ABSTRACT

BRENT A. ALTEMOSE. An Investigation of Factors Affecting the Performance of Laboratory Fume Hoods. (Under the direction of Dr. MICHAEL R. FLYNN)

A "user tracer gas test" was performed on laboratory hoods, with a human subject standing in front of the hood, to assess hood containment ability. The relationship of face velocity and cross draft variables to hood containment ability is investigated. The ability of these variables and other tests, such as smoke challenges or tracer gas tests performed with a manikin at the hood, to predict the results of the user tracer gas test is evaluated.

All of the laboratory hoods tested in this study were identical bench top bypass hoods with horizontally sliding sashes. A face velocity traverse, cross draft measurements, a pitot traverse to measure exhaust flow, a smoke test, a manikin tracer gas test, and a user tracer gas test were performed on each hood in several different sash positions.

Based on the data collected, face velocity, its distribution and variability, and the magnitude of cross drafts relative to face velocity are important variables in determining hood leakage. "Unblocked" vortices, formed such that no physical barrier exists between the vortex and room air or a person in front of the hood, are identified as important sites of leakage. For the hoods evaluated in this study, unblocked vortices were observed along the beveled side edges. The data support the hypothesis that in the presence of a person standing in front of the hood, leakage is more likely to occur if unblocked vortices are formed than if all vortices are blocked. Evidence suggests that cross drafts are more likely to cause leakage when flowing in a direction that may cause separated flow along a beveled edge of the hood and thereby augment the unblocked vortices along the edge.

Results indicate that smoke tests, manikin tracer gas tests, and average face velocity all serve as useful monitoring techniques. Face velocity measurements and smoke tests, which are easy and inexpensive, may provide information which is as valuable as traditional manikin tracer gas tests. However, the agreement between the results of these tests and the results of the user tracer gas test are inconsistent and suggest that more research is needed to determine how to evaluate whether a hood protects its users.

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ACKNOWLEDGMENTS

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INTRODUCTION

Many factors affect the containment ability of laboratory hoods. Some are dependent on work practices, such as arm movements of the user, the source characteristics and location, and the positioning of the hood sash.(1-6) Physical characteristics such as the shape of the hood opening and baffle locations and settings in the hood can also affect containment ability.(3,6-8) Furthermore, the location of a hood can lead to disruptive cross drafts across the face, generated perhaps due to the location of air supply diffusers, doorways, windows, or aisle ways relative to the hood.(9,10) Finally, operating parameters, such as the exhaust flow rate, which determine the face velocity, are also very important.(2,7,11,12)

Historically, the parameter recommended for assessing hood performance is face velocity.(11-13) However, this practice has been called into question, so new methods for hood testing have been developed. Visualization of air flow into the hoods with smoke or other visible plumes is one recommended test.(14,15) Tracer tests which involve releasing a test gas in the hood and measuring its concentration in the breathing zone of a manikin, positioned at the hood face, are also commonly used.(1,14,16) To more closely approximate the conditions of actual use for the hood, a tracer gas test performed while a human user is working at the hood has also been developed and tested.(3,17)

Information obtained when testing a hood should predict its ability to minimize exposure. Ideally, to determine the predictive ability of a test, its results could be compared to user chemical or biological exposure data. However, the low concentrations and variability in the types of contaminants and the conditions of their generation, under typical laboratory conditions, prohibit meaningful correlations with hood test data. Administering a tracer gas at a known release rate with a human user at the hood, under actual use conditions, as in Ivany et al. and DiBerardinis et al.,(3,17) is an excellent method of determining how well a specific hood protects that user, under those use conditions. However, under more or less rigorous use conditions, the amount of tracer gas reaching the breathing zone will undoubtedly change. So, correlation of the test results to other parameters would be confounded by the hood use conditions.

For this study, tracer gas tests were performed on each hood with a human subject standing at the hood. The subject made prescribed movements during the test. This "user tracer gas test" was assumed to be the best indicator of the actual protective ability of a hood in the sash position tested.

This study investigates the relationship of face velocity and cross draft variables to hood containment ability, as indicated by the user tracer gas test. The ability of these variables and other tests, such as smoke challenges or tracer gas tests performed with a manikin at the hood, to predict the results of the user tracer gas test are evaluated.

METHODS

All of the laboratory hoods tested in this study were identical Laboratory Furniture bench top bypass hoods with horizontally sliding sashes. The sashes were altered so that four doors, two on each track at the hood face, were present. On each track, one small door and one large door were present. Top, front, and side views, as well as the dimensions, of this type hood are shown in Figure 1.

The configuration of the four sash doors could be classified as either "stacked" or "staggered", as illustrated in Figure 2, which also shows the various possible sash configurations and the naming conventions used. The sash configurations shown are not an exhaustive list, only those configurations which were tested in this study are shown.

The rooms in which the hoods were placed were similar in all cases. Figure 3 depicts a typical room geometry and the convention used to designate the hood location. Four hoods, two on each side, were present in each room. In some rooms, all four hoods were bench top enclosures. In other rooms, the two hoods closest to the air supply (one on each side of the room) were walk-in hoods. Only bench top hoods were evaluated in this study.

Fifteen bench top hoods were studied. For fourteen of these, three sash configurations were tested. The full left and full right openings were tested on all fourteen hoods, and the third set of tests was done in one of the possible center opening positions. For one hood, only two sash positions were tested, the full left opening and one center opening. Therefore, forty four sets of measurements were completed. For each hood opening, the following were performed: a face velocity traverse, cross draft measurements, a pitot traverse to measure exhaust flow, a smoke test, a manikin tracer gas test, and a user tracer gas test.

Face velocity traverses were completed with a thermoanemometer at six points across the hood face in each sash position. For each sash position, the hood doors were closed and cross draft measurements were made at two different heights with the thermoanemometer 18 inches from the hood face. Smoke tests were performed on each sash position, which was assigned a rating of good, fair, or poor. Good indicates the smoke was cleared quickly and no leakage occurred, fair indicates slow clearance or slight leakage, and poor indicates slow clearance and obvious leakage.

Both the manikin and user tracer gas tests were performed by releasing pure sulfur hexafluoride at 4 liters per minute inside of the hood from a 18 inch by 6 inch rectangular diffuser. The concentration of sulfur hexafluoride in the breathing zone of the manikin or human subject was monitored for five minutes with an Ion Track Instruments Model 120 Leakmeter, which contained an electron capture detector. The peak concentration of sulfur hexafluoride during the five minute tests was recorded and used to indicate hood leakage.

The conditions of the two tracer tests were identical with two exceptions. During the user test, a sampling line connected the breathing zone of the human subject to the detector. In the manikin test, the detector probe was placed directly in the manikin breathing zone. The human subject, during the user test, placed both arms into the hood, above the tracer gas diffuser, once every 30 seconds. The manikin's arms remained static at its side throughout the manikin test.

The methodology for the measurements and tests performed on these hoods is described in more detail in Appendix A. Calibration data for the instrumentation used to make the measurements are contained in Appendix B.

In addition to the measurements obtained for this study, a set of historical data were evaluated for 88 bench top hoods. These hoods were of the same type used in this study, Laboratory Furniture bench top bypass hoods with horizontally sliding sashes. The historical data provide information on a face velocity traverse, a smoke challenge, and a manikin tracer gas test for each hood in only one sash position. The face velocity traverses consisted of either six or nine points. The manikin tracer gas test was performed on each hood by releasing sulfur hexafluoride at 4 L/min, for five minutes, from an ejector which met the specifications of ASHRAE 110.(14) The concentration of sulfur hexafluoride in the manikin breathing zone was monitored with an electron capture detector. The peak concentration of sulfur hexafluoride measured during the test was recorded and used to indicate hood leakage.

RESULTS AND DISCUSSION

The raw data used in these analyses are contained in Appendix C. The forty-four sets of measurements obtained for this study and the eighty-eight sets of measurements available from historical data are both included in the appendix. In the analysis of the first set of data, the user tracer gas tests are assumed to be the best indicator of the ability of a hood to protect its users. In analyzing the historical data, since a user test is unavailable, the manikin tracer gas tests are assumed to be the best indicator of this ability.

Comparison of High and Low Leakage Hoods

Definitions for the face velocity and cross draft variables evaluated are listed in Appendix D. A number of these variables are highly correlated with one another. So, four groups of variables were identified and one variable chosen from each group. The four variables chosen are the average face velocity , the average temporal coefficient of variation of the face velocity, the spatial coefficient of variation of the face velocity, and the ratio of the maximum cross draft measured to the minimum average face velocity at any of the six traverse points. The average temporal coefficient of variation is calculated from the average of the standard deviations for the ten measurements taken at each face velocity traverse point. The spatial coefficient of variation is calculated from the standard deviation of the average velocity at the six traverse points.

Building a regression equation for hood containment with the four chosen variables is inappropriate with this data set, given the limited number of peak concentrations which exceeded the limit of detection for the Leakmeter, 0.1 ppm. Instead, the data are stratified into a "high leakage" group and a "low leakage" group. The level chosen as the cutoff between the high and low leakage groups is 0.25 ppm, the level at which the Leakmeter reliably differentiated between concentrations of the tracer gas.

The relationship of the four variables to hood containment ability is assessed by testing for the significance of the difference in their mean values in the two leakage groups. Table 1 shows the mean value for each of the four chosen variables for the high and low leakage groups. The t-test for comparing the means in each of these groups yields three variables for which $p < 0.05$. These variables are the average face velocity, the average temporal coefficient of variation of the face velocity, and the ratio of the maximum cross draft to the minimum face velocity. The direction in which the means increase or decrease for the four variables are all in the a priori expected direction. On average, for the high leakage hoods, the face velocities are lower, the variations of the face velocity are higher, and the ratios of the maximum cross drafts to the minimum face velocities are higher.

The historical data are analyzed in the same manner, using the same cutoff value for tracer gas concentration to stratify the hoods as high or low leakage. In this case, however, a manikin tracer gas test is used to characterize hood containment ability since a user test is unavailable. Table 2 shows the mean values of the average face velocity and the spatial coefficient of variation of the face velocity for the high and low leakage groups. The differences between the mean values in the high and low leakage groups is statistically significant for both variables, with $p < 0.01$. The direction of increase or decrease for the two variables is in the a priori expected direction; the average face velocity is lower and its variation is greater for the high leakage hoods.

These findings suggest that, as practitioners have long observed, face velocity, its distribution and variability, and the magnitude of cross drafts relative to face velocity are important variables in determining hood leakage. Unfortunately, the complex interaction of these variables, the sensitivity of the tracer gas detector, and the inherent variability of the peak measures used as an outcome variable inhibit building a parametric model to predict leakage. It is encouraging, however, that despite these limitations, several of these face velocity and cross draft variables are related, in the expected directions, to the amount of leakage from the hood.

Appendix E contains the mean values and t-test information for other variables which were assessed from either data set but are not presented in this section. The equations used to perform the statistical analyses presented are also included in Appendix E.

Boundary Layer Separation Theory Applied to Explain Leakage

Although a parametric model to predict leakage could not be formulated, a theoretical explanation for one mechanism by which face velocity and cross drafts can interact to allow tracer gas to escape from hoods with horizontally sliding sashes is developed.

Air flowing into a hood past any of its edges may result in boundary layer separation. This separation causes vortices and a region of low pressure to be formed.(18) The effect of the vortices is to inhibit the exhaust of contaminants in the hood and to allow for their accumulation over time. The decreased pressure in these regions may draw contaminants from elsewhere in the hood into the vortices. Figure 4 depicts a top view of the location of these vortices for the one-half full left opening and for a center opening. In the absence of cross drafts, the flow pattern for the one-half full right opening is typically the mirror image of the one-half left opening. Figure 5 depicts a side view of vortices formed behind the top and bottom edges of the hood.

Vortices are formed behind the top edge, behind the sash doors, and behind the bottom edge. However, in these three cases, the vortices are formed inside the hood with a physical barrier between it and room air or a person in front of the hood.

Vortices are also formed along the beveled side edge of the hood face. These vortices and low pressure regions are formed along the hood perimeter, where no barrier exists between the region and room air. Because the vortices are not blocked, they are may be more prone to leakage.

Air flowing into a hood around a manikin or person will generate a wake zone.(7,19) Vortices and negative pressure in this wake zone will tend to draw contaminants out of the hood. If this wake zone overlaps vortices formed by the physical shape of the hood, leakage is even more likely to occur. The wake zone may be more likely to overlap with a vortex and draw contaminants from it if the vortex is unblocked, as is the case for vortices formed along the beveled edge of the hoods in this study. Figure 6 shows the location of a hypothetical wake zone relative to a vortex formed along the beveled edge.

As shown in Figure 5, the center openings are not expected to produce unblocked vortices. The wake zone around a person standing in front of a center opening will be less likely to overlap with and draw contaminants from these blocked vortices. Therefore, a hood is expected to perform better in a center sash position than in a left or right opening position.

When tested in a center sash position, only 2 of 15 hoods had peak breathing zone concentrations during the user test greater than 0.25 ppm, with 0.3 ppm being the highest concentration in both cases. When tested in the left or right sash position, the peak breathing zone concentration exceeded 0.25 ppm in 12 of 29 cases, with one concentration reaching 5.5 ppm. Furthermore, for the smoke tests, none of the center positions tested received a fair or poor rating, while 14 of the 29 left or right positions received a fair or poor rating. Notably, the center positions typically had a higher face velocity than the left or right openings, which might explain their superior performance. However, five of the center positions tested had face velocities below 100 fpm. Among these five, only one hood had a peak breathing zone concentration above 0.25 ppm and none received a fair or poor rating during the smoke tests. So, the data in this study support the hypothesis that unblocked vortices along the beveled edge of the hood, perhaps disrupted by the wake zone of a manikin or person at the hood face, are more likely to cause leakage than vortices which are blocked.

A second, less intuitive reason for leakage to occur along a particular edge of a hood is hypothesized. The placement of hoods in this study relative to the room air supply often resulted in observable, consistent cross drafts parallel to the hood face. The flow of cross drafts past the beveled edge of the hood is expected to favor the generation of a vortex and a region of low pressure, separated flow.[18] Figure 7 shows locations where these hypothetical vortices might form due to cross draft flow separation. The hypothetical vortices which correspond in location and direction of rotation to vortices already being formed by air flow into the hood are expected to augment these vortices. So, as indicated in Figure 7, the vortex formed along the first beveled edge the cross draft flows past is expected to augment vortices already being formed along the edge in the presence of air flow into the hood. Cross drafts may disrupt but are not expected to augment vortices along other edges of the hood.

As shown in Figure 7, for hoods with horizontally sliding sashes, the vortex formed along the first edge a cross draft flows past can either be in front of the hood opening or in front of the sash doors. Sash positions for which cross drafts form a vortex in front of the hood opening, and thereby augment the vortices formed by air flowing into the hood, are expected to have greater leakage. When the same hood's sash doors are pushed to the opposite side, the cross draft is no longer expected to augment vortex formation for the hood, and less leakage is expected to occur.

This hypothesis, that cross drafts generating a vortex in front of a hood opening will be more likely to cause leakage, can be evaluated by comparing the left and right openings of each hood tested in this study. For the two openings of a given hood, all of the operating parameters remain constant and the only significant change is the relative direction of the cross drafts. For instance, again consider Figure 7. In the top picture, for the left opening of the hood, the vortex generated by the cross draft is in front of the hood face and could augment the vortices along the beveled edge. When the doors are moved to the opposite side to provide a right opening, as in the bottom picture, the vortex is generated in front of the sash doors and will not augment vortices formed by air flowing into the hood.

Test information was available on the full left and full right openings for fourteen hoods. Because of the sensitivity limitations of the detector used in the tracer gas tests, the sash positions were considered different with respect to containment ability only if the peak breathing zone concentrations during the user test were greater than 0.2 ppm apart. Under this criterion, only four of the hoods demonstrated significant differences between the two sash positions in their peak breathing zone concentration measurements.

As shown in Table 3, three of the four hoods leaked more in the sash position for which the cross draft is expected to augment the vortex along the beveled entrance of the hood. One hood leaked more in its left sash position, for which the cross draft was not expected to augment the vortex along the beveled edge. Notably, for this hood, the magnitude of the cross draft was significantly higher in front of the left opening, where it was 43 fpm, than in front of the right opening, where it was 26 fpm. So, although the cross draft is not expected to augment the vortex for the left opening of the hood, it may have caused greater leakage because of its greater magnitude.

The hypothesis that cross drafts flowing past a beveled edge may augment vortices formed along that edge, and thereby cause leakage, is supported. So, these findings suggest that the interplay of cross drafts with face velocities along an opening's beveled edge is an important factor in determining whether a hood will leak.

Prediction of Hood Containment Ability

In order to asses their utility for predicting hood containment ability, the manikin tracer gas test, the smoke test, and average face velocity results are compared to the user tracer gas test results. For each test, a cutoff for passing or failing a hood is chosen. For the user and manikin tracer gas tests, hoods with a peak breathing zone concentration below 0.25 ppm are given a passing rating and all others a failing rating. For the smoke tests, a good rating is considered passing and a fair or poor rating is considered failing. An average face velocity above 90 fpm is given a pass rating, and below 90 fpm, a fail rating. Table 4 lists the number of hoods passing or failing the user test when passing or failing each candidate monitoring test.

The usefulness of each test may be evaluated by determining its sensitivity and specificity for predicting the results of the user test.[20] The sensitivity of a test is the percentage of times it correctly fails the hoods which fail the user test. The specificity of a test is the percentage of times it correctly passes the hoods which pass the user test. Table 5 shows the sensitivity and specificity for the smoke test, the manikin tracer gas test, and the average face velocity.

Average face velocity is the most sensitive and least specific test. The smoke test is the most specific and least sensitive test. The manikin test was moderately sensitive and specific. Face velocity measurements and smoke tests, which are easy and inexpensive, may provide information which is as valuable as traditional manikin tracer gas tests.

The repercussions of basing decisions on the results of a particular test must be considered. For instance, based on the results of this study, using average face velocity to classify hoods identifies most hoods which are performing poorly. The consequence, however, is many hoods which are performing well are classified as failing. Increasing the air flow for these misclassified hoods may result in operating cost increases which are unnecessary.

These results indicate that smoke tests, manikin tracer gas tests, and average face velocity all serve as useful monitoring techniques. No test, including the manikin test, agrees with the user test for all of the hoods. The lack of consistent agreement between the user and manikin tests, in particular, suggests more research is needed to determine how to evaluate whether a hood protects its users. Perhaps peak concentrations during a five minute tracer gas test are not accurate indicators of hood containment ability. Or, perhaps the use of a static manikin during tracer gas tests is not an appropriate model for actual dynamic use conditions. However, the user and manikin tests may agree more often if average concentrations are recorded or the tracer gas is detected with greater sensitivity and precision.

CONCLUSIONS

The findings of this study suggest that face velocity, its distribution and variability, and the magnitude of cross drafts relative to face velocity are important variables in determining whether a hood will leak. However, the complex interaction of cross drafts with face velocity and their relationship to hood performance are not well understood and warrant further study.

When air is being drawn into a hood, vortices form along its edges. If no barrier exists between a vortex and the hood's user, that vortex is expected to be a primary site of leakage for contaminants. Vortices and negative pressure in the wake zone formed around a user standing in front of a hood will also tend to cause leakage. If this wake zone overlaps vortices formed by the physical shape of the hood, as was the case for vortices formed along the beveled edge of the horizontally sliding sash hoods in this study, leakage is even more likely to occur. Because the vortices formed in center sash positions are blocked and therefore are less likely to leak, these positions perform better than left or right openings.

The hypothesis that cross drafts flowing in a direction so as to augment vortices along a hood's opening are more likely to cause leakage is supported. The findings in this study suggest that the interplay of cross drafts and face velocities along an opening's beveled edge is an important factor in determining whether a hood will leak.

Results indicate that smoke tests, manikin tracer gas tests, and average face velocity all serve as useful monitoring techniques. Face velocity measurements and smoke tests, which are easy and inexpensive, may provide information which is as valuable as traditional manikin tracer gas tests. However, the lack of consistent agreement between these tests and the results of a user tracer gas test suggests more research is needed to determine how to best evaluate whether a hood will protect its users.

RECOMMENDATIONS

A laboratory hood should provide a barrier between its user and the vortices formed along its entrance edges. Horizontally sliding sashes should be arranged, if possible, to provide a center opening with doors flush against both side edges of the hood face. These measures should help to reduce leakage.

Laboratory hood users should avoid standing in front of regions where unblocked vortices may be formed. Arm movements in any regions where vortices are formed, and particularly in regions where unblocked vortices are formed, should be minimized.

Cross drafts across laboratory hood faces should be minimized. Cross drafts which may cause separated flow in front of the hood face are particularly problematic and should be redirected.

Face velocity measurements and smoke tests can be used as easy and inexpensive hood testing procedures. The utility of tracer gas tests should be investigated further.

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Table 1. Comparison of Mean Values of Face Velocity and Cross Draft Variables for Low and High Leakage Hoods, Classified by a User Tracer Gas Test.

Variable	Low leakage group (< 0.25 ppm) n = 30*	High leakage group (> 0.25 ppm) n = 14	T - test p - value
Average face velocity (fpm)	92	77	0.01
Spatial CV** across face (%)	13.4	14.5	0.36
Average temporal CV for face (%)	4.2	5.4	0.05
Maximum Cross Draft / Minimum Face Velocity	0.43	0.77	0.05

*n = sample size (number of hoods in group)

**CV = coefficient of variation = standard deviation / mean

Table 2. Comparison of Mean Values of Face Velocity Variables, from Historical Data, for Low and High Leakage Hoods, Classified by a Manikin Tracer Gas Test.

Variable	Low leakage group (< 0.25 ppm) n = 75*	High leakage group (> 0.25 ppm) n = 13	T - test p - value
Average face velocity (fpm)	127	94	< 0.001
Spatial CV** across face (%)	12.0	16.8	< 0.01

*n = sample size (number of hoods in group)
**CV = coefficient of variation = standard deviation / mean

Table 3. Comparison of Left and Right Sash Positions for a Given Hood to Evaluate the Effect of Cross Draft Direction on Leakage.

Hood Identification	Sash Position	Is Cross Draft Expected to Augment Vortices?	Maximum Cross Draft Velocity Near Edge (fpm)	User Test Peak Concentration (ppm)
2509AR	Right	No	13	<LOD*
	Left	Yes	20	3.40
2513BR	Left	No	43	1.30
	Right	Yes	26	0.40
2517AL	Left	No	133	0.30
	Right	Yes	82	1.00
2563BR	Right	No	95	0.30
	Left	Yes	83	5.50

*LOD = limit of detection

Table 4. Number of Hoods Passing or Failing Hood Tests, Stratified by User Tracer Gas Test Result.

TEST	RESULT	User Tracer Gas Test Result Pass (< 0.25 ppm)	User Tracer Gas Test Result Fail (> 0.25 ppm)
Smoke Challenge	Pass (Good)	23	7
	Fail (Fair or Poor)	7	7
Manikin Tracer Gas Test	Pass (< 0.25 ppm)	21	5
	Fail (> 0.25 ppm)	9	9
Average Face Velocity	Pass (> 90 fpm)	13	2
	Fail (< 90 fpm)	17	12

Table 5. Sensitivity and Specificity of Hood Tests for Predicting the User Tracer Gas Test Results.

TEST	Sensitivity	Specificity
Smoke Challenge	50%	77%
Manikin Tracer Gas Test	64%	70%
Average Face Velocity	86%	43%

Figure 1. Dimensions of Laboratory Hoods Tested.

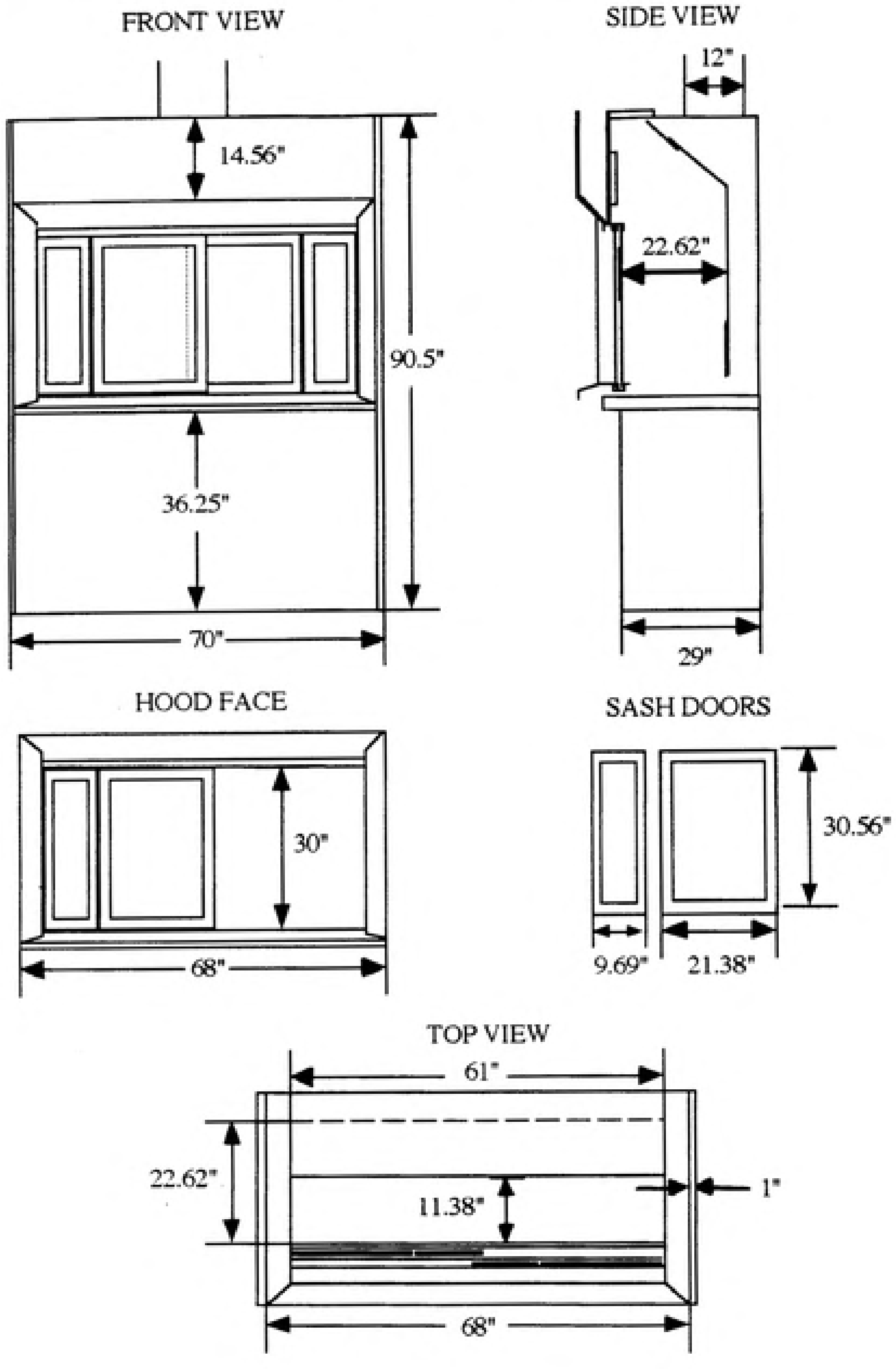


Figure 2. Sash Configurations Tested.

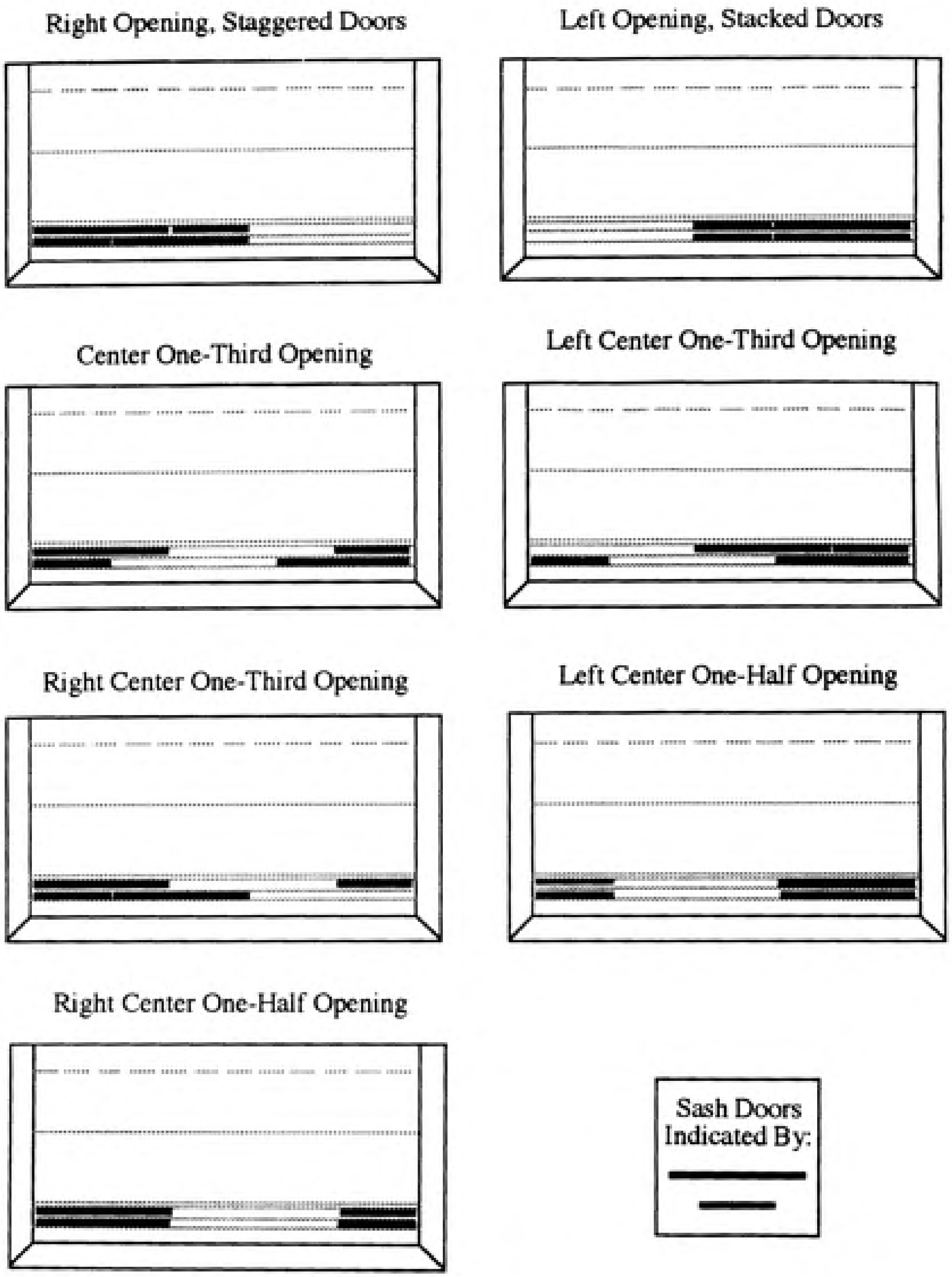
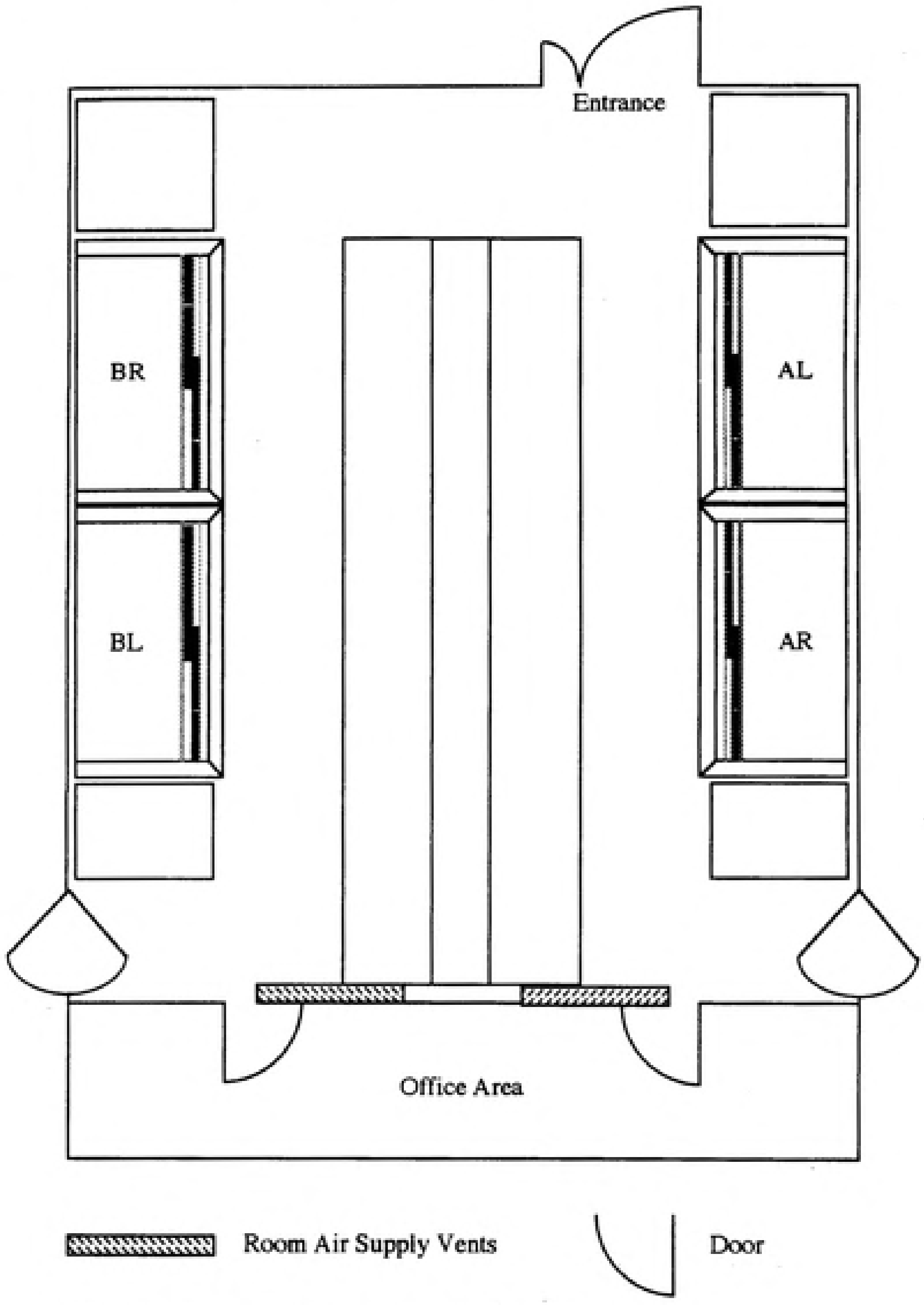
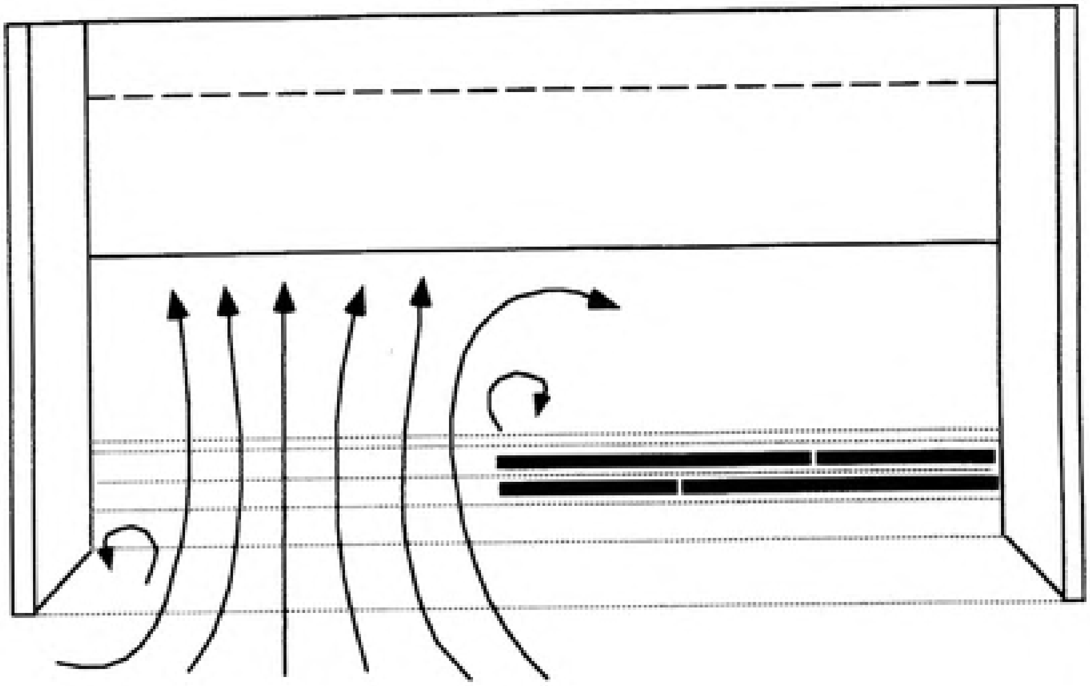


Figure 3. Typical Positions of Tested Hoods in Laboratories.



Hood Positions: BR = Right side of lab, right hood
BL = Right side of lab, left hood
AL = Left side of lab, left hood
AR = Left side of lab, right hood

Figure 4. Top View of Vortex Formation for Air Flow into a Hood with Horizontally Sliding Sashes.



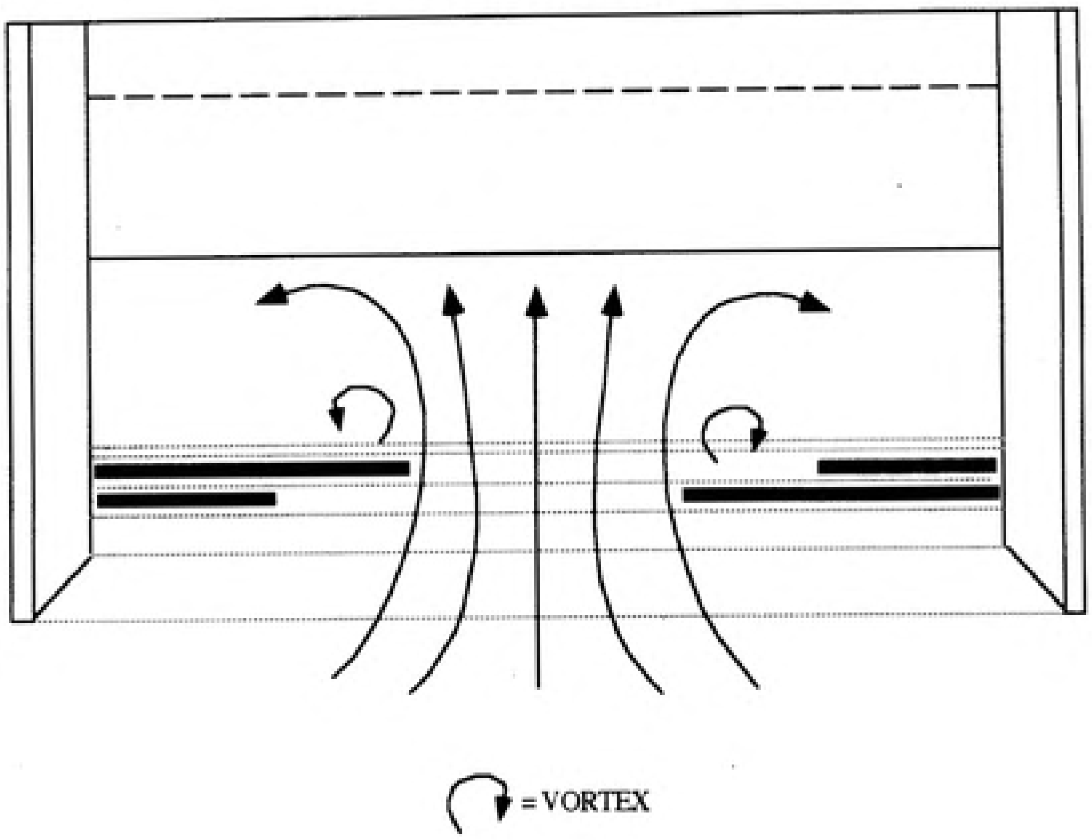


Figure 5. Side View of Vortex Formation for Air Flow into a Hood.

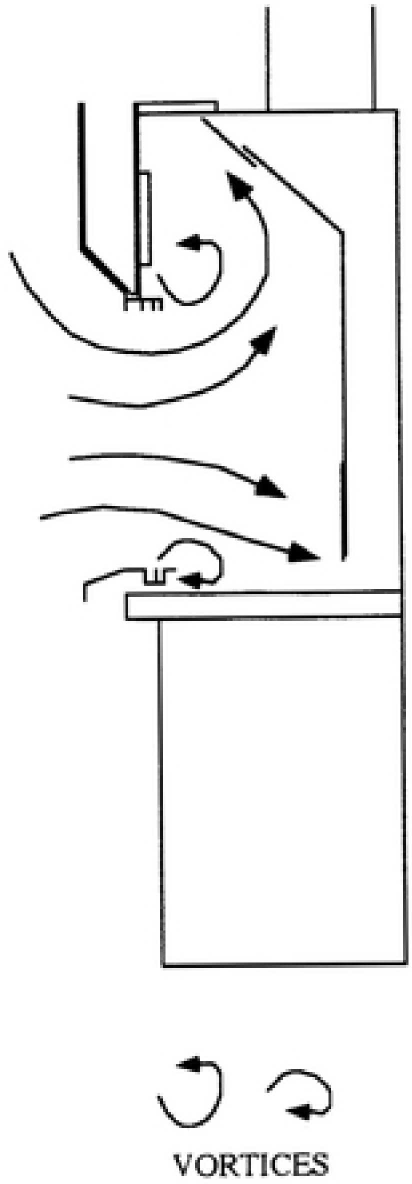


Figure 6. Location of Vortices Relative to the Wake Zone Formed Around a Person or Manikin in Front of a Hood with Horizontally Sliding Sashes.

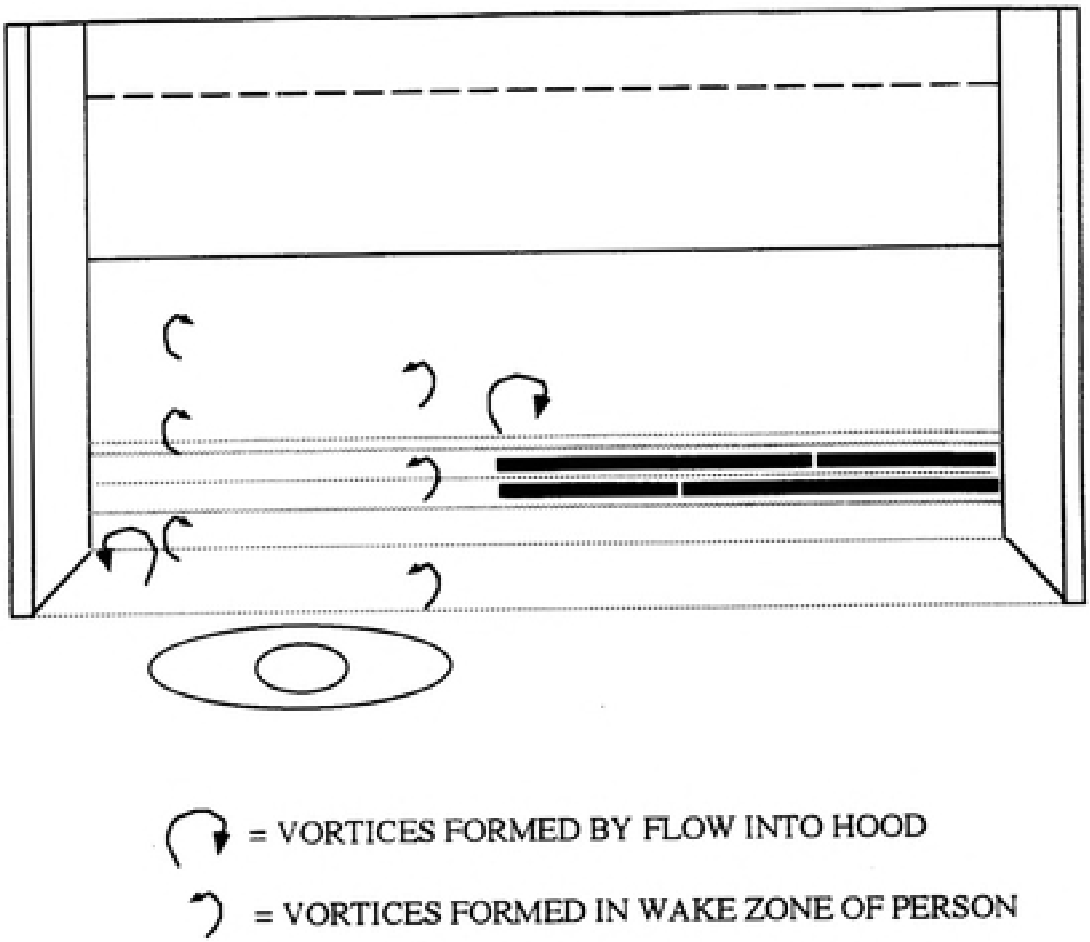
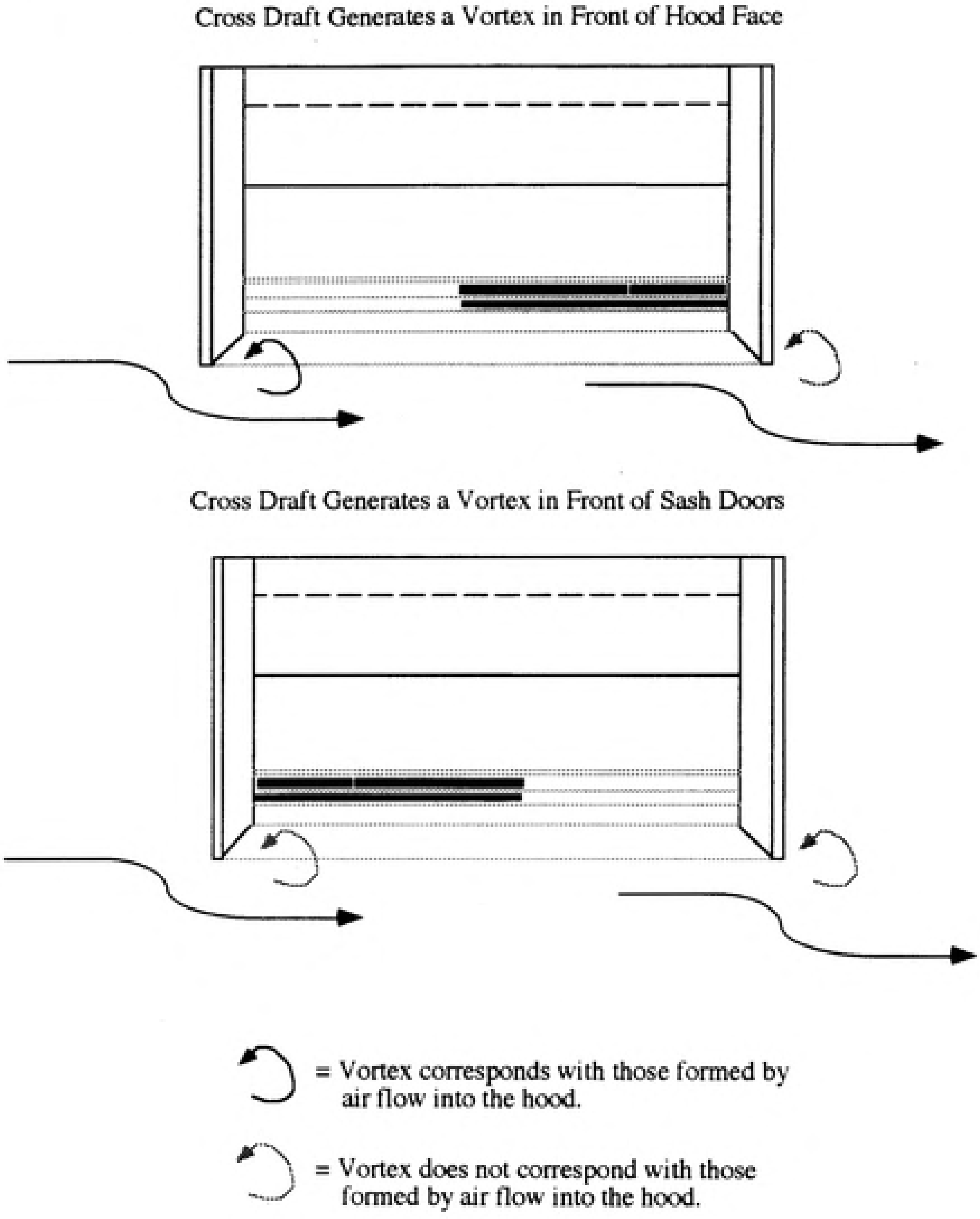


Figure 7. Expected Cross Draft Flow Patterns at a Hood Face in the Absence of Air Flow into the Hood.



APPENDIX A - TEST METHODOLOGIES

Face Velocity

Face velocity was measured at six points across the hood face with an Alnor model 8565 ThermoAnemometer (SN 003632). Information on the calibration of this instrument is contained in Appendix B. The traverse points were chosen to be at the center of six equal rectangles dividing the hood opening, approximately one square foot each. For one-half opening positions, this convention led to two horizontal rows consisting of three points. For one-third opening positions, the measurements were obtained in three horizontal rows of two points each. These locations, their spacing, and the numbering convention used to list the points are shown in Figure 8. Ten readings, spaced ten seconds apart, were taken at each point. The direction of the face velocity was observed with smoke and its approximate angle relative to the plane of the hood face was noted. The thermoanemometer probe was oriented based on the observed direction of the flow into the face.

Cross Drafts

The velocity of cross drafts proximate to the hood were also measured with the thermoanemometer. The hood doors were closed and the velocity of the air in the room was measured at six points eighteen inches from the plane of the hood face. The six points were chosen such that their height from the floor was the same as six points which would be the center of six equal rectangles across the entire hood face. The location of these readings relative to the hood face and the numbering convention used to record them are shown in Figure 9. Ten readings, spaced ten seconds apart, were taken at each position. The direction of the cross drafts was observed with smoke and recorded. The thermoanemometer probe was oriented based on the prevailing direction of the cross drafts.

Exhaust Flow

The exhaust flow of the hood was determined by measuring the flow rate of air upstream and downstream of the junction of the main exhaust duct and the hood exhaust duct. Exhaust ducts were either 12 or 14 inches in diameter. The locations and methodology for the pitot traverses followed the ACGIH convention.[13] A pitot tube and a micromanometer, a Dwyer Instruments Microtector (SN M19B), were employed for this task.

Smoke Test

A smoke test was performed on the hood face, and a rating of good, fair, or poor was assigned. A rating of good indicates that the smoke was cleared quickly and none leaked from the hood face. A rating of fair indicates that the smoke was not cleared quickly or slight leakage was observed. A rating of poor indicates that clearance was slow and some of the smoke leaked from the hood. Smoke was generated with tubes containing ethylenediamine and acetic acid (Mine Safety Appliances Company Ventilation Smoke Tubes).

Manikin Tracer Gas Test

Figure 10 shows the set up used for the manikin tracer gas test. During the test, 99.99% pure sulfur hexafluoride was released in the hood at 4 liters per minute from a rectangular diffuser. Concentrations of the gas in the breathing zone of a manikin were monitored continuously monitored with an Ion Track Instruments Model 120 Leakmeter electron capture detector (SN 29325) and recorded with a Metrosonics dl-712 data logger (SN 1178). The flow of tracer gas to the diffuser was monitored continuously with a calibrated rotameter. Calibration information for all of these instruments is contained in Appendix B.

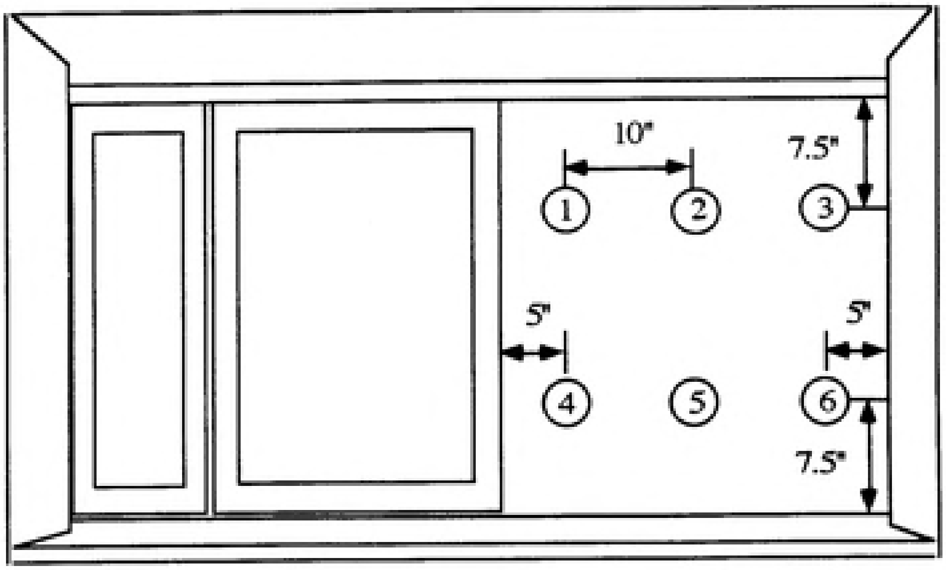
The duration of the manikin tracer gas test was five minutes. The total height from the floor to the top of the manikin's head was 66 inches. The maximum width of the manikin, at the shoulders, was 16 inches. The nose of the manikin was positioned 6 inches from the face of the hood. As shown in Figure 10, the ejector was positioned 6 inches deep in the hood and 6 inches off the bottom surface of the hood.

User Tracer Gas Test

Figure 11 shows the set up for the user tracer gas test. The conditions and equipment used for the user tracer gas test were identical to the manikin test, except additional tubing was connected to the inlet of the Leakmeter to extend to the breathing zone of the human subject. Every thirty seconds for the five minute duration of the test, the subject extended both arms into the hood and pulled them back out in one motion.

Figure 8. Position and Numbering Convention for Face Velocity Traverses.

One- Half Openings



One- Third Openings

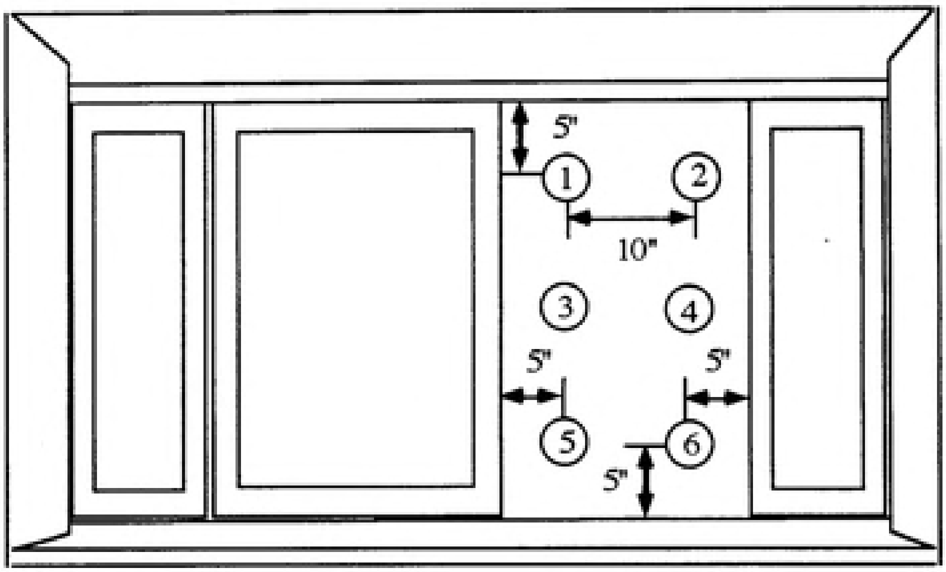


Figure 9. Position and Numbering Convention for Cross Draft Measurements.

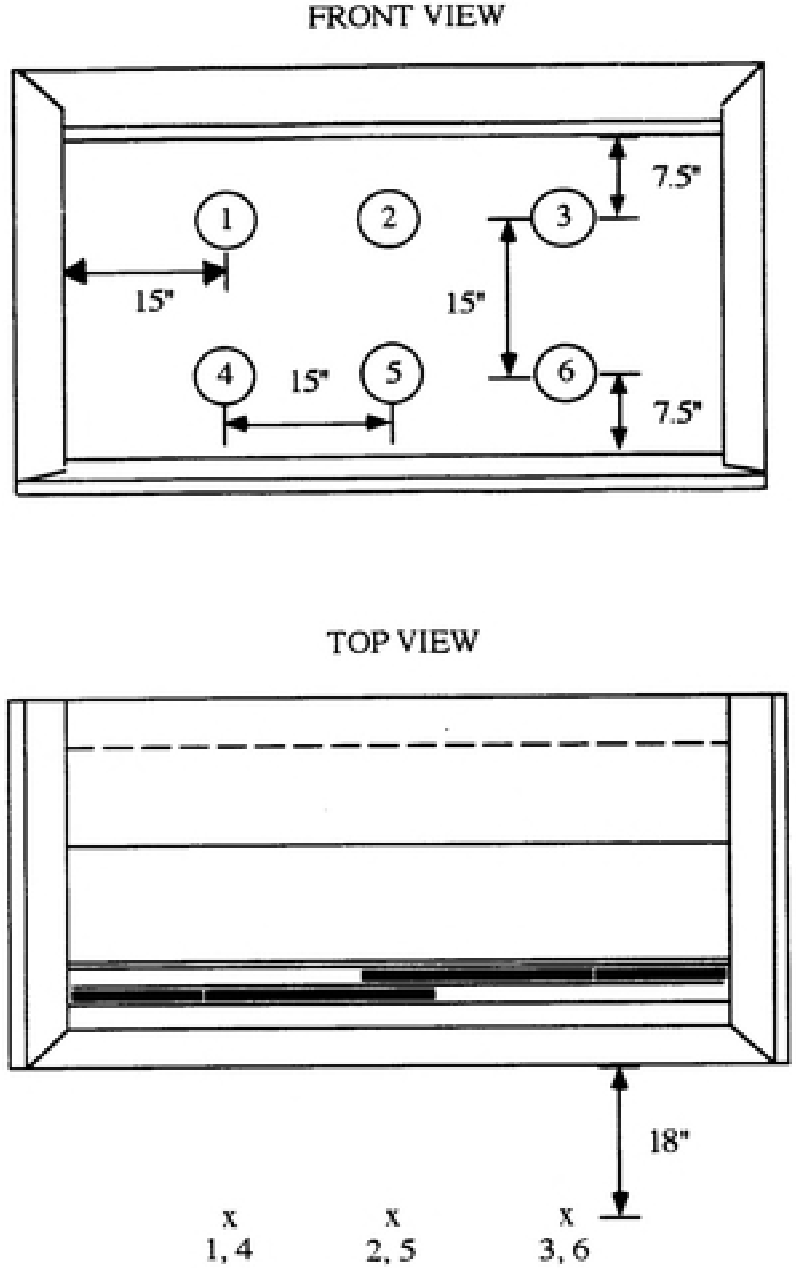


Figure 10. Setup for Manikin Tracer Gas Test.

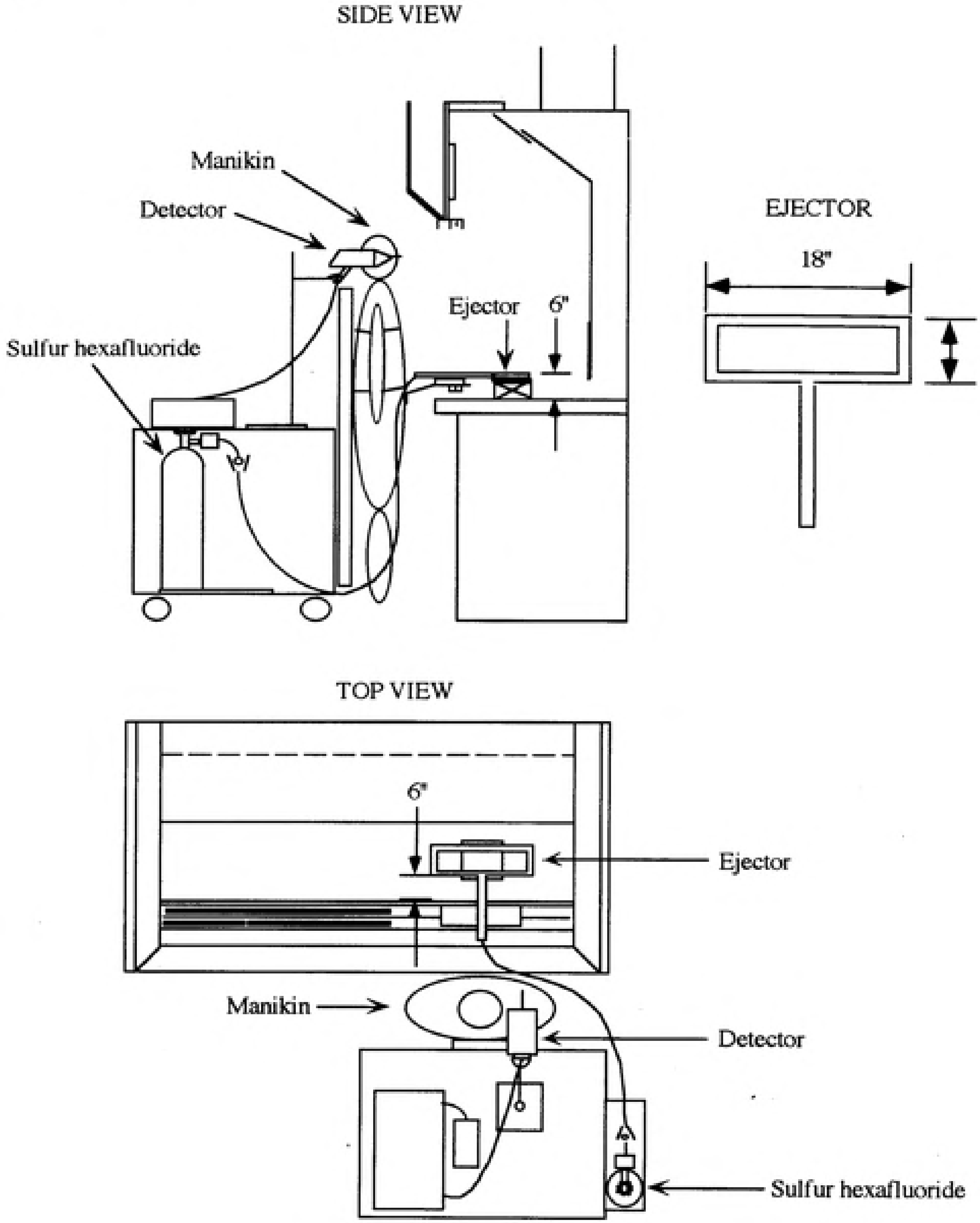
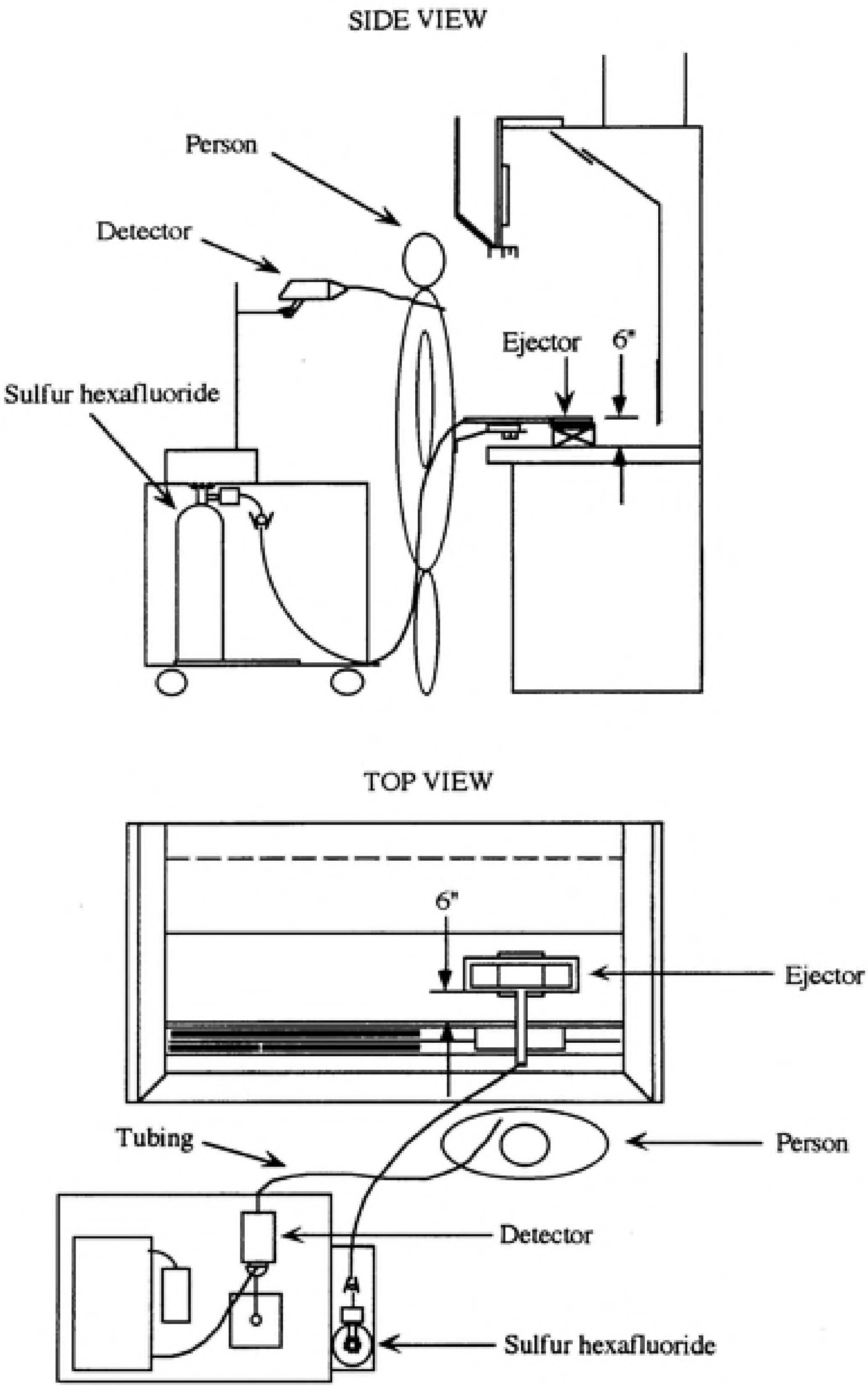


Figure 11. Setup for User Tracer Gas Test.



APPENDIX B - INSTRUMENT CALIBRATIONS

Thermoanemometer Calibration

An Alnor model 8565 ThermoAnemometer (SN 003632) was used to measure air velocities in this study. The thermoanemometer was calibrated in a wind tunnel with a cross sectional area of 2.56 square feet. The set up used for this calibration is shown in Figure 12.

First, the air velocities in the wind tunnel were related to the static pressure in the 8 inch duct directly behind the tunnel. This preliminary calibration was accomplished by measuring the static pressure at this point with a pitot tube and determining the flow rate of air through the system by taking a pitot traverse in a six inch duct far downstream of the wind tunnel. Static and total pressures were measured with a micromanometer, a Dwyer Instruments Microtector (SN M19B). Temperature and relative humidity were determined with a Cole-Palmer Hygrometer; atmospheric pressure was read from a Fisher Scientific Barometer. The results of the wind tunnel calibration are shown in Table 6 and Figure 13.

The thermoanemometer was then calibrated by taking the average of five static pressure measurements and five readings from the thermoanemometer. Calibrations of the instrument were completed on six separate occasions throughout the period of its use for this study. The results of the thermoanemometer calibration are shown in Table 7 and Figure 14. A least squares regression line was fit to the data and used to calculate the actual velocity for a given thermoanemometer reading.

Leakmeter Calibration

An Ion Track Instruments Model 120 Leakmeter (SN 29325) was used to detect sulfur hexafluoride during tracer gas tests of the laboratory hoods. In order to calibrate this instrument, known concentrations of sulfur hexafluoride were prepared in an SKC sampling bag.

The sampling bags were filled with pure nitrogen to avoid interference from contaminants present in room air. Figure 15 shows the set up used to fill the sampling bags. An SKC sampling pump was used to pull nitrogen from a bag containing an unknown volume through a BIOS International Dry Cal DC-1 Flow Calibrator (Dry Cal Base SN B0394, Standard Flow Cell SN S0243). The calibration bags were filled for several minutes from the exhaust of the sampling pump. The flow rate of nitrogen through the flow calibrator was checked every 15 to 30 seconds during filling so that 10 readings were obtained. The volume of nitrogen in the calibration bag was calculated by multiplying average of the 10 flow rate readings by the time of filling as indicated by a stopwatch.

Pure sulfur hexafluoride was taken from a second sampling bag with a syringe and injected into the calibration bag. 10 μL and 100 μL Unimetrics syringes and a 1.0 mL Hamilton Gastight syringe were used to complete this step. The concentration of sulfur hexafluoride in the calibration bag after injection is given in equation 1.

$$C = \frac{V_{SF_6}}{V_{SF_6} + V_{N_2}} \qquad (1)$$

where, C = resulting concentration of sulfur hexafluoride in calibration bag
V_{SF_6} = volume of sulfur hexafluoride injected into calibration bag
V_{N_2} = volume of nitrogen in calibration bag

Low concentrations of sulfur hexafluoride, below about 1 ppm, were generally prepared in two steps. A first sampling bag was prepared with a sulfur hexafluoride concentration C_i. The calibration bag was then injected with a known volume from the first bag. The concentration of sulfur hexafluoride in the calibration bag is given in equation 2.

$$C = \frac{C_i V_i}{V_i + V_{N_2}} \qquad (2)$$

where, C = concentration of sulfur hexafluoride in calibration bag
C_i = concentration of sulfur hexafluoride in volume injected into calibration bag
V_i = volume injected into calibration bag
V_{N_2} = volume of nitrogen in calibration bag

Once a known concentration of sulfur hexafluoride was prepared, the calibration bag was connected directly to the inlet of the Leakmeter with tubing. A calibration point was set by showing the Leakmeter a 5.0 ppm concentration of sulfur hexafluoride and inputting this concentration on the Leakmeter console. Once this calibration point is set, it is stored in the Leakmeter even after turning the instrument off. Once during the test period of this study, the instrument malfunctioned and erased the set calibration point and required resetting.

Calibrations for the response of the Leakmeter were completed on several dates over a wide range of concentrations. This calibration data are shown in Table 8. The data are arranged in order of the concentration of the calibration bag (the "Prepared Concentration").

Figure 16 shows the response of the Leakmeter as a function of sulfur hexafluoride concentrations. Shown on the figure is the least squares regression line fit to the data to allow conversion of a Leakmeter response to a sulfur hexafluoride concentration. The equation was obtained from a linear regression of the logarithms of both parameters.

In addition to the careful calibrations performed on the Leakmeter, quick calibration checks were performed on the instrument before each set of tracer gas tests on a hood on any given day.

Two or three different calibration bags, with several different sulfur hexafluoride concentrations, were shown to the Leakmeter before each set of tests and its response recorded. Calibration bags were prepared in the same manner as the more careful tests, but were reused a number of times before preparing a new bag. The same calibration bag may have been used to run a check on the Leakmeter before tests on several different days. The calibration bag was resealed immediately after each check, but the true concentration of sulfur hexafluoride in the bag may have changed over time. The intention of the calibration checks was not to ascertain the exact response of the Leakmeter to a given concentration. Instead, the intention was to determine if the Leakmeter's calibration point was still in place and the instrument appeared to be functioning correctly prior to use. The calibration check information is given in Table 9. Figure 17 shows the response of the Leakmeter to the calibration checks.

Data Logger Calibration

A Metrosonics dl-712 Data Logger (SN 1178) was used to record the Leakmeter output during the five minute tracer gas tests. The relationship of output voltage to the data logger as a function of the Leakmeter response was established. The output voltage did not change continuously when sulfur hexafluoride concentrations were varied. Rather, the voltage changed discretely corresponding with changes in the concentration displayed by the Leakmeter.

The voltage output for a given Leakmeter display was consistent, although several linear regression lines were fit to the data because the relationship between voltage and Leakmeter response changed, in a step function manner, in different concentration ranges. Table 10 contains the data logger calibration data. Table 11 shows the equations for the relationship between output voltage and Leakmeter display. One regression equation was not best for the data because the relationship between output voltage and Leakmeter display changed abruptly, in a step function manner, at two points. The r-square values for these least squares regression lines were all greater than 0.99. Figure 18 graphically displays the relationship between output voltage and Leakmeter display. The step changes in the relationship between output voltage and Leakmeter display are not evident in the figure, but are obvious from the data in Table 10.

Rotameter Calibration

A Dwyer rotameter was used to set and monitor the flow rate of sulfur hexafluoride during the tracer gas tests. The rotameter was calibrated to 4 L/min with all tubing and equipment used in the tests in place. A BIOS International Dry Cal DC-1 Flow Calibrator (DryCal Base SN B0394, Standard Flow Cell SN S0243) was used for the calibration.

Table 6. Wind Tunnel Calibration Data.

Hood Static Pressure ("wg)	Square Root of Hood Static Pressure	Wind Tunnel Velocity* (fpm)	Predicted Velocity**
0.0018	0.0424	21.6	19.9
0.0024	0.0490	26.4	23.2
0.0036	0.0600	28.9	28.7
0.0116	0.1077	53.8	52.7
0.0270	0.1643	81.9	81.1
0.0440	0.2098	103.7	104.0
0.0660	0.2569	128.6	127.7
0.0910	0.3017	149.2	150.1
0.1200	0.3464	171.9	172.6
0.1550	0.3937	196.0	196.4
0.1940	0.4405	219.3	219.9
0.2340	0.4837	237.9	241.6
0.2770	0.5263	263.3	263.0
0.3390	0.5822	289.9	291.1
0.3840	0.6197	314.1	309.9
0.4460	0.6678	336.6	334.1
0.5150	0.7176	355.4	359.2
0.5830	0.7635	384.0	382.2

*Determined from pitot traverse of duct downstream of wind tunnel

** Regression equation (r square = 0.999):
Tunnel Velocity = -1.42 + 502.4458 * SQRT(SP)

Wind tunnel cross sectional area = 2.56 square feet
Duct diameter at point of pitot traverse = 6 inches

Table 7. Thermoanemometer Calibration Data.

Date	Hood SP ("wg)	SQRT (SP)	Indicated* Velocity (fpm)	Wind Tunnel** Velocity (fpm)	Predicted*** Velocity (fpm)
6/12/94	0.0037	0.0610	50	29.0	28.8
6/12/94	0.0075	0.0865	67	41.7	42.9
6/12/94	0.0123	0.1108	86	53.8	58.6
6/12/94	0.0178	0.1336	96	65.1	66.9
6/12/94	0.0248	0.1576	106	77.1	75.9
6/12/94	0.0339	0.1841	122	90.2	89.0
6/12/94	0.0436	0.2088	137	102.6	101.5
6/12/94	0.0642	0.2535	163	124.8	122.9
6/12/94	0.0880	0.2966	190	146.3	145.7
6/12/94	0.1192	0.3453	215	170.5	166.6
6/12/94	0.1530	0.3911	236	193.3	184.1
6/12/94	0.1797	0.4239	264	209.7	207.4
6/12/94	0.2332	0.4829	292	239.0	231.1
6/18/94	0.0050	0.0707	58	33.9	35.2
6/18/94	0.0088	0.0936	71	45.3	46.2
6/18/94	0.0146	0.1207	85	58.8	57.9
6/18/94	0.0197	0.1403	96	68.5	67.1
6/18/94	0.0280	0.1673	114	82.0	82.3
6/18/94	0.0362	0.1902	126	93.4	92.1
6/18/94	0.0465	0.2156	142	106.1	105.3
6/18/94	0.0566	0.2380	158	117.3	119.0
6/18/94	0.0681	0.2609	169	128.7	128.2
6/18/94	0.0803	0.2833	187	139.9	143.1
6/18/94	0.0940	0.3067	200	151.5	153.7
6/18/94	0.1084	0.3292	212	162.7	164.1
6/18/94	0.1235	0.3514	221	173.8	171.9
6/18/94	0.1420	0.3768	238	186.5	186.1
6/18/94	0.1590	0.3988	250	197.5	196.2
6/18/94	0.1780	0.4219	263	209.0	206.7
6/18/94	0.1960	0.4427	273	219.4	215.2
6/18/94	0.2392	0.4890	305	242.5	241.6
6/18/94	0.2840	0.5329	332	264.3	264.0
6/18/94	0.3356	0.5793	366	287.5	292.4
6/18/94	0.3917	0.6259	385	310.7	308.6
6/18/94	0.4552	0.6747	418	335.0	336.1
7/4/94	0.0056	0.0748	61	35.8	38.0
7/4/94	0.0150	0.1226	86	59.5	59.1
7/4/94	0.0289	0.1701	113	83.1	81.6
7/4/94	0.0467	0.2161	142	105.9	105.7
7/4/94	0.0668	0.2585	171	127.0	129.9
7/4/94	0.0942	0.3070	201	151.1	154.6
7/4/94	0.1251	0.3537	225	174.3	175.0
7/4/94	0.1550	0.3936	247	194.2	193.0
7/4/94	0.1941	0.4406	275	217.5	216.7
7/4/94	0.2881	0.5367	333	265.2	264.8
7/4/94	0.3964	0.6296	392	311.4	314.6

(continued on following page)

Date	Hood SP ("wg)	SQRT (SP)	Indicated* Velocity (fpm)	Wind Tunnel** Velocity (fpm)	Predicted*** Velocity (fpm)
7/18/94	0.0018	0.0420	31	19.6	13.0
7/18/94	0.0024	0.0490	42	23.1	22.3
7/18/94	0.0051	0.0713	58	34.3	35.8
7/18/94	0.0162	0.1274	89	62.4	61.6
7/18/94	0.0477	0.2184	144	108.1	107.2
7/18/94	0.1138	0.3373	220	167.6	170.4
7/18/94	0.2076	0.4556	277	226.9	218.4
7/18/94	0.3274	0.5722	357	285.3	285.2
7/18/94	0.4842	0.6958	422	347.3	339.6
7/18/94	0.6162	0.7850	477	392.0	385.0
9/5/94	0.0019	0.0434	43	20.4	23.0
9/5/94	0.0030	0.0548	49	26.1	28.0
9/5/94	0.0041	0.0642	54	30.9	32.5
9/5/94	0.0066	0.0810	65	39.3	41.0
9/5/94	0.0100	0.1000	72	48.9	47.4
9/5/94	0.0158	0.1255	86	61.7	59.2
9/5/94	0.0226	0.1505	99	74.3	70.1
9/5/94	0.0311	0.1764	114	87.3	82.3
9/5/94	0.0400	0.1999	130	99.2	95.3
9/5/94	0.0483	0.2197	142	109.1	105.3
9/5/94	0.0730	0.2701	171	134.5	129.9
9/5/94	0.1010	0.3179	200	158.5	154.4
9/5/94	0.1542	0.3927	236	196.2	183.8
9/5/94	0.2104	0.4587	274	229.4	215.9
11/2/94	0.0040	0.0636	46	31.3	25.2
11/2/94	0.0068	0.0825	56	41.0	34.0
11/2/94	0.0156	0.1249	85	62.9	57.7
11/2/94	0.0280	0.1673	113	84.8	81.3
11/2/94	0.0464	0.2154	137	109.5	101.6
11/2/94	0.0672	0.2592	164	132.1	123.7
11/2/94	0.1056	0.3250	208	166.0	160.4
11/2/94	0.1580	0.3975	237	203.3	185.0
11/2/94	0.1932	0.4395	262	225.0	206.2

* Indicated velocity calculated by averaging five thermoanemometer readings

** Wind tunnel velocity calculated by averaging five hood static pressure measurements taken with pitot tube and micromanometer, converted to velocity by the equation:
Tunnel Velocity = 502.4*SQRT(SP) - 1.42

*** Regression equation based on 6/18 data (r square = 0.997)
Wind tunnel velocity = -12.92 + 0.835*Thermo reading
Thermoanemometer reading = 15.5 + 1.20*Wind tunnel velocity

Table 8. Leakmeter Calibration Data.

Date	Prepared Concentration (ppm)	Leakmeter Response (ppm)	Date	Prepared Concentration (ppm)	Leakmeter Response (ppm)
8/6/94	0.06	0.0	7/25/94	2.05	2.7
7/26/94	0.08	0.0	7/26/94	2.14	2.4
9/6/94	0.10	0.1	7/9/94	2.35	3.2
7/26/94	0.11	0.1	7/9/94	2.43	2.8
8/6/94	0.11	0.0	7/26/94	2.63	3.0
7/25/94	0.11	0.0	8/30/94	2.63	3.0
7/26/94	0.13	0.2	8/6/94	2.79	3.3
7/26/94	0.15	0.2	7/25/94	2.82	3.3
8/6/94	0.16	0.1	8/8/94	2.89	3.0
7/26/94	0.18	0.2	7/26/94	3.05	3.7
9/6/94	0.21	0.2	7/25/94	3.40	3.3
7/26/94	0.21	0.2	9/6/94	3.97	3.4
8/6/94	0.22	0.1	7/26/94	4.20	4.7
7/9/94	0.24	0.2	7/28/94	4.22	4.5
8/8/94	0.26	0.1	7/25/94	4.56	4.4
7/26/94	0.27	0.3	7/9/94	4.88	5.1
7/28/94	0.30	0.4	7/9/94	4.99	5.0
7/26/94	0.30	0.3	8/6/94	5.04	5.0
7/25/94	0.33	0.3	7/26/94	5.17	5.5
8/8/94	0.36	0.3	7/25/94	5.53	4.8
8/1/94	0.37	0.4	9/6/94	6.43	5.9
8/8/94	0.46	0.4	7/9/94	7.32	8.4
7/9/94	0.48	0.5	7/26/94	7.44	8.6
9/6/94	0.53	0.5	7/25/94	7.79	7.5
7/26/94	0.53	0.8	8/6/94	7.90	8.7
7/25/94	0.56	0.5	9/6/94	8.33	8.7
7/25/94	0.67	0.7	7/9/94	9.49	11.5
8/8/94	0.72	0.7	8/8/94	9.53	12.9
8/30/94	0.82	0.9	7/26/94	9.60	12.4
7/26/94	0.83	1.1	7/28/94	10.25	11.1
7/25/94	0.99	0.9	8/1/94	10.70	13.0
8/6/94	1.10	1.2	8/6/94	10.82	14.1
7/9/94	1.18	1.4	7/25/94	11.70	12.7
7/26/94	1.28	2.6	8/6/94	12.06	15.4
8/30/94	1.65	1.8	7/26/94	12.70	17.8
7/26/94	1.70	2.0	9/6/94	13.29	17.9
9/6/94	1.88	1.9			

Table 9. Leakmeter Calibration Check Data.

Hood ID	Date	Prepared Concentration (ppm)	Leakmeter Response (ppm)
2509AR	8/1/94	0.4	0.5
2509AR	8/1/94	4.5	2.9
2509AR	8/1/94	11.1	10.1
2511AL	10/12/94	1.9	1.1
2511AL	10/13/94	1.9	1.2
2511AL	10/12/94	5.9	4.0
2511AL	10/13/94	5.9	4.1
2513AL	9/15/94	1.9	1.6
2513AL	9/15/94	5.9	4.8
2513BR	9/8/94	1.9	1.7
2513BR	9/8/94	5.9	5.4
2515AL	8/3/94	0.4	0.4
2515AL	8/3/94	10.4	12.3
2517AL	7/27/94	0.5	0.4
2517AL	7/27/94	5.0	3.9
2517AL	7/27/94	10.0	>19.9
2517BR	8/1/94	0.4	0.5
2517BR	8/1/94	4.5	2.9
2517BR	8/1/94	11.1	10.6
2555AR	7/28/94	0.3	0.2
2555AR	7/28/94	4.1	3.9
2555AR	7/28/94	10.1	10.4
2555BR	8/9/94	0.7	0.8
2555BR	8/9/94	2.9	2.9
2555BR	8/9/94	9.6	11.2
2557BL	8/2/94	0.4	0.4
2557BL	8/2/94	10.4	13.7
2561AR	8/4/94	0.4	0.4
2561AR	8/4/94	10.4	13.3
2563AL	9/18/94	1.9	1.6
2563AL	9/18/94	5.9	4.6
2563BR	8/8/94	0.7	0.7
2563BR	8/8/94	2.9	2.8
2563BR	8/8/94	9.6	12.0
2571AL	7/29/94	0.4	0.5
2571AL	7/29/94	4.5	4.7
2571AL	7/29/94	11.1	15.5
2571BR	7/29/94	0.4	0.5
2571BR	7/29/94	4.5	4.1
2571BR	7/29/94	11.1	11.4

Table 10. Data Logger Calibration Data.

Date	Data Logger Voltage (V)	Leakmeter Reading (ppm)	Predicted Reading* (ppm)
6/10/94	0.0040	0.00	0.00
6/10/94	0.0045	0.00	0.00
6/10/94	0.0045	0.00	0.00
6/10/94	0.0045	0.00	0.00
6/22/94	0.0055	0.00	0.00
6/22/94	0.0130	0.00	0.00
6/22/94	0.0045	0.00	0.00
6/22/94	0.0055	0.00	0.00
6/22/94	0.0050	0.00	0.00
6/23/94	0.0040	0.00	0.00
6/23/94	0.0190	0.00	0.00
6/24/94	0.0060	0.00	0.00
6/24/94	0.0055	0.00	0.00
6/10/94	0.0145	0.10	0.10
6/10/94	0.0145	0.10	0.10
6/22/94	0.0145	0.10	0.10
6/22/94	0.0150	0.10	0.11
6/10/94	0.0245	0.20	0.20
6/22/94	0.0345	0.30	0.30
6/10/94	0.0545	0.40	0.40
6/24/94	0.0555	0.40	0.41
6/22/94	0.0640	0.50	0.50
6/10/94	0.0740	0.60	0.60
6/22/94	0.0745	0.60	0.60
6/23/94	0.0750	0.60	0.61
6/23/94	0.0850	0.70	0.71
6/22/94	0.1135	0.90	0.90
6/23/94	0.1145	0.90	0.90
6/23/94	0.1140	0.90	0.90
6/23/94	0.1145	0.90	0.90
6/23/94	0.1220	1.00	0.96
6/23/94	0.1245	1.00	0.98
6/23/94	0.1540	1.20	1.21
6/23/94	0.1535	1.20	1.21
6/24/94	0.1715	1.35	1.35
6/23/94	0.1735	1.40	1.37
6/23/94	0.1935	1.50	1.52
6/10/94	0.2130	1.70	1.68
6/23/94	0.2330	1.80	1.83
6/23/94	0.2430	1.90	1.91
6/24/94	0.2430	1.90	1.91
6/22/94	0.2530	2.00	1.99
6/23/94	0.2515	2.00	1.98
6/23/94	0.2535	2.00	1.99
6/23/94	0.2630	2.10	2.07
6/23/94	0.3090	2.40	2.43
6/23/94	0.3230	2.50	2.54
6/24/94	0.3330	2.60	2.62

*Regression equations given in Table 11

Date	Data Logger Voltage (V)	Leakmeter Reading (ppm)	Predicted Reading* (ppm)
6/10/94	0.3525	2.80	2.77
6/23/94	0.4920	3.90	3.86
6/23/94	0.5200	4.10	4.08
6/23/94	0.5220	4.10	4.10
6/22/94	0.5285	4.20	4.15
6/10/94	0.6360	5.00	4.99
6/23/94	0.6420	5.00	5.04
6/23/94	0.6720	5.30	5.27
6/23/94	0.6860	5.40	5.38
6/23/94	0.6920	5.40	5.43
6/23/94	0.7000	5.50	5.49
6/23/94	0.7115	5.60	5.58
6/23/94	0.7315	5.70	5.74
6/24/94	0.7315	5.70	5.74
6/23/94	0.7415	5.80	5.82
6/24/94	0.8010	6.30	6.28
6/23/94	0.8710	6.80	6.83
6/10/94	0.8915	7.00	6.99
6/23/94	0.9405	7.40	7.38
6/23/94	1.1000	8.60	8.63
6/23/94	1.1200	8.80	8.79
6/23/94	1.4855	11.70	11.65
6/23/94	1.5610	12.20	12.24
6/23/94	1.5585	12.20	12.22
6/23/94	1.7180	13.50	13.47
6/22/94	1.7395	13.60	13.64
6/23/94	2.1340	16.80	16.73
6/23/94	2.1460	16.80	16.83
6/23/94	2.1765	17.00	17.07
6/23/94	2.1655	17.00	16.98
6/23/94	2.2205	17.45	17.41
6/23/94	2.2655	17.75	17.76
6/23/94	2.3825	18.70	18.68
6/23/94	2.3850	18.70	18.70
6/23/94	2.4495	19.20	19.21
6/10/94	2.5440	>19.9	
6/22/94	2.5435	>19.9	
6/22/94	2.5440	>19.9	
6/22/94	2.5435	>19.9	
6/23/94	2.5440	>19.9	
6/23/94	2.5440	>19.9	

*Regression equations given in Table 11

Table 11. Least Squares Regression Equations to Calculate Leakmeter Response Given Data Logger Voltage Output.

Data Logger Response (Volts)	Leakmeter Response (ppm)*	r-square
<0.01	<0.01	
0.01 to 0.05	10X - 0.045	0.9995
0.05 to 0.1	10X - 0.145	0.998
0.1 to 2.54	7.838X + 0.0065	0.99998
>2.54	>19.9	

*X = Data logger voltage.

Figure 12. Thermoanemometer Calibration Set Up.

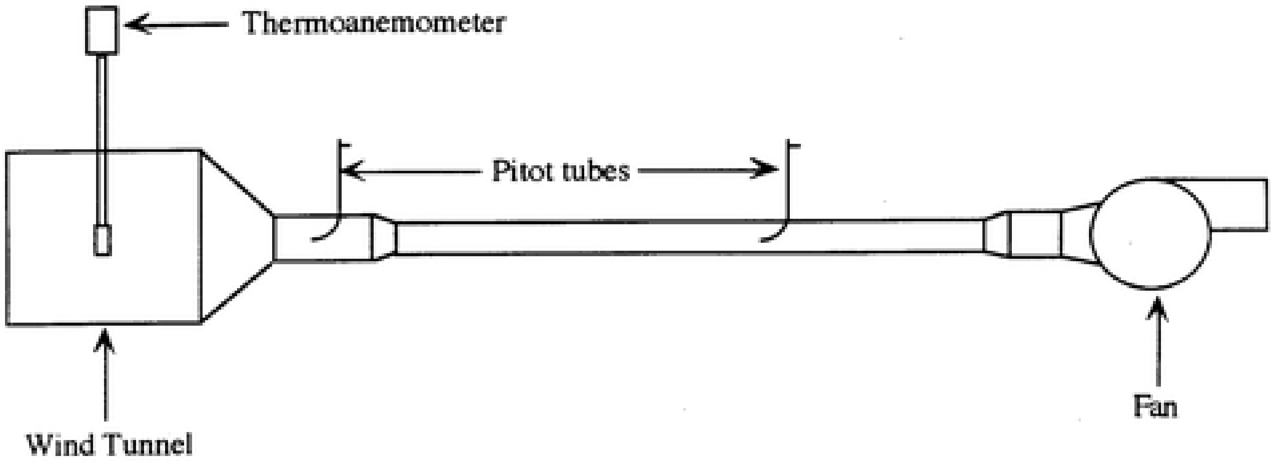


Figure 13. Calibration of Wind Tunnel Velocity to Hood Static Pressure.

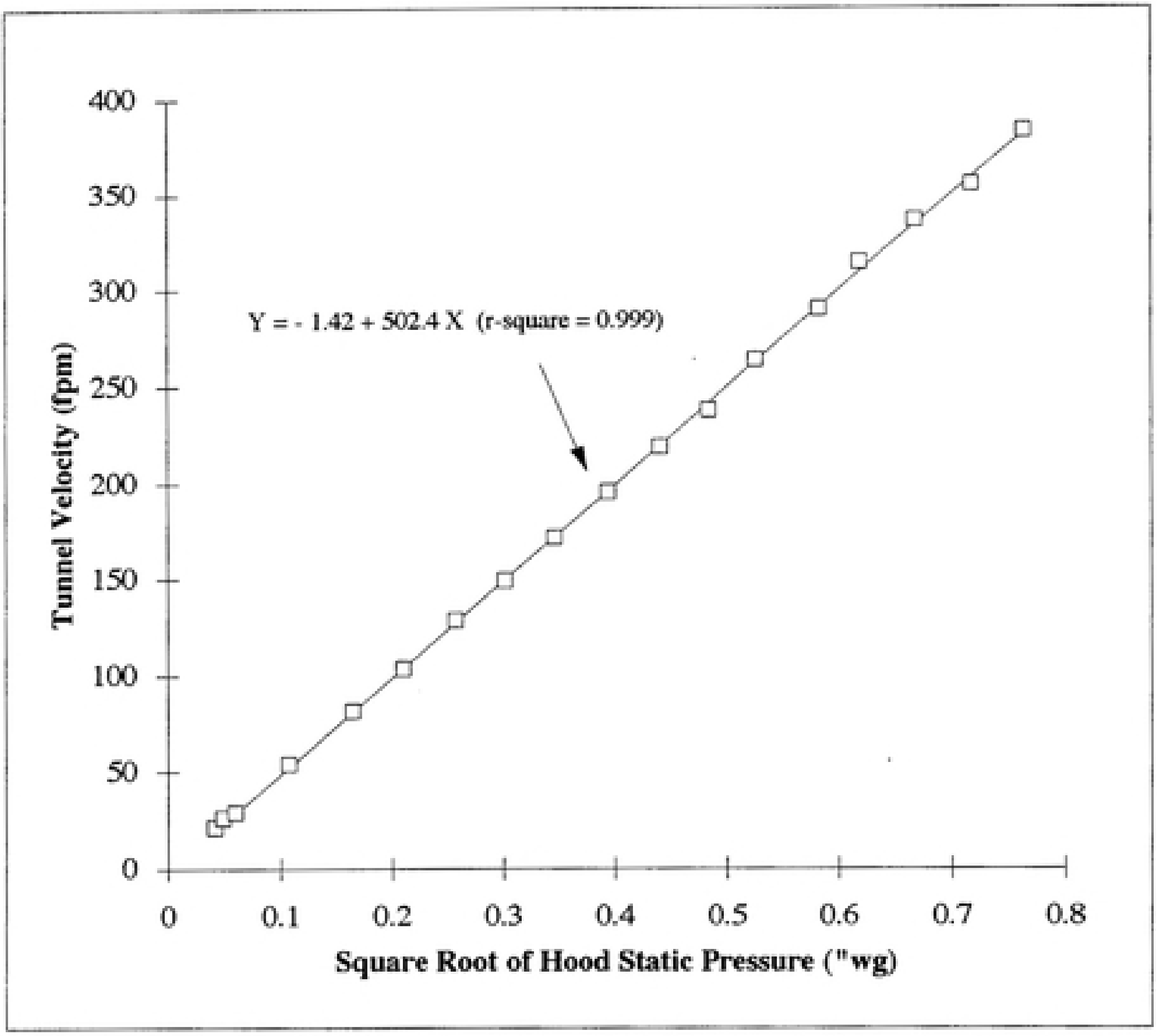


Figure 14. Thermoanemometer Reading as a Function of Wind Tunnel Velocity.

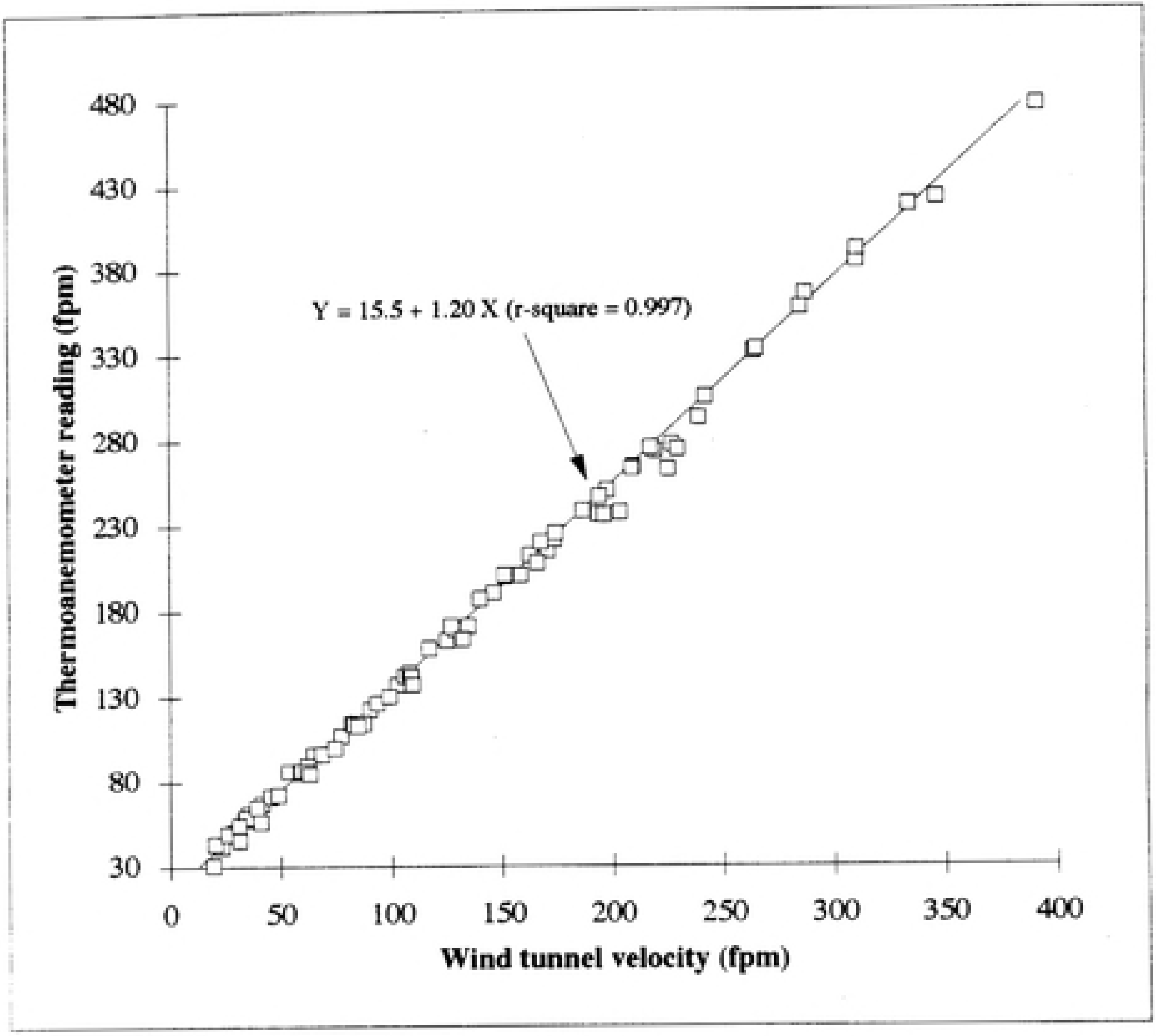


Figure 15. Set Up to Fill Calibration Bag for Leakmeter Calibration.

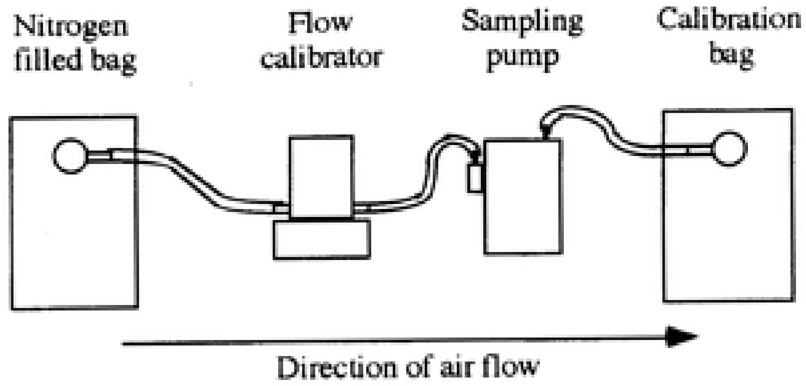


Figure 16. Leakmeter Response as a Function of Sulfur Hexafluoride Concentration.

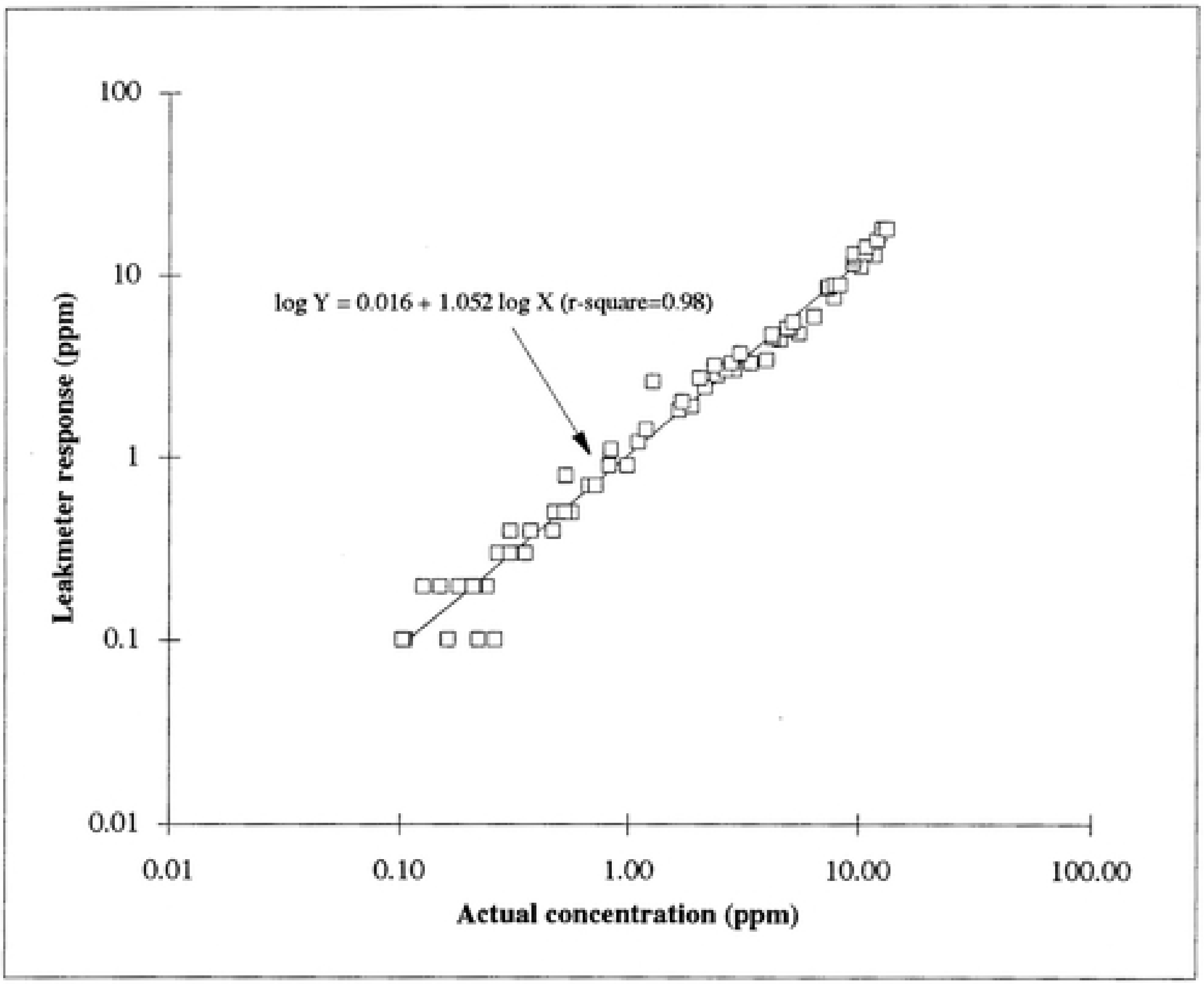


Figure 17. Leakmeter Response During Calibration Checks Prior to Tracer Gas Tests.

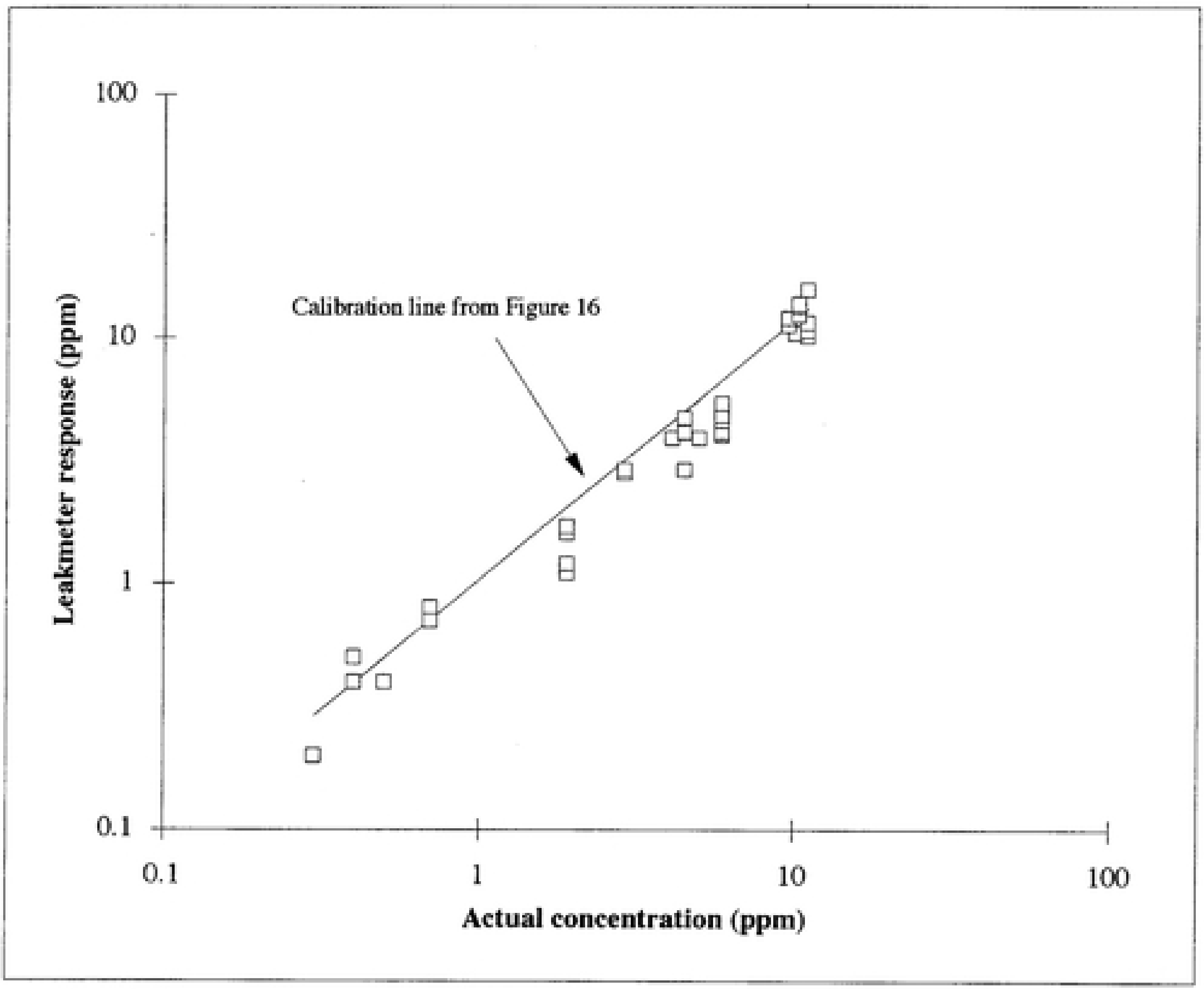
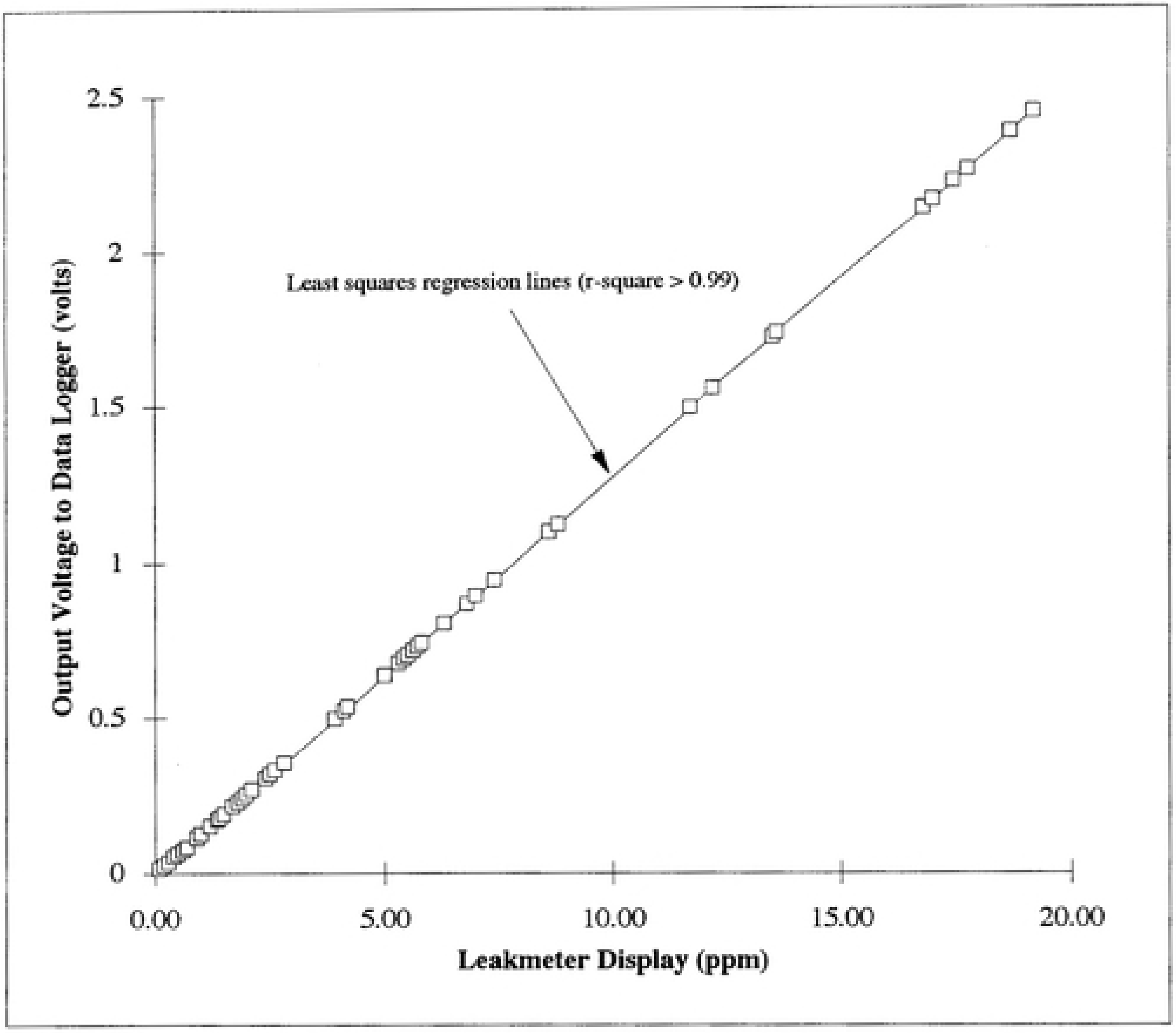


Figure 18. Output Voltage to Data Logger as a Function of Leakmeter Display.



APPENDIX C - RAW DATA

Table 12. Test Data Collected June through October 1994.

Hood ID	Sash Position	Rel. to supply	Area (sq. ft)	Smoke Test	Smoke Rank	Q (cfm)	Q/A	AFV	MxFV	MnFV	MnEV
2509AR	Left	Far	6.250	Good	1	491	79	69	84	61	65
2509AR	C1/3	Center	3.802	Good	1	488	128	106	118	96	n/a*
2509AR	Right	Near	6.250	Good	1	472	76	68	89	52	58
2511AL	Left	Far	6.224	Fair	2	451	72	70	89	42	42
2511AL	RC1/3	Near	4.167	Good	1	451	108	103	122	74	n/a
2511AL	Right	Near	6.198	Fair	2	451	73	78	112	56	46
2513AL	Left	Far	6.250	Good	1	611	98	85	95	76	76
2513AL	LC1/3	Far	4.208	Good	1	611	145	125	133	119	n/a
2513BR	Left	Near	6.250	Good	1	610	98	83	101	66	74
2513BR	RC1/3	Far	4.167	Good	1	610	146	119	130	99	n/a
2513BR	Right	Far	6.250	Good	1	610	98	85	100	69	85
2515AL	Left	Far	6.224	Fair	2	588	94	97	123	74	66
2515AL	LC1/3	Far	4.167	Good	1	597	143	139	159	122	n/a
2515AL	Right	Near	6.224	Good	1	635	102	92	99	85	69
2517AL	Left	Far	6.302	Fair	2	467	74	63	72	40	40
2517AL	LC1/3	Far	4.254	Good	1	464	109	97	113	80	n/a
2517AL	Right	Near	6.302	Fair	2	489	78	66	74	59	59
2517BR	Left	Near	6.224	Fair	2	651	105	82	107	59	59
2517BR	RC1/3	Far	4.193	Good	1	621	148	116	121	109	n/a
2517BR	Right	Far	6.224	Fair	2	634	102	83	87	80	80
2555AR	Left	Far	6.198	Good	1	436	70	78	98	57	57
2555AR	C1/3	Center	3.646	Good	1	450	123	129	134	119	n/a
2555AR	Right	Near	6.224	Fair	2	444	71	79	89	69	69
2555BR	Left	Near	6.250	Good	1	488	78	81	107	63	63
2555BR	RC1/2	Far	6.250	Good	1	488	78	83	91	62	n/a
2555BR	Right	Far	6.250	Fair	2	488	78	80	90	74	76
2557BL	Left	Near	6.198	Good	1	571	92	79	91	71	72
2557BL	RC1/2	Far	6.198	Good	1	562	91	83	89	77	n/a
2557BL	Right	Far	6.250	Good	1	581	93	80	98	75	75
2561AR	Left	Far	6.015	Fair	2	508	84	70	80	62	67
2561AR	C1/3	Center	3.802	Good	1	503	132	103	112	97	n/a
2561AR	Right	Near	5.990	Fair	2	506	84	68	87	56	55
2563AL	Left	Far	6.250	Fair	2	524	84	69	90	46	64
2563AL	RC1/3	Near	4.219	Good	1	523	124	110	127	93	n/a
2563AL	Right	Near	6.250	Good	1	540	86	81	113	55	55
2563BR	Left	Near	6.172	Poor	2	306	50	41	62	22	22
2563BR	LC1/3	Near	4.219	Good	1	305	72	64	75	51	n/a
2563BR	Right	Far	6.224	Fair	2	302	49	54	68	30	30
2571AL	Left	Far	6.250	Good	1	629	101	92	105	80	80
2571AL	RC1/3	Near	4.219	Good	1	624	148	128	135	123	n/a
2571AL	Right	Near	6.250	Good	1	652	104	92	102	85	85
2571BR	Left	Near	6.302	Good	1	621	99	88	101	73	89
2571BR	LC1/2	Near	6.276	Good	1	570	91	87	99	78	n/a
2571BR	Right	Far	6.250	Good	1	579	93	84	108	66	71

* n/a = not applicable. Since MnEV refers to the minimum velocity along the beveled edge of the hood, it could not be calculated for center sash positions.

Hood ID	Sash Position	FSCV	FMxTCV	FATCV	CD Direct	ACD	ACD/ AFV	ACD/ MxFV	ACD/ MnFV
2509AR	Left	6.9	6.6	3.4	1	10	0.14	0.12	0.16
2509AR	C1/3	3.8	4.7	2.2	n/a*	8	0.07	0.06	0.08
2509AR	Right	11.9	13.5	5.0	0	8	0.12	0.09	0.15
2511AL	Left	24.3	27.7	10.0	1	49	0.70	0.55	1.17
2511AL	RC1/3	20.1	5.7	3.5	n/a	37	0.35	0.30	0.49
2511AL	Right	34.9	10.6	5.3	0	32	0.40	0.28	0.56
2513AL	Left	7.2	6.3	4.4	1	33	0.39	0.35	0.43
2513AL	LC1/3	4.4	4.0	2.7	n/a	26	0.21	0.20	0.22
2513BR	Left	15.5	7.7	5.3	0	31	0.37	0.31	0.47
2513BR	RC1/3	10.7	3.3	2.6	n/a	28	0.24	0.22	0.28
2513BR	Right	14.0	5.3	4.4	1	14	0.16	0.14	0.20
2515AL	Left	17.9	8.4	5.6	0	28	0.29	0.23	0.38
2515AL	LC1/3	9.8	9.9	4.0	n/a	31	0.22	0.19	0.25
2515AL	Right	6.9	12.3	6.1	1	42	0.46	0.42	0.49
2517AL	Left	20.6	19.8	10.5	0	73	1.15	1.01	1.81
2517AL	LC1/3	12.9	4.6	3.5	n/a	48	0.49	0.42	0.60
2517AL	Right	10.1	10.6	7.0	1	49	0.73	0.66	0.82
2517BR	Left	23.8	15.8	5.3	0	13	0.16	0.12	0.22
2517BR	RC1/3	4.2	2.9	2.1	n/a	13	0.11	0.10	0.11
2517BR	Right	3.1	8.5	3.9	1	19	0.22	0.21	0.23
2555AR	Left	20.8	5.5	3.4	0	30	0.38	0.30	0.52
2555AR	C1/3	4.2	3.3	2.1	n/a	23	0.17	0.17	0.19
2555AR	Right	8.5	7.2	4.7	1	19	0.24	0.21	0.28
2555BR	Left	21.9	11.6	6.3	1	22	0.27	0.20	0.34
2555BR	RC1/2	13.3	8.1	6.0	n/a	23	0.28	0.25	0.37
2555BR	Right	7.6	13.5	5.8	0	22	0.28	0.24	0.30
2557BL	Left	10.0	4.7	3.4	1	20	0.25	0.22	0.28
2557BL	RC1/2	5.2	9.9	4.5	n/a	24	0.28	0.26	0.31
2557BL	Right	11.4	6.7	3.3	0	13	0.16	0.13	0.17
2561AR	Left	8.8	8.5	3.9	0	6	0.08	0.07	0.09
2561AR	C1/3	5.2	3.7	2.7	n/a	7	0.07	0.06	0.07
2561AR	Right	19.7	4.2	3.0	1	6	0.09	0.07	0.11
2563AL	Left	21.0	11.8	6.6	1	24	0.35	0.27	0.52
2563AL	RC1/3	14.2	6.7	3.2	n/a	15	0.13	0.11	0.16
2563AL	Right	31.8	3.5	2.8	0	10	0.12	0.08	0.17
2563BR	Left	41.7	18.4	9.6	1	36	0.88	0.58	1.64
2563BR	LC1/3	16.9	7.4	5.5	n/a	43	0.67	0.57	0.84
2563BR	Right	28.2	17.8	10.8	0	54	0.99	0.79	1.78
2571AL	Left	10.4	9.8	4.7	0	6	0.06	0.05	0.07
2571AL	RC1/3	3.8	3.7	2.4	n/a	16	0.13	0.12	0.13
2571AL	Right	6.2	4.0	2.8	1	18	0.19	0.17	0.21
2571BR	Left	8.5	3.9	2.7	1	4	0.05	0.04	0.05
2571BR	LC1/2	6.8	2.9	2.0	n/a	6	0.07	0.06	0.08
2571BR	Right	16.0	6.6	3.0	0	7	0.08	0.06	0.10

*n/a = not applicable. A value for CD Direct could not be assigned to center sash positions. See Appendix D for a definition of the variable.

Hood ID	Sash Position	MxCD	MxCD/ AFV	MxCD/ MxFV	MxCD/ MnFV	Peak-M	CL-M	Peak-U	CL-U	StgC (kHz)
2509AR	Left	20	0.29	0.24	0.33	0.07	3.6	3.40	1.9	9
2509AR	C1/3	13	0.12	0.11	0.14	0.07	3.6	0.07	3.6	9
2509AR	Right	13	0.19	0.15	0.25	0.07	3.6	0.07	3.6	9
2511AL	Left	57	0.81	0.64	1.36	0.10	3.5	0.10	3.5	8
2511AL	RC1/3	49	0.48	0.40	0.66	0.07	3.6	0.07	3.6	8
2511AL	Right	43	0.55	0.38	0.77	0.20	3.2	0.07	3.6	8
2513AL	Left	44	0.52	0.46	0.58	0.10	3.4	0.07	3.5	8
2513AL	LC1/3	42	0.34	0.32	0.35	0.20	3.1	0.07	3.5	8
2513BR	Left	43	0.52	0.43	0.65	0.40	2.8	1.30	2.2	10
2513BR	RC1/3	45	0.38	0.35	0.45	0.30	2.9	0.07	3.5	10
2513BR	Right	26	0.31	0.26	0.38	0.30	2.9	0.40	2.8	10
2515AL	Left	51	0.53	0.41	0.69	0.07	3.5	0.20	3.1	9
2515AL	LC1/3	53	0.38	0.33	0.43	0.07	3.5	0.07	3.5	9
2515AL	Right	64	0.70	0.65	0.75	0.07	3.5	0.10	3.3	9
2517AL	Left	133	2.11	1.85	3.33	0.07	3.6	0.30	3.0	9
2517AL	LC1/3	93	0.96	0.82	1.16	0.07	3.6	0.10	3.5	9
2517AL	Right	82	1.24	1.11	1.39	1.20	2.4	1.00	2.5	9
2517BR	Left	20	0.24	0.19	0.34	0.40	2.7	0.30	2.9	9
2517BR	RC1/3	20	0.17	0.17	0.18	0.30	2.9	0.30	2.9	9
2517BR	Right	25	0.30	0.29	0.31	0.30	2.9	0.30	2.9	9
2555AR	Left	66	0.85	0.67	1.16	0.70	2.7	0.20	3.2	9
2555AR	C1/3	38	0.29	0.28	0.32	0.30	3.0	0.20	3.2	9
2555AR	Right	41	0.52	0.46	0.59	0.50	2.8	0.20	3.2	9
2555BR	Left	45	0.56	0.42	0.71	0.10	3.5	0.20	3.2	8
2555BR	RC1/2	42	0.51	0.46	0.68	0.30	3.0	0.10	3.5	8
2555BR	Right	30	0.38	0.33	0.41	0.20	3.2	0.10	3.5	8
2557BL	Left	36	0.46	0.40	0.51	0.40	2.8	0.07	3.5	8
2557BL	RC1/2	37	0.45	0.42	0.48	0.10	3.4	0.07	3.6	8
2557BL	Right	26	0.33	0.27	0.35	0.07	3.5	0.10	3.4	8
2561AR	Left	10	0.14	0.13	0.16	0.30	3.0	0.40	2.8	8
2561AR	C1/3	21	0.20	0.19	0.22	0.30	3.0	0.20	3.1	8
2561AR	Right	18	0.26	0.21	0.32	0.60	2.7	0.07	3.6	8
2563AL	Left	37	0.54	0.41	0.80	0.07	3.6	0.07	3.6	10
2563AL	RC1/3	22	0.20	0.17	0.24	0.07	3.6	0.07	3.6	10
2563AL	Right	20	0.25	0.18	0.36	0.07	3.6	0.07	3.6	10
2563BR	Left	83	2.02	1.34	3.77	14.50	1.5	5.50	1.9	7
2563BR	LC1/3	77	1.20	1.03	1.51	0.07	3.8	0.07	3.8	7
2563BR	Right	95	1.76	1.40	3.17	0.20	3.4	0.30	3.2	7
2571AL	Left	10	0.11	0.10	0.13	0.50	2.6	0.40	2.7	7
2571AL	RC1/3	54	0.42	0.40	0.44	0.70	2.5	0.20	3.0	8
2571AL	Right	33	0.36	0.32	0.39	0.10	3.3	0.10	3.3	9
2571BR	Left	7	0.08	0.07	0.10	0.07	3.5	0.40	2.8	9
2571BR	LC1/2	11	0.13	0.11	0.14	0.10	3.4	0.30	2.9	9
2571BR	Right	16	0.19	0.15	0.24	0.07	3.5	0.10	3.4	9

Table 13. Historical Data Collected May 13, 1992 Through July 17, 1992 by Contamination Control Technologies, Inc.

Hood ID	Sash Pos.	Area (sq. ft)	Smoke	Smoke Rank	AFV	MxFV	MnFV	FSCV	Peak-M	CL-M
1507A	C1/2	6.61	Fair	2	141	168	120	10.0	0.09	1.1
1507B		6.61	Fair	2	136	165	108	12.4	0.09	1.1
1509AL	Left	6.61	Fair	2	120	138	105	10.5	0.02	0.5
1509AR	Left	6.61	Poor	3	101	120	83	13.4	0.02	0.6
1509BL	Left	6.61	Poor	3	90	118	50	24.3	0.02	0.7
1509BR	Right	6.61	Fair	2	129	165	89	19.8	0.09	1.2
1511A	Left	6.61	Fair	2	138	165	102	15.9	0.02	0.5
1511B	Left	6.61	Good	1	156	185	130	14.6	0.02	0.4
1517AR	C1/2	6.56	Poor	3	93	122	79	14.1	0.10	1.4
1519AR		3.90	Fair	2	97	115	84	13.2	0.02	0.9
1519B	LC1/3	4.00	Fair	2	208	230	180	9.7	0.02	0.5
1521A	C1/3	4.10	Fair	2	185	200	170	6.8	0.02	0.6
1521B	C1/3	3.90	Fair	2	156	180	140	8.9	0.02	0.7
1523A	C1/3	3.90	Poor	3	120	140	110	8.9	0.02	0.8
1525A	Right	8.80	Fair	2	134	182	105	20.0	0.09	1.0
1525B	Left	6.40	Fair	2	144	177	123	12.1	0.10	1.2
1561AR	Left	6.70	Fair	2	132	145	118	7.7	0.02	0.5
1561BL	Right	6.70	Fair	2	150	200	120	15.9	0.02	0.4
1563AR	Right	6.70	Fair	2	134	160	105	14.0	0.02	0.5
1563BL		6.70	Fair	2	148	189	103	22.1	0.09	1.1
1565AR		6.70	Poor	3	75	104	46	27.1	0.25	1.8
1565BL	Right	6.70	Poor	3	40	50	24	18.1	5.07	3.4
1571AR	Right	6.70	Fair	2	71	87	50	17.5	0.09	1.4
1571BL	Right	6.70	Poor	3	101	112	90	7.8	0.25	1.7
1573AR	Left	6.70	Fair	2	100	135	80	17.2	0.48	2.0
1573BL	Left	6.70	Fair	2	101	123	82	11.9	0.02	0.6
1575AR	Left	6.40	Fair	2	145	166	104	12.1	0.02	0.5
1575BL	L1/3	4.10	Fair	2	135	146	122	5.8	0.10	1.4
1577AR	Left	6.40	Fair	2	78	105	40	27.8	0.02	0.7
1577BL	Right	6.70	Fail	3	83	94	46	17.3	0.17	1.6
1579BL	Right	6.40	Poor	3	74	94	63	14.2	1.18	2.5
1711	L1/3	4.10	Good	1	233	250	210	6.8	0.02	0.5
1732	L1/3	4.40	Good	1	172	200	155	9.3	0.02	0.6
2509AL	Right	6.77	Good	1	109	150	66	24.5	0.02	0.6
2509AR	Right	6.77	Fair	2	97	130	74	19.0	0.02	0.6
2509BL	RC1/3	4.57	Fair	2	97	105	90	5.2	0.02	0.8
2509BR	Right	6.77	Good	1	99	112	86	8.9	0.02	0.6
2511AL	RC1/2	6.71	Good	1	98	125	78	18.8	0.02	0.6
2511AR	Left	6.71	Good	1	95	112	84	9.8	0.02	0.6
2511BL	LC1/2	6.67	Good	1	107	122	87	11.7	0.007	0.1
2511BR		6.66	Fair	2	128	145	115	9.5	0.02	0.5
2513AL	Right	6.77	Good	1	129	175	105	17.9	0.02	0.5
2513AR	C1/3	4.06	Good	1	135	155	120	8.8	0.02	0.7
2513BL	LC1/3	4.57	Good	1	109	120	96	8.4	0.02	0.7

Hood ID	Sash Pos.	Area (sq. ft)	Smoke	Smoke Rank	AFV	MxFV	MnFV	FSCV	Peak-M	CL-M
2513BR	C1/3	4.12	Fair	2	144	150	129	5.6	0.02	0.7
2515AL	C1/3	4.51	Fair	2	156	180	137	10.2	0.01	0.3
2515AR	RC1/3	4.51	Fair	2	132	145	115	8.3	0.02	0.7
2515BL	L1/3	4.51	Fair	2	116	127	105	6.6	0.02	0.7
2515BR		4.51	Fair	2	127	142	115	7.4	0.02	0.7
2517AL	R1/3	4.56	Fair	2	120	127	112	4.9	0.02	0.7
2517BR	LC1/3	4.44	Fair	2	150	180	112	13.1	0.02	0.6
2519AL	Left	6.30	Fair	2	137	145	129	4.5	0.02	0.5
2519BR	LC1/3	4.00	Poor	3	120	145	100	13.5	0.02	0.8
2523AL	LC1/2	6.10	Good	1	93	105	75	10.3	0.09	1.3
2523BR	LC1/2	6.60	Good	1	109	130	92	9.7	0.17	1.5
2525AL	Right	6.30	Fair	2	120	140	86	14.7	1.80	2.5
2525BR	LC1/2	6.70	Fair	2	90	100	80	7.9	0.63	2.2
2527B	Right	6.30	Poor	3	139	155	112	10.6	0.02	0.5
2529B	Right	6.40	Good	1	174	205	150	10.8	0.02	0.4
2539B	C1/3	4.00	Fair	2	233	243	220	4.2	0.02	0.5
2555AL	Right	6.67	Fair	2	127	148	105	13.4	0.10	1.2
2555AR	Right	6.67	Fair	2	94	103	88	6.0	0.02	0.6
2555BL	Left	6.70	Fair	2	93	105	75	9.9	0.10	1.4
2555BR	Left	6.70	Fair	2	115	125	96	7.8	0.02	0.6
2557AL	Left	6.67	Poor	3	112	125	99	7.8	0.02	0.6
2557AR	LC1/2	6.67	Good	1	96	104	88	5.5	0.02	0.6
2557BL	Right	6.67	Fair	2	105	135	81	21.3	0.02	0.6
2557BR	LC1/2	6.67	Good	1	124	140	113	7.1	0.17	1.5
2559AL	LC1/2	6.61	Good	1	128	155	110	14.2	0.02	0.5
2559AR	Right	6.67	Fair	2	109	150	79	25.1	5.45	3.0
2559BL	Right	6.61	Fair	2	94	120	50	28.5	0.63	2.2
2559BR	Right	6.67	Fair	2	128	155	110	10.8	0.10	1.2
2561AL	LC1/2	6.67	Fair	2	129	175	95	23.5	0.02	0.5
2561AR	RC1/3	4.11	Fair	2	139	150	130	5.8	0.02	0.7
2561BL	LC1/3	4.50	Fair	2	140	172	115	14.9	0.02	0.6
2561BR	LC1/3	4.44	Good	1	169	185	150	7.1	0.02	0.6
2563AL	Right	6.66	Fair	2	102	138	72	24.4	0.02	0.6
2563BR	Right	6.67	Fair	2	79	105	55	21.5	2.97	2.9
2563BR	C1/3	4.11	Fair	2	94	103	72	12.9	0.02	0.9
2565A	C1/3	4.10	Fair	2	163	175	140	8.0	2.74	2.8
2569AL	LC1/3	4.00	Good	1	135	150	122	7.6	0.02	0.7
2569BR	LC1/2	6.67	Good	1	124	140	110	8.3	0.02	0.5
2571AL	RC1/2	6.67	Fair	2	77	93	59	14.1	6.39	3.2
2571BR	LC1/2	6.67	Fair	2	121	145	107	11.2	0.02	0.5
2573AL	RC1/3	4.50	Fair	2	136	151	120	10.1	0.02	0.7
2573BR	RC1/3	4.44	Fair	2	113	135	92	10.9	0.09	1.4
2573BR	RC1/3	4.44	Fair	2	113	135	92	10.9	0.09	1.4
2573BR	Left	6.56	Poor	3	89	105	72	13.6	4.13	3.0

APPENDIX D - VARIABLE DEFINITIONS

The face velocity and cross draft variables potentially important for predicting hood containment are listed and defined below. The variables are divided into four groups, based on their statistical correlation with one another. Many of the variables considered were merely ratios of other variables. These are listed only by the abbreviations of their constituent variables. The units used for each variable, where appropriate, are indicated at the end of the definition. Feet per minute is abbreviated fpm.

<u>Group 1</u>

- Average face velocity (AFV) - the arithmetic average of the measurements taken at the six face velocity traverse points. (fpm)
- Maximum face velocity (MxFV) - the maximum average velocity at any of the six face velocity traverse points. (fpm)
- Minimum face velocity (MnFV)- the minimum average velocity at any of the six face velocity traverse points. (fpm)
- Predicted average face velocity (Q/A) - the average face velocity predicted by dividing the total exhaust flow as measured with a pitot traverse by the cross sectional area of the hood face.
- Minimum edge velocity (MnEV) - The minimum average velocity at either of the two traverse points along the beveled edge of a hood opening. (fpm)

<u>Group 2</u>

- Face velocity spatial coefficient of variation (FSCV) - the coefficient of variation (standard deviation divided by the mean) of the average velocities at the six face velocity traverse points. (%)

<u>Group 3</u>

- Face velocity average temporal coefficient of variation (FATCV) - the average value of the six coefficient of variations (standard deviation divided by the mean) calculated from the ten readings taken at each face velocity traverse point. (%)
- Face velocity maximum temporal coefficient of variation (FMxTCV) - the maximum value of the six coefficient of variations (standard deviation divided by the mean) calculated from the ten readings taken at each face velocity traverse point. (%)

Group 4

- Average cross draft (ACD) - the arithmetic average of the cross draft measurements taken at two points proximate to each hood opening. (fpm)
- Maximum cross draft (MxCD) - the maximum average cross draft velocity at either of teh two measurement locations proximate to a hood opening. (fpm)

The remaining cross draft variables considered with Group 4 were ratios ofcross draft and face velocity variables:

- ACD/AFV
- ACD/MxFV
- ACD/MnFV
- MxCD/AFV
- MxCD/MxFV
- MxCD/MnFV

The abbreviations of other variables recorded or used in some manner in the text or the appendices of this report are listed below, with units where appropriate. Cubic feet per minute is abbreviated cfm; parts per million is abbreviated ppm.

- Exhaust flow rate (Q) - the total flow rate of air exhausting from the hood. (cfm)
- Smoke rank - the results of the smoke test were quantified, with good being assigned a value of 1, fair assigned 2, and poor assigned 3.
- Cross draft direction (CD Direct) - a variable used to indicate the prevailing direction of cross drafts relative to a hood face. A value of 0 indicates that the cross drafts were moving in a direction such that they would not be expected to augment the vortex along the beveled edge of a hood opening. A value of 1 indicates that the cross drafts were moving in a direction such that they wouldbe expected to augment the vortices along the beveled edge of a hood opening.
- Peak breathing zone concentration, manikin test (Peak-M) - the maximum concentration of sulfur hexafluoride detected in the breathing zone of a manikin outside of the hood during a five minute challenge of 4 liters per minute inside the hood. (ppm)
- Peak breathing zone concentration, user test (Peak-U) - the maximum concentration of sulfur hexafluoride detected in the breathing zone of a human user outside of the hood during a five minute challenge of 4 liters per minute inside the hood. (ppm)

• Containment level, manikin test or user test (CL-M or CL-U) - a variable used to normalize the leakage concentration to the exhaust flow rate of the hood and to transform the concentration to a log scale. The equation to calculate containment level, CL is:

$$CL = \log\left(\frac{G / Q}{Co}\right);$$

where G is the generation rate of the tracer gas, Q is the exhaust flow rate, and Co is the peak concentration of tracer gas detected in the manikin or user's breathing zone.

• Standing current (StgC) - a parameter which indicates the status of the electron capture detector used to quantify the concentration of sulfur hexafluoride leaking from a hood. A standing current below 20 kHz is deemed acceptable by the instrument manufacturer. (kHz)

APPENDIX E - STATISTICAL TEST RESULTS

Table 14. Test Data T-test Results for the Comparison of Mean Values of All Considered Variables for High and Low Leakage Groups as Determined by a User Tracer Gas Test.

User Test Result (ppm)	n	Smoke Rank	Q/A	AFV	MxFV	MnFV	FSCV
<0.25	30	1.23	100	92	107	77	13.4
>0.25	14	1.50	89	77	90	63	14.5
	Sp^2	0.21	630	390	349	515	82
	T	-1.79	1.29	2.28	2.85	1.87	-0.36
	p	0.04	0.10	0.01	0.003	0.03	0.36

User Test Result (ppm)	n	FMxTCV	FATCV	ACD	ACD/AFV	ACD/MxFV	ACD/MnFV
<0.25	30	7.8	4.2	23.7	0.27	0.23	0.34
>0.25	14	9.9	5.4	23.9	0.37	0.31	0.56
	Sp^2	27	5	246	0.07	0.04	0.18
	T	-1.25	-1.66	-0.02	-1.23	-1.14	-1.56
	p	0.11	0.05	0.49	0.11	0.13	0.06

User Test Result (ppm)	n	MxCD	MxCD/AFV	MxCD/MxFV	MxCD/MnFV	Mkn Conc	Mkn CL
<0.25	30	29.7	0.34	0.29	0.43	0.20	3.28
>0.25	14	31.3	0.51	0.41	0.77	1.22	2.94
	Sp^2	466	0.14	0.09	0.38	3.55	0.2
	T	-0.22	-1.39	-1.29	-1.73	-1.66	2.42
	p	0.41	0.09	0.10	0.05	0.05	0.01

n = number of hoods in User Test Result category.

Sp^2 = pooled sample variance = $\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}$

n_1 = number of hoods in low leakage group (user test concentration < 0.25 ppm)

S_1^2 = variance of given variable for hoods in low leakage group

n_2 = number of hoods in high leakage group (user test concentration > 0.25 ppm)

S_1^2 = variance of given variable for hoods in high leakage group

T = two-sample t test statistic = $\frac{(\overline{Y}_1 - \overline{Y}_2)/\sqrt{1/n_1 + 1/n_2}}{S_p}$

$\overline{Y}_1$ = mean value, as given in table, for a given variable in low leakage group

$\overline{Y}_2$ = mean value, as given in table, for a given variable in high leakage group

p = critical value for the one tailed t test for the difference in means between the two groups

Table 15. Historical Data T-test Results for the Comparison of Mean Values of All Considered Variables for High and Low Leakage Groups as Determined by a Manikin Tracer Gas Test.

Manikin Test Result (ppm)	n	Smoke Rank	AFV	MxFV	MnFV	FSCV
<0.25	75	1.84	127	149	106	12.0
>0.25	13	2.38	93	114	71	16.8
	Sp^2	0.36	969	1139	1003	33.3
	T	3.04	-3.61	-3.40	-3.71	2.77
	p	0.002	0.0003	0.0005	0.0002	0.003

n = number of hoods in Manikin Test Result category.

Sp^2 = pooled sample variance = $\dfrac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}$

n_1 = number of hoods in low leakage group (user test concentration < 0.25 ppm)

S_1^2 = variance of given variable for hoods in low leakage group

n_2 = number of hoods in high leakage group (user test concentration > 0.25 ppm)

S_1^2 = variance of given variable for hoods in high leakage group

T = two-sample t test statistic = $\dfrac{(\overline{Y}_1 - \overline{Y}_2)/\sqrt{1/n_1 + 1/n_2}}{S_p}$

$\overline{Y}_1$ = mean value, as given in table, for a given variable in low leakage group

$\overline{Y}_2$ = mean value, as given in table, for a given variable in high leakage group

p = critical value for the one tailed t test for the difference in means between the two groups