the ability of the lower supply plenum to sweep the lower portions of the hood.

- Operating the front plenum at a "high" flow rate caused spillage. One reason might be that the velocities are much higher with the same volume flow rate at the lower plenum because the front plenum's outlet size is relatively smaller. Increasing the front plenum's outlet opening would reduce the outlet velocity.

- Outflow velocity of each plenum was measured along its width. As expected, the distance the velocity probe was positioned from the outlet surface influenced the measurement. It was found that measurements one inch above supply plena screen/grills provided the most accurate readings when correlated with total flow indicated by the plenum's critical-orifice flow-monitoring system.

- Supply outlet velocity varied across each plenums width to the following degree: (while still providing containment).
  - lower plenum had greatest degree of variation, 27 percent
  - front plenum, 15 percent
  - top plenum,<15 percent

  Note that even with these amounts of variation, containment was provided during the majority of tests, demonstrating a robust operating range.

- The profile of the hood's face velocity was studied without the Berkeley hood's push supply fans operating in relationship to actual total exhaust. It was found that total exhaust volume will be overestimated if the hood evaluator only uses face velocity measurements, per the ASHRAE 110-1995 method.

Chapter II. Fume Hood Overview

Section 2.01 Introduction

A fume hood is an enclosed working chamber that flows room air through it with an exhaust air system. Fume hoods are used in laboratories all over the world as a primary worker-safety device. Fume hoods eject potentially contaminated air outside the laboratory, typically above the lab's roof. They typically operate 24 hours a day, 365 days a year.

Lawrence Berkeley National Laboratory has invented a new fume hood, which is known as the Berkeley Hood. The Berkeley hood has the potential to reduce airflow and increase worker safety. See Section 2.04, below.

In the 1960's, worker safety was assumed to be "attained" by providing specific face velocities. It was claimed that a high face velocity provided a high degree of safety. Further, it was assumed that the higher the velocity, the more effectively the hood should be operating, i.e., more is better. At that time there was no accepted protocol, or method, for measuring a hood's containment performance.

In the mid 1970's, K. J. Caplan and G. W. Knutson began developing a test method to verify fume hood containment performance. Their findings were the basis for the ASHRAE Standard 110-1985, *Method of Testing Performance of Laboratory Fume Hoods* and the revised ASHRAE Standards 110-1995, currently in use.

Section 2.02 Fume Hood Improvements

The only substantive improvements to standard hood designs since the 1950s are a divided back baffle, a lower air foil, and chamfered sidewalls, all of which help achieve a better flow pattern for air entering the hood.

Since the 1970's, various techniques have been developed to improve performance and reduce energy costs including bypass airflow hoods, auxiliary make-up air hoods, restricted sash positioning, and variable air volume (VAV) hoods that adjust airflow according to sash position. VAV hoods offer nearly constant velocity of airflow into the hood's interior providing greater safety than older hood designs.

Section 2.03 The Berkeley Fume Hood

Lawrence Berkeley National Laboratory has developed a promising new technology, a High-Performance Fume Hood, referred to as the Berkeley Hood throughout this document. The Berkeley hood reduces airflow requirements by 50 to 70 percent while maintaining, or enhancing, worker safety.

Berkeley Lab's hood design uses a "push-pull" approach to contain fumes and exhaust them from the hood. Small supply fans located at the top and bottom of the hood's sash, or "face," gently push air into the hood (see Figure 2.03.1).

These low-velocity airflows create an "air divider" that separates the fume hood's interior from the exterior (unlike an air curtain approach that uses high-velocity airflow). Berkeley Lab's air-divider approach of separating and distributing air leads to greater containment and exhaust efficiency. The result is an extremely effective and energy-efficient unit.

It is important to know how the supply volume flow rates influence the Berkeley hood's containment performance. Up to a point, each plenum's flow can be adjusted individually for a particular exhaust flow rate and not materially affect the hood's containment performance. Therefore, understanding this range, called the "operational envelope" is necessary to determine the optimum operating point and to define the tolerance that supply volume flow rate can vary without performance degradation; thus, segueing into this study.

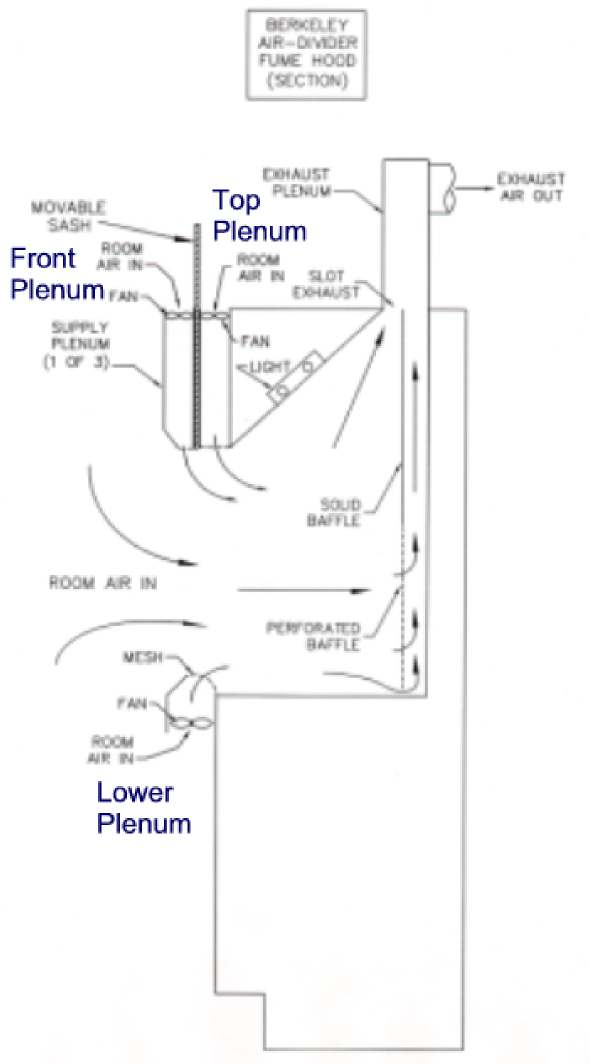


Fig. 2.03.1 Berkeley Hood

Chapter III. Operational Envelope Evaluations

Section 3.01 Visualizing the Operational Envelope

As stated in Section 1.01 (e), an idealized operational envelope study presents a complete depiction of the entire range of supply flows that provide acceptable containment performance. Thus, the envelope describes the boundary between where the hood fails to contain contaminants and where it can be operated safely for a range of supply airflows at a particular exhaust flow rate.

To picture the boundary, or surface of an "operational envelope", one first needs to visualize the range of supply fan operation in a three dimensional space where each axis X,Y,Z refers to airflow volume from each plenum; top, front, and lower respectively. The units for each axis can be chosen as volume flow rate or as normalized values of a percentage of total exhaust volume flow rate. See Figure 3.01.1, below.

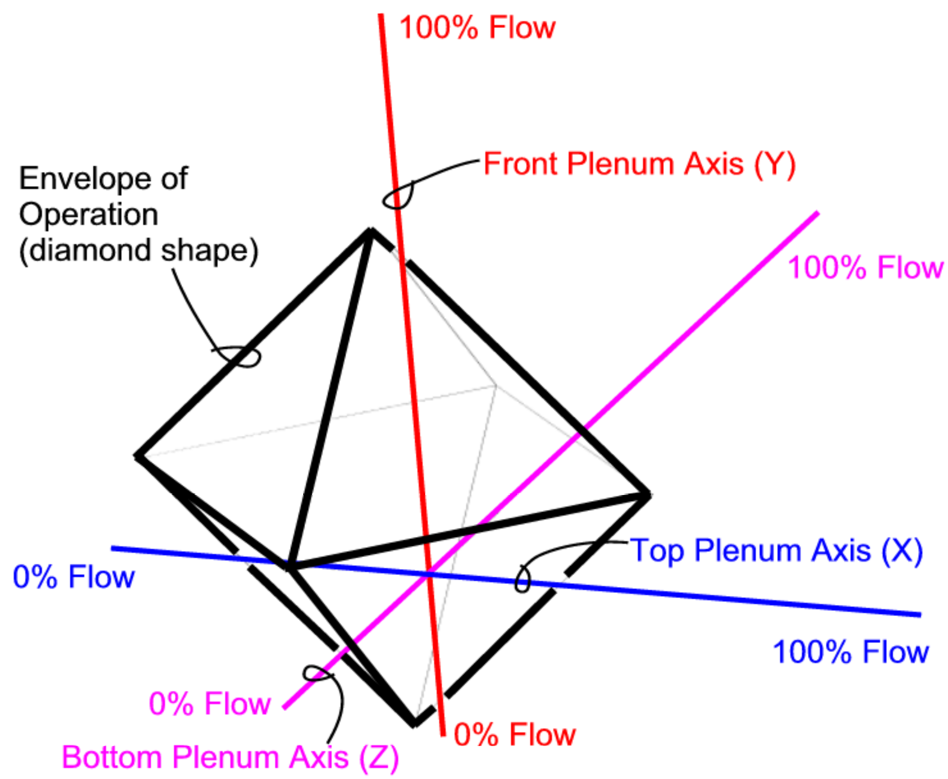
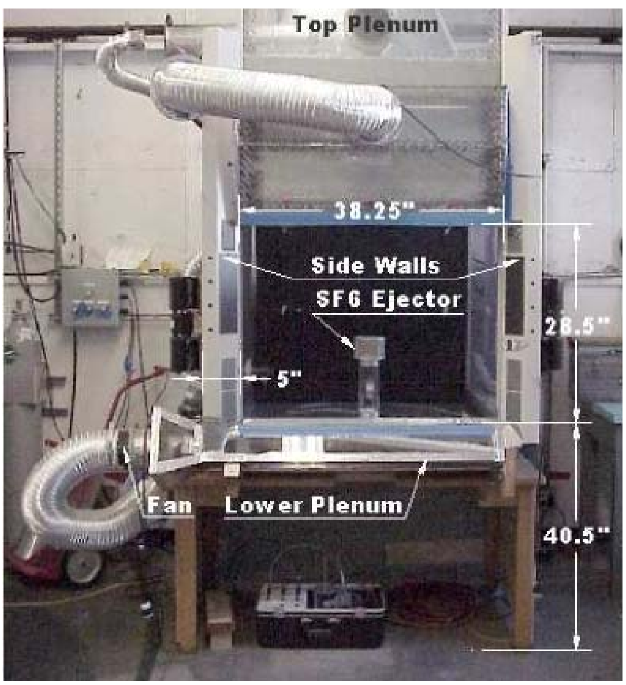


Fig. 3.01.1: Operational Envelope Depiction

In Figure 3.01.1, the operational envelope of the Berkeley Fume Hood is shown as a “diamond shape” for the sake of illustration. Acceptable containment performance would lie within this three dimensional space defined by the diamond. Therefore, the surface of this diamond-shaped envelope is the boundary between “containing” hood operation and “spilling” hood operation, i.e., the boundary where the hood fails to contain contaminants. In this example (Figure 3.01.1), the intersection of the three axies is within the boundary of the operational envelope at a total of 70 percent push rate (Top@30 percent + Front@20 percent + Bottom@20 percent = 70 percent). Little is known about an actual shape operational envelope (surface geometry).

Section 3.02 Test Hood Arrangement

This study’s results are based on a modified four-foot hood from Labconco; a standard *Protector* fume hood with a vertical sash. This modified test hood was arranged with transparent sidewalls so the interior of the hood is observable from outside the hood. A copper tube for the tracer gas supply enters the hood at the right sidewall. The left sidewall holds the orifice piece for the smoke supply. See Figure 3.02.1



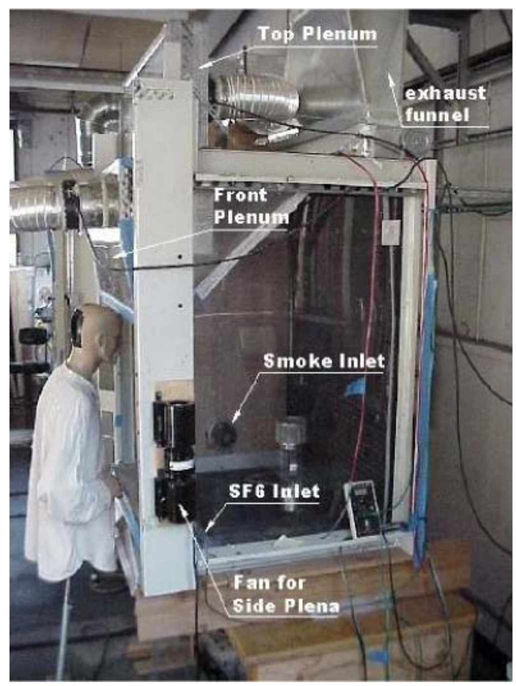


Figure 3.02.1: Four-foot Berkeley Fume Hood. Front and Side View

Each plenum box (top, front and lower) were constructed with transparent plastic. Accordingly, the air flow inside the plena can be easily examined. Every plenum has it’s own axial fan (Comair Rotron, model: Patriot 2B3) that is mounted to its plenum. Air is delivered through a system of six inch (15.2 cm) diameter rigid steel and flexible aluminum ductwork. The rigid ductwork has a “critical” orifice plate at its entrance that is used to calibrate flow measurements. The size of the critical orifice can be changed to provide adjustments from low volume to high flow rate for each plenum. See Figure 3.02.2, below.

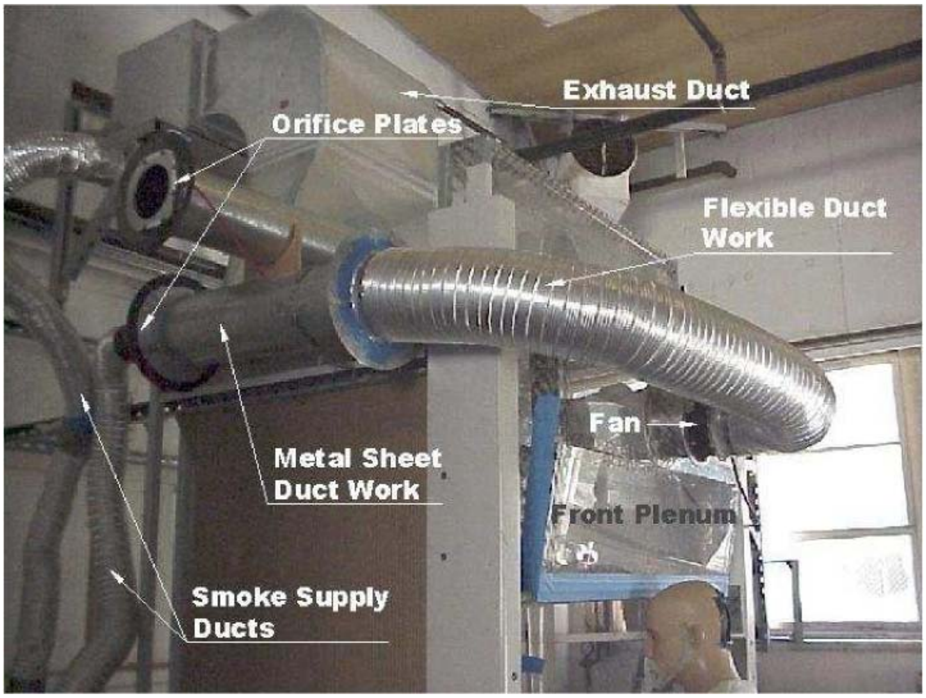


Figure 3.02.2: Four-foot Berkeley Fume Hood. Side View with Ductwork and Orifice Plates

Section 3.03 Initial Berkeley Hood Setup

Establishing the hood's operational envelope began by having the Berkeley test hood complete a successful "pass" of the ASHRAE 110-1995 tracer gas test method per the ANSI Z9.5-1992 standard. Per ANSI Z9.5, a pass for an "as installed" (AI) hood is achieved when the measured tracer gas concentration in the mannequin's breathing zone (see Figure 3.02.1) is 0.10 ppm, or less, over a period of five minutes.

Initially, the Berkeley Fume Hood was set with an exhaust flow rate of 40 percent, when compared to a standard hood. This is 313 cfm (532 m3/s) total exhaust. The supply air flow rates were set to be 70 percent of the total exhaust air flow. Table 3.03.1 provides these values:

Table 3.03.1: Air flow rates for Helium Bubble Test Runs

Exhaust	Top	Front	Lower	Total Supply
313.4 cfm	76.8 cfm	65.8 cfm	76.8 cfm	219.4 cfm

The total supply air flow was distributed by percentage as shown in Table 3.03.2:

Table 3.03.2: Supply airflow rate distribution

Top	Front	Lower
35%	30%	35%

This arrangement of exhaust and supply air flows was used as the starting point for the helium bubble containment tests, see Section 3.04.

Section 3.04 Helium Bubble Containment Tests

Containment testing started by using a helium bubble generator to find the "edges" of the envelope. These tests (test runs #0 through #44) were rechecked with the large-volume smoke source (see Section 3.11, below) because the smoke test procedure is more stringent than the helium bubble test.

From the initial setup noted in Section 3.03, above, the hood's supply airflow rates were adjusted, incrementally, one plenum at a time, to initiate a "fail", i.e., a spillage of helium bubbles outside of the hood's interior. The top plenum's air flow rate was adjusted from maximum flow (maximum air flow rate equaled 117.2 cfm in this case due to the maximum capacity of this plenum's supply fan and plenum box arrangement) down to zero flow in steps of five percent. It took nearly three days to finish all of these test runs. The test run itself was done in five minutes, but setup and other data collection required much greater time. For instance, the static pressure differences between the plena and the exhaust, the humidity, and temperature both inside and outside of the building need to be measured and recorded. In addition, smoke visualization tests with a small smoke source were conducted, including noting the time it took for the hood to clear of smoke. Importantly, throughout these test runs, the hood did not fail.

The next series of tests were performed on the front plenum in incremental steps of 10 percent, varying air flow from 100 percent to zero percent. The process was repeated on the lower plenum. Neither test showed any failure with the helium bubbles.

Section 3.05 Airflow Settings for Tracer Gas Tests

For tracer gas test runs, the Berkeley Fume Hood was set with an exhaust flow rate of 40 percent, when compared to a standard hood. This is 313 cfm (532 m3/s) total exhaust. The total supply air flow rate was reset to be 64.5 percent of the total exhaust air flow. Table 3.05.1 provides these values:

Table 3.05.1: Air flow rates for Tracer Gas Test Runs

Exhaust	Top	Front	Lower	Total Supply
312.9 cfm	70.6 cfm	60.8 cfm	70.3 cfm	201.7 cfm

The total supply air flow was distributed by percentage as shown in Table 3.05.2:

Table 3.05.2: Supply air flow rate distribution

Top	Front	Lower
35%	30%	35%

Section 3.06 Sash Opening Traverse Tests

A tracer gas test procedure, per ASHRAE 110-1995 (See ASHRAE 110-1995, Sections 7.1 through 7.10), is a mannequin breathing zone test rated on an averaged reading computed over a five minute interval. Also included in the ASHRAE 110-1995 method (See ASHRAE 110-1995, Sections 7.11) is a "sash traverse test" that requires removing the mannequin and guiding the tracer gas detector's probe around the entire circumference of the sash opening at a distance of one inch inside the sash opening at a rate of three inches per second.

A hood may contain at the mannequin's breathing zone, but a containment loss could be overlooked at the edge of the sash's opening without the traverse test. Consequently, a traverse test ensures containment is being achieved around the edge of the hood's sash opening and provides insight into the difference between "excellent" and "good" containment performance. Conventional hood designs may not provide excellent containment performance at the perimeter of the sash opening. Airflow in this region will become undesirably turbulent due to flow around the sash opening, into the hood's interior, and over the sidewalls and work surface. Some standards, such as the CAL/OSHA 5154.1 hood standard, exempt this region from face velocity requirements since perimeter airflow is typically turbulent and lower in velocity than airflow through the center of the sash opening. Therefore, hoods that have inflowing air with low "turbulence intensity" around the sash perimeter can provide higher containment performance, as demonstrated in part by low traverse test leakage.

Section 3.07 Traverse Tests Thresholds

In early test runs, SF_6 tracer gas concentrations in the mannequin's breathing zone indicated an AI "pass" level of containment. However, at the same time some traverse opening tests indicated higher concentrations of tracer gas. Therefore, the traverse opening test became an important evaluation technique in subsequent test runs.

Unfortunately, there are no commonly used criteria or guidelines for rating traverse tracer gas tests and no consideration is given for "averaging" recorded values in the ASHRAE 110-1995 method. No threshold values are provided by any standards organizations, including ANSI/AIHA. Therefore, for purposes of this study, a "pass" traverse test had a reading below 0.1 ppm. In some cases recorded data had "spikes" with values higher than this threshold. When a reading of 0.1 ppm persisted for more than four seconds, equating to distance of 12 inches, the containment was considered to be a "fail." Table 3.07.1 was used for the compiling the test run data.

Table 3.07.1: Tracer gas test ratings

Range of concentration (ppm)	110 Rating	LBNL Traverse Rating
0.000 to <0.050	AM Pass	Pass
0.050 to <0.100	AI Pass	Pass
0.100 & above	Fail	Fail

Section 3.08 Testing Low Push-Rate Region

Prior to this envelope study, most Berkeley hood operations had been in a region of 65 to 70 percent push, when compared to total exhaust airflow. Therefore, a so called “Low Push-Rate Region” was designated as hood operation with less than a 65 percent push.

Tracer gas tests began with run #45. Tests results showed very good tracer gas containment, even while reducing lower plenum volume. The lower plenum airflow was turned off in tests 56 and 56-2. In addition, for test run 56-2, the SF6 ejector was positioned at the left side of the hood. Similar to prior tests, they have good results. See Table 3.08.1.

Table 3.08.1: Tracer gas tests results for Low Push-Rate[1]

Test No.	% Supply	Top [cfm]	Front [cfm]	Lower [cfm]	Conc. [ppm]
45	64.5%	70.6	60.8	70.3	0.000
46	58.8%	70.4	60.7	52.8	0.000
47	57.3%	70.3	60.6	48.7	0.000
48	56.0%	70.3	60.6	44.8	0.000
49	54.6%	70.5	60.8	40.6	0.000
50	53.2%	70.5	60.8	36.2	0.015
51	51.8%	70.7	60.7	31.6	0.006
52	50.6%	70.4	60.7	27.5	0.019
53	50.9%	70.6	60.8	28.8	0.007
54	46.8%	70.6	60.7	17.8	0.000
55	45.5%	70.7	60.8	11.2	0.000
56	42.1%	70.3	60.8	0.0	0.005
56-2	42.1%	70.3	60.8	0.0	0.009

The ASHRAE 110-1995 traverse opening evaluations performed during runs 56 and 56-2, showed peak tracer gas concentrations of 0.0307 ppm and 0.0180 ppm, respectively. Note that these peaks were much lower than the ANSI/AIHA threshold for a failing grade during a stringent AM test at the mannequin's

[1] Note that tracer gas concentrations are shown for detector positioned at mannequin breathing zone.

breathing zone and were of short duration of two or three seconds.

Section 3.09 Testing High Push-Rate Region

All tests, to this point in the study were of the "low" supply-flow region. All of these test results had readings below both the more stringent 0.05 ppm for the AM rating and the 0.1 ppm AI rating, with reference to ANSI Z9.5-1992. In addition, visual tests with helium bubbles or smoke, indicated no failures. Therefore, additional low supply-flow region tests were temporarily abandoned and tests in a "high" supply-flow region commenced. The so called "High Push-Rate Region" was designated as hood operation with a push-rate greater than 70 percent. See Table 3.09.1 for a sample set of test data.

Table 3.09.1: Tracer gas tests results for High Push-Rate

Test No.	% Supply	Top [cfm]	Front [cfm]	Lower [cfm]	Total Supply	Conc. [ppm]
62	82.1%	92.2	68.5	89.9	250.6	0.031
63	72.9%	76.7	74.9	73.3	224.9	0.019
65	89.7%	114.2	79.9	79.9	274	***0.157***[2,4]
66	79.5%	83.3	80	80.2	243.5	**0.059**[3,4]
67	79.5%	32.4	105.4	105	242.8	0.028
68	89.2%	62.7	106.1	105.1	273.9	**0.091**[3,4]
69	79.2%	83.1	108.2	49.9	241.2	0.03
70	89.7%	114.3	110.2	50.1	274.6	0.049[4]
71	80.3%	83.4	49.9	110.5	243.8	0.039
72	89.9%	114.1	50	109.6	273.7	0.039
73	95.5%	129	49.9	110.2	289.1	0.05[4]
75	79.3%	37.4	136.2	70	243.6	**0.074**[3,4]
76	89.7%	67.8	136	70	273.8	***0.136***[2,4]

As can be seen from the data, tracer gas concentrations began to exceed the AM threshold of 0.05 PPM at push-rates of approximately 80 percent. However, it is important to note that this in not an absolute situation. Depending on the proportioning between the supply plena providing the "push", containment, per the ANSI standard, is maintained in some cases. This further shows that the performance of the Berkeley hood is quite robust.

Tracer gas concentrations exceeded the ANSI AI threshold at push-rates above 90 percent. Again, this is not a situation where containment failure is a certainty. Note that test number 73 maintains containment at this threshold with over a 95 percent push rate.

[2] Note that this value exceeds ANSI 4.0-AI-0.10
[3] Note that this value exceeds ANSI 4.0-AM-0.05
[4] Failed traverse test per this study's threshold value, see Section 3.07

Section 3.10 Tests with Equal Push-Pull

Tests were conducted to understand containment performance when the total amount of supply air was equal to exhaust air volume. In test number 74, the top plenum's flow was increased until the total supply "push" equaled the exhaust volume. The hood failed to contain during this test at the mannequin's breathing zone and the sash traverse test. See Table 3.10.1.

Table 3.10.1: Tracer gas tests results for High Push-Rate

Test No.	% Supply	Top [cfm]	Front [cfm]	Lower [cfm]	Total Supply	Conc. [ppm]
74	99.8%	143.8	49.9	110.3	304	***0.116***

Section 3.11 Inoperative Plena Tests

It was anticipated that the hood might fail when an individual plenum, or combination of plena, was inoperative. Hood operational envelope failure was confirmed when all plena were inoperative in earlier testing (see LBID-2458).

During this phase of studying the hood's operational envelope, three sets of test runs were completed. The Top and Lower plena were turned off individually and a combination of two plena were turned off. These results are presented in Tables 3.11.1, 3.11.2, and 3.11.3, respectively. Note that in only one test run, No. 57, the tracer gas concentration exceeded the more stringent AM requirement of 0.05 ppm. In the case of test No. 100, the traverse test indicated a concentration exceeding 0.1 ppm, but passed the AM threshold of 0.05 ppm. Importantly, during all of these tests, none indicated a loss of containment at the AI threshold.

Table 3.11.1: Tracer gas tests results with Top Inoperative

Test No.	% Supply	Top [cfm]	Front [cfm]	Lower [cfm]	Total Supply	Conc. [ppm]
59	41.9%	0	60.8	70.6	131.4	0.008
106	70.3%	0	105.7	104.7	210.4	0.028

Table 3.11.2: Tracer gas tests results with Lower Inoperative

Test No.	% Supply	Top [cfm]	Front [cfm]	Lower [cfm]	Total Supply	Conc. [ppm]
56	42.1%	70.3	60.8	0	131.1	0.005
56-2	42.1%	70.3	60.8	0	131.1	0.009

Table 3.11.3: Tracer gas tests results with Combination Inoperative

Test No.	% Supply	Top [cfm]	Front [cfm]	Lower [cfm]	Total Supply	Conc. [ppm]
61	9.6%	0	29.1	0	29.1	0.013
60	14.3%	0	44.7	0	44.7	0.000
58	19.1%	0	60.7	0	60.7	0.004
99	32.8%	0	100	0	100	0.037
100	47.5%	0	140.1	0	140.1	0.047[5]
101	24.7%	0	0	76.9	76.9	0.03
103	44.9%	0	0	141	141	0.037
57	22.3%	70.5	0	0	70.5	**0.063**
98	22.9%	70.4	0	0	70.4	0.04
102	46.1%	140	0	0	140	0.03

Section 3.12 Testing with Large Volume Smoke

At this point in the study, It was decided that after performing over 30 tracer gas test runs, a quicker method for determining the envelope boundaries was needed. Therefore, large volume smoke tests were performed to determine if hood spillage could be reliably indicated visually versus tracer gas detection. If a smoke test could be substituted, the time and expense of SF_6 testing would be greatly reduced.

A large volume smoke test was performed in a hood that passed an SF_6 test. A smoke diffuser's surface was positioned where the SF_6 ejector's surface was situated. See Figure 3.12.1.

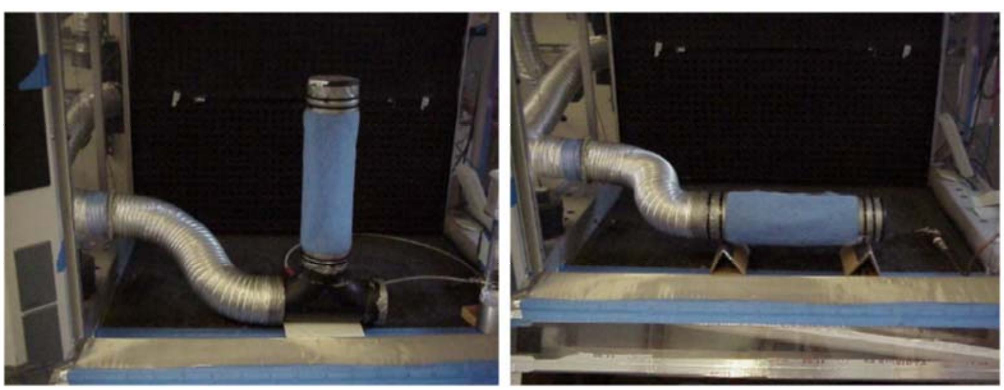


Figure 3.12.1 Vertical and Horizontal Smoke Diffusers

In the initial large-volume smoke test, both vertical and horizontal diffusers were

[5] Failed traverse test per this study's threshold value, see Section 3.07.

used. A visual spillage (failure) was noted where the SF_6 tracer gas test indicated a "pass." This means that the smoke diffusers provide a greater "challenge" for containment than the tracer gas ejector. An example of containment spillage is shown in Figure 3.12.2, below. Note smoke plume extends beyond the plane of the sash. We were unable to design a diffuser's geometry and arrange its position to duplicate the challenge of a tracer gas test.

Tests 77 through 86 were conducted with large volume smoke. Smoke was observed to be leaving the hood, i.e., smoke plumes extending outside the hood's interior beyond the plane of the sash, during many of the high supply air flow-rate test runs. SF_6 spillage for some of these high flow-rate situations were verified in later test runs. See Table 3.12.1.

Table 3.12.1: Large Volume Smoke Tests Results

Test No.	% Supply	Top [cfm]	Front [cfm]	Lower [cfm]	Total Supply	Rating
77	76.7%	21.9	138.5	70.6	231.0	FAIL
78	79.8%	32.3	75.7	135.5	243.5	PASS
79	89.7%	62.8	75.9	135.3	274.0	FAIL
80	79.6%	85.7	140.2	17.8	243.7	FAIL
81	89.8%	115.4	140.1	17.8	273.3	FAIL
82	75.0%	70.2	140.3	17.8	228.3	FAIL
83	63.5%	36.0	138.0	17.7	191.7	FAIL
84	81.1%	85.5	17.8	140.0	243.3	PASS
85	100.3%	115.7	17.8	140.4	273.9	PASS
86	46.1%	146.6	17.8	140.1	304.5	FAIL

Fig. 3.12.2 Large Smoke containment failure, note smoke outside sash plane in far left of this side view.

Section 3.13 Face Velocity Profile

The profile of the hood's face velocity was studied without the Berkeley hood's push supply fans operating. These face velocity measurements were studied in relationship to actual total exhaust.

It was found that a coarse (low resolution) "grid" of velocity measurement will actually indicate higher-than-actual total exhaust volume. A coarse grid is a measurement taken at a point in the plane of the sash every 8 to 12 inches.

When a face velocity test is conducted with a fine (high resolution; every one to two inches) grid, the resulting measurement of average face velocity will be lower than the coarse grid due to low velocities along the hood's vertical sidewalls and horizontal work surface.

Natural resistance to airflow, along the hood's sidewalls and work surface, is a problem that the Berkeley hood air divider technique addresses because air is introduced by the Berkeley hood supply plenums along these surfaces with low turbulence intensity to "encourage" airflow.

Chapter IV. Additional Results

Section 4.01 Plena Outflow Velocity Profiles

The outflow air distribution was measured for each plenum. The following charts are provided that depict the velocity measured every two inches across the width of the plenum's outlet. It is important to note that even though outlet velocity varied in these prototype plenum designs, the Berkeley hood still provides containment over a wide range of operation. See Figures 4.01.1-3.

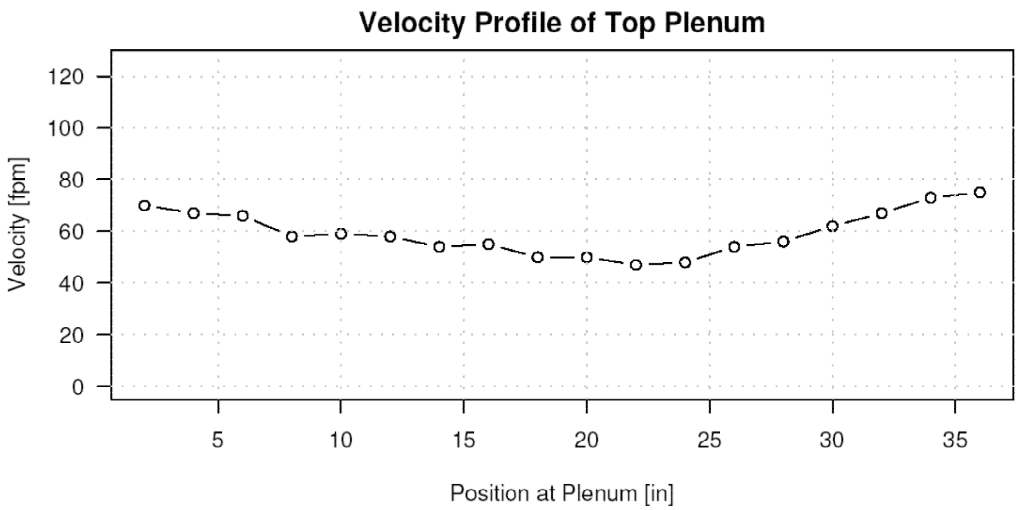


Figure 4.01.1: Velocity Profile for Top Plenum

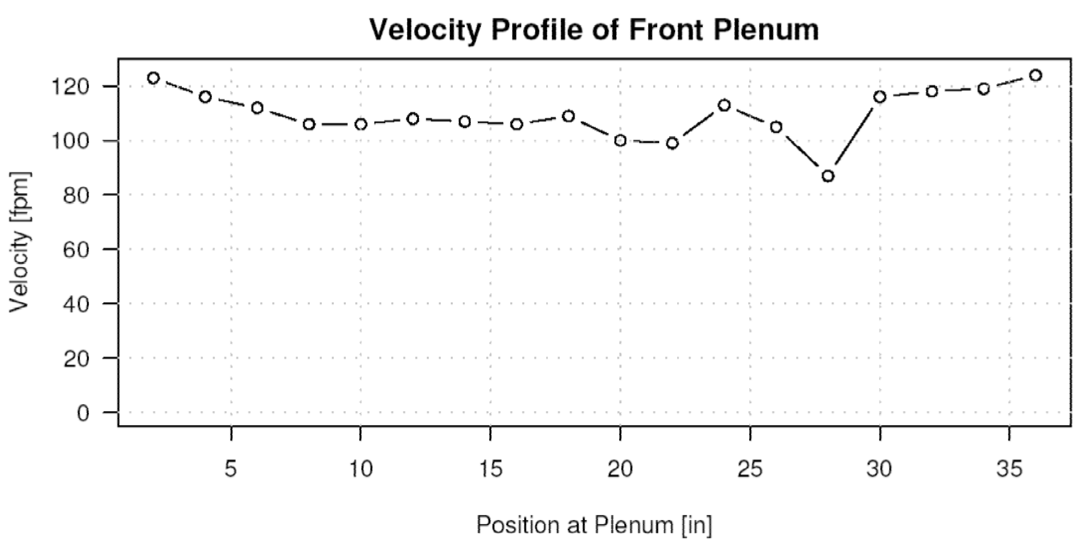


Figure 4.01.2: Velocity Profile for Front Plenum

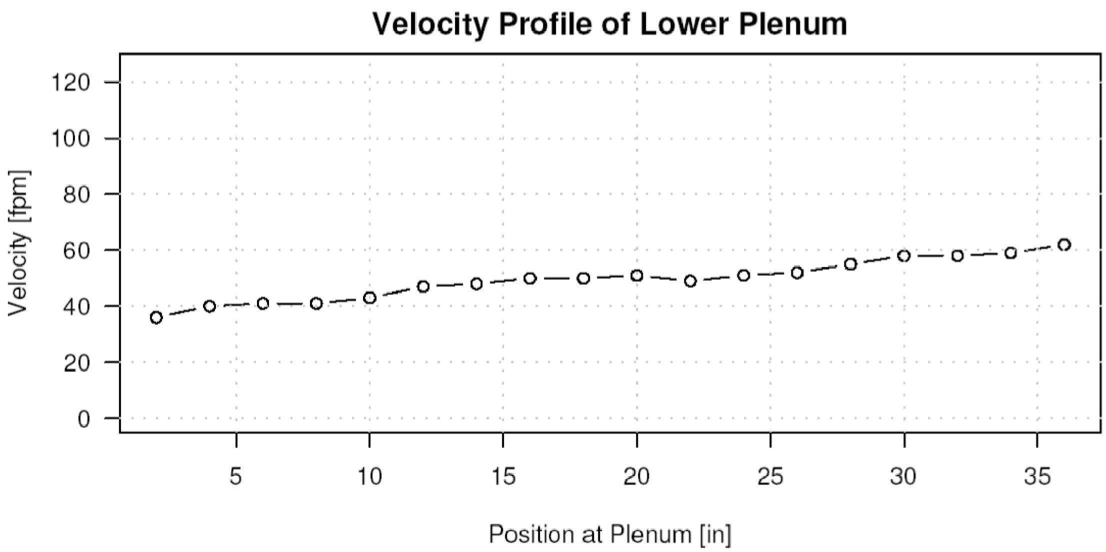


Figure 4.01.3: Velocity Profile for Lower Plenum

Section 4.02 Plena Outflow Velocity Measurements

Outflow velocity was measured at two distances from each plenum's outlet surface: ¾ inch and 1 ½ inches. The results from the lower plenum are provided for reference in Figure 4.02.1.

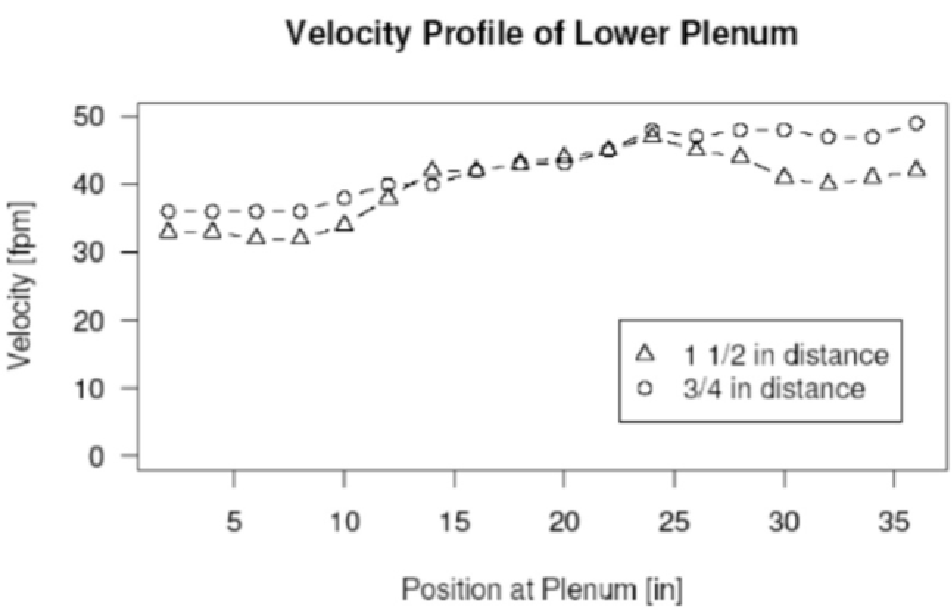


Figure 4.02.1: Velocity Profile for Lower Plenum (3/4" and 1 1/2" from mesh)

This work was performed to correlate measured outflow velocity (in FPM) with actual volumetric flow. Volumetric flow is determined by using the critical orifice measurement data (CFM) through a particular plenum. When the value for the most representative outflow velocity is multiplied by the outflow plenum area, a resulting value for total volumetric flow results (velocity x area= volume). Interpolation evaluations of velocity plots, as in Figure 4.02.1, indicate that the best location to measure the average outlet velocity of each plenum is one inch from the plenum's outlet surface (screen mesh or grill). At this distance, an averaged velocity value for three positions; left, middle and right, provides the best representation of total flow through the plenum when multiplied by the plenum's outlet area.

These results were also confirmed by measuring the static pressure differential readings inside-to-outside of the plena. These measurements were also taken to determine if reading the static pressure inside the plena would be another convenient way to determine the flow rate for each plenum. This procedure is equivalent to flow readings determined with the critical orifice at the supply inlet to each plenum (by pressure vs. flow curve-fitting with regression analyses). Either approach provides good total flow data.

Chapter V. Expanded Data Results

Page 1 of 3

Run No.	Top Plenum (cfm)	Front Plenum (cfm)	Lower Plenum (cfm)	Total Supply (cfm)	Total Exhaust flow rate (cfm)	% Top Supply	% Front Supply	% Lower Supply	% Supply (of Total Exhaust)	Detected SF6 @ 26 " (ppm)	ASHRAE 110 rating	Traverse rating
45	70.6	60.8	70.3	201.7	312.9	35.0%	30.1%	34.9%	64.5%	0.000	AM Pass	PASS
46	70.4	60.7	52.8	183.9	312.9	38.3%	33.0%	28.7%	58.8%	0.000	AM Pass	PASS
47	70.3	60.6	48.7	179.6	313.7	39.1%	33.7%	27.1%	57.3%	0.000	AM Pass	PASS
48	70.3	60.6	44.8	175.7	313.7	40.0%	34.5%	25.5%	56.0%	0.000	AM Pass	PASS
49	70.5	60.8	40.6	171.9	314.6	41.0%	35.4%	23.6%	54.6%	0.000	AM Pass	PASS
50	70.5	60.8	36.2	167.5	314.6	42.1%	36.3%	21.6%	53.2%	0.015	AM Pass	PASS
51	70.7	60.7	31.6	163	314.6	43.4%	37.2%	19.4%	51.8%	0.006	AM Pass	PASS
52	70.4	60.7	27.5	158.6	313.7	44.4%	38.3%	17.3%	50.6%	0.019	AM Pass	PASS
53	70.6	60.8	28.8	160.2	309.5	44.1%	38.0%	18.0%	51.8%	0.007	AM Pass	PASS
54	70.6	60.7	17.8	149.1	318.7	47.4%	40.7%	11.9%	46.8%	0.000	AM Pass	PASS
55	70.7	60.8	11.2	142.7	313.7	49.5%	42.6%	7.8%	45.5%	0.000	AM Pass	PASS
56	70.3	60.8	0	131.1	311.2	53.6%	46.4%	0.0%	42.1%	0.005	AM Pass	PASS
56-2	70.3	60.8	0	131.1	311.2	53.6%	46.4%	0.0%	42.1%	0.009	AM Pass	PASS
57	70.5	0	0	70.5	316.2	100.0%	0.0%	0.0%	22.3%	0.063	AI Pass	FAIL
58	0	60.7	0	60.7	317.8	0.0%	100.0%	0.0%	19.1%	0.004	AM Pass	PASS
59	0	60.8	70.6	131.4	313.7	0.0%	46.3%	53.7%	41.9%	0.008	AM Pass	PASS
60	0	44.7	0	44.7	312.1	0.0%	100.0%	0.0%	14.3%	0.000	AM Pass	PASS
61	0	29.1	0	29.1	304.5	0.0%	100.0%	0.0%	9.6%	0.013	AM Pass	PASS
62	92.2	68.5	89.9	250.6	305.3	36.8%	27.3%	35.9%	82.1%	0.031	AM Pass	PASS
63	76.7	74.9	73.3	224.9	308.7	34.1%	33.3%	32.6%	72.9%	0.019	AM Pass	PASS
65	114.2	79.9	79.9	274	305.3	41.7%	29.2%	29.2%	89.7%	0.157	FAIL	FAIL
66	83.3	80	80.2	243.5	306.2	34.2%	32.9%	32.9%	79.5%	0.059	AI Pass	FAIL
67	32.4	105.4	105	242.8	305.3	13.3%	43.4%	43.2%	79.5%	0.028	AM Pass	PASS

Run No.	Top Plenum (cfm)	Front Plenum (cfm)	Lower Plenum (cfm)	Total Supply (cfm)	Total Exhaust flow rate (cfm)	% Top Supply	% Front Supply	% Lower Supply	% Supply (of Total Exhaust)	Detected SF6 @ 26 " (ppm)	ASHRAE 110 rating	Traverse rating
68	62.7	106.1	105.1	273.9	307	22.9%	38.7%	38.4%	89.2%	0.091	AI Pass	FAIL
69	83.1	108.2	49.9	241.2	304.5	34.5%	44.9%	20.7%	79.2%	0.03	AM Pass	PASS
70	114.3	110.2	50.1	274.6	306.2	41.6%	40.1%	18.2%	89.7%	0.049	AM Pass	FAIL
71	83.4	49.9	110.5	243.8	303.6	34.2%	20.5%	45.3%	80.3%	0.039	AM Pass	PASS
72	114.1	50	109.6	273.7	304.5	41.7%	18.3%	40.0%	89.9%	0.039	AM Pass	PASS
73	129	49.9	110.2	289.1	302.7	44.6%	17.3%	38.1%	95.5%	0.05	AM Pass	FAIL
74	143.8	49.9	110.3	304	304.5	47.3%	16.4%	36.3%	99.8%	0.116	FAIL	FAIL
75	37.4	136.2	70	243.6	307	15.4%	55.9%	28.7%	79.3%	0.074	AI Pass	FAIL
76	67.8	136	70	273.8	305.3	24.8%	49.7%	25.6%	89.7%	0.136	FAIL	FAIL
77	21.9	138.5	70.6	231	301	9.5%	60.0%	30.6%	76.7%	SMOKE	FAIL	FAIL
78	32.3	75.7	135.5	243.5	305.3	13.3%	31.1%	55.6%	79.8%	SMOKE	PASS	PASS
79	62.8	75.9	135.3	274	305.3	22.9%	27.7%	49.4%	89.7%	SMOKE	FAIL	FAIL
80	85.7	140.2	17.8	243.7	306.2	35.2%	57.5%	7.3%	79.6%	SMOKE	FAIL	FAIL
81	115.4	140.1	17.8	273.3	304.5	42.2%	51.3%	6.5%	89.8%	SMOKE	FAIL	FAIL
82	70.2	140.3	17.8	228.3	304.5	30.7%	61.5%	7.8%	75.0%	SMOKE	FAIL	FAIL
83	36	138	17.7	191.7	301.9	18.8%	72.0%	9.2%	63.5%	SMOKE	FAIL	PASS
84	85.5	17.8	140	243.3	300.1	35.1%	7.3%	57.5%	81.1%	SMOKE	PASS	PASS
85	115.7	17.8	140.4	273.9	304.5	42.2%	6.5%	51.3%	90.0%	SMOKE	PASS	PASS
86	146.6	17.8	140.1	304.5	303.6	48.1%	5.8%	46.0%	100.3%	SMOKE	FAIL	FAIL
87	32.3	76.1	135.2	243.6	302.7	13.3%	31.2%	55.5%	80.5%	0.034	AM Pass	PASS
88	62.7	76	135	273.7	305.3	22.9%	27.8%	49.3%	89.6%	0.058	AI Pass	PASS

Run No.	Top Plenum (cfm)	Front Plenum (cfm)	Lower Plenum (cfm)	Total Supply (cfm)	Total Exhaust flow rate (cfm)	% Top Supply	% Front Supply	% Lower Supply	% Supply (of Total Exhaust)	Detected SF6 @ 26 " (ppm)	ASHRAE 110 rating	Traverse rating
89	115.8	17.8	140.6	274.2	303.6	42.2%	6.5%	51.3%	90.3%	0.13	FAIL	FAIL
90	85.4	17.8	139.8	243	304.5	35.1%	7.3%	57.5%	79.8%	0.037	AM Pass	PASS
91	78.1	76.2	134.7	289	304.5	27.0%	26.4%	46.6%	94.9%	0.059	AI Pass	FAIL
92	35.9	140.2	17.8	193.9	302.7	18.5%	72.3%	9.2%	64.1%	0.043	AM Pass	PASS
93	11.6	132.6	129.4	273.6	302.7	4.2%	48.5%	47.3%	90.4%	0.082	AI Pass	FAIL
94	60.8	78.3	105.5	244.6	302.7	24.9%	32.0%	43.1%	80.8%	0.041	AM Pass	PASS
95	90.7	77.8	104.5	273	306.2	33.2%	28.5%	38.3%	89.2%	0.043	AM Pass	FAIL
96	60.2	107.6	75.1	242.9	305.3	24.8%	44.3%	30.9%	79.6%	0.043	AM Pass	PASS
97	90.1	108.7	75	273.8	306.2	32.9%	39.7%	27.4%	89.4%	0.136	FAIL	FAIL
98	70.4	0	0	70.4	307	100.0%	0.0%	0.0%	22.9%	0.04	AM Pass	PASS
99	0	100	0	100	305.3	0.0%	100.0%	0.0%	32.8%	0.037	AM Pass	PASS
100	0	140.1	0	140.1	294.9	0.0%	100.0%	0.0%	47.5%	0.047	AM Pass	FAIL
101	0	0	76.9	76.9	311.2	0.0%	0.0%	100.0%	24.7%	0.03	AM Pass	PASS
102	140	0	0	140	303.6	100.0%	0.0%	0.0%	46.1%	0.03	AM Pass	PASS
103	0	0	141	141	313.7	0.0%	0.0%	100.0%	44.9%	0.037	AM Pass	PASS
104	27.4	77.9	107.4	212.7	304.5	12.9%	36.6%	50.5%	69.9%	0.017	AM Pass	PASS
105	53	80.2	80.4	213.6	303.6	24.8%	37.5%	37.6%	70.4%	0.031	AM Pass	PASS
106	0	105.7	104.7	210.4	299.3	0.0%	50.2%	49.8%	70.3%	0.028	AM Pass	PASS
107	52.8	110.1	50.1	213	306.2	24.8%	51.7%	23.5%	69.6%	0.023	AM Pass	PASS
108	30	107.2	75.4	212.6	305.3	14.1%	50.4%	35.5%	69.6%	0.034	AM Pass	PASS