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Using the ASHRAE 110 Test as a TQM Tool to Improve Laboratory Fume Hood Performance

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ABSTRACT

ANSI/ASHRAE 110-1995, Method of Testing Performance of Laboratory Fume Hoods *(ASHRAE 1995) yields quantitative data about fume hood containment and can be used in a classical total quality management (TQM) approach to process improvement. This involves measuring process indicators, analyzing probable causes of poor performance, implementing changes to the process, and again measuring the indicators to determine the efficacy of the changes implemented. This paper outlines the ASHRAE 110 method and how it was used to evaluate the containment performance of fume hoods in the quality control laboratory of a pharmaceutical manufacturing plant, the techniques implemented to improve performance, and the final results. An average reduction of 99.5% in ASHRAE 110 tracer gas control levels was realized. These ASHRAE 110 tests, combined with several thousand others, reveal that 30% to 50% of the hoods tested that meet industry standard face velocity specifications have leakage rates that exceed industry guidelines.*

INTRODUCTION

ANSI/ASHRAE 110-1995, Method of Testing Performance of Laboratory Fume Hoods (ASHRAE 1995) yields quantitative data about fume hood containment and can be used in a classical total quality management (TQM) approach to process improvement. This process involves measuring process performance indicators, analyzing probable causes for poor performance or opportunities for improvement, implementing specific changes to the process, and again measuring the indicators to determine the efficacy of the changes implemented. This paper outlines the ASHRAE 110 method and how it was used to evaluate the containment performance of fume hoods in the quality control laboratory of a pharmaceutical manufacturing plant, the techniques implemented to improve performance, and the final performance results.

Periodic performance evaluation of laboratory fume hoods is required by the Occupational Safety and Health Administration's laboratory standard (OSHA 1990). Most frequently, the performance evaluation test method chosen is a face velocity traverse of the sash opening of the hood using a hand-held anemometer and the recording of instantaneous or short-term (one to five seconds) average velocity readings at each traverse point. The mean of these readings is then compared to the user's specifications to determine if the hood is safe to use. Others also compute the standard deviation of the traverse readings to get an idea of the variation in the face velocity profile and compare this number to some threshold to determine acceptability or unacceptability. This calculation of standard deviation gives a representation of the variability of the face velocity from traverse point to traverse point but yields no information about the variability of the face velocity over time at each traverse point.

However, "face velocity alone is inadequate to describe hood performance and is not more important than supply air distribution" (AIHA 1992) and many other laboratory environmental factors. The ability of the laboratory fume hood to capture and contain hazardous fumes and vapors is often equated to its face velocity. Although average face velocity and containment efficiency are related under ideal conditions, they are not the same. In fact, the coefficient of correlation between the hood's average face velocity and the log of the tracer gas control level from 176 ASHRAE 110 hood performance tests was determined to be only 0.24 (Hitchings 1995). Many fume hoods that meet the simple face velocity specification described above may be allowing worker exposure to the hazards used in them. Furthermore, instantaneous face velocity tests ignore transient effects on the face velocity, such as turbulence and interference from external sources such as supply air diffusers, doors, and traffic on the hood.

Medical screening and personal air sampling are by far the most accurate ways to determine worker exposure to

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hazardous substances used in fume hoods, but they are frequently impractical due to the time and cost involved in sampling each worker at each hood for each agent used in the hood and re-testing when new agents are introduced or new procedures implemented.

In the late 1970s, Caplan and Knutson began publishing research using a new method of determining capture efficiency by using a tracer gas sampling method (Caplan and Knutson 1977, 1978). This was the precursor to *ANSI/ASHRAE 110-1985, Method of Testing Performance of Laboratory Fume Hoods* and the 1995 version of the standard. The draft version of the revised standard was used as the basis for the tracer gas containment testing cited in this paper. Modifications and enhancements were made to this test protocol either to simplify the procedure and make it more cost-effective to perform or to enhance the results. One of these enhancements is the use of real-time data acquisition of velocity data at each traverse point and the application of statistical techniques to give a more accurate picture of fume hood performance. This technique reveals significantly more about the variation of the face velocity over time and is explained in detail elsewhere in this paper in "The ANSI/ASHRAE 110 Test Method." ASHRAE 110 testing is also recommended in the newly revised *Prudent Practices in the Laboratory* (NRC 1995). The OSHA laboratory standard heavily references the 1981 version of this excellent work and implies adherence to its recommendations (OSHA 1990).

Complaints from laboratory workers and concerns about potential exposures to agents leaking from old fume hoods in an old laboratory facility provided the motivation to investigate and mitigate the situation. Some personal air sampling was done, requiring considerable time and expense. However, a comprehensive study of this type involving all workers and all agents using this method proved impractical, and traditional face velocity testing of hoods proved inadequate to evaluate actual fume hood performance (containment). ASHRAE 110 testing was chosen as the most cost-effective method of determining quantitative fume hood performance, and the results were used as the basis of a project that involved diagnosing hood containment problems, identifying solutions to them, and implementing those solutions to reduce potential worker exposures.

THE LABORATORY FACILITY

The subject facility is an analytical laboratory for a large midwestern pharmaceutical manufacturing plant. Nine laboratories were created by renovating an existing office/cafeteria building more than 20 years ago. There are 46 chemical fume hoods with individual exhaust fans and stacks.

Large amounts of solvents are used in these laboratories, and several different products of varying potency are tested in them, some of which are severe allergens. A "potent" compound is one that produces significant physiological effects at very low exposure concentrations. "Severe allergens" are compounds that can produce serious undesirable effects in susceptible individuals.

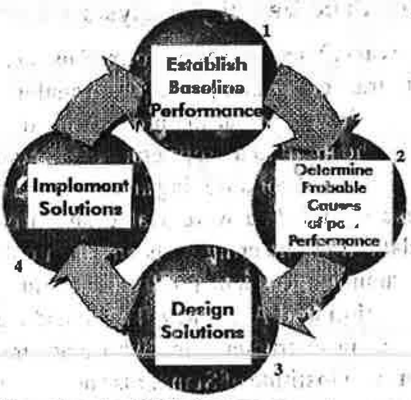

Figure 1 *The classical TQM process.*

THE PERFORMANCE IMPROVEMENT PROCESS

A classical TQM approach was used in the planning and execution of this project (see Figure 1).

1. Baseline performance was first determined by testing all 46 fume hoods using the ASHRAE 110 method.
2. Probable causes of poor performance were determined.
3. Solutions were generated for most of the problems determined in step 2.
4. A mitigation plan was implemented that included the solutions in step 3.

The process was then completed by retesting the fume hoods and comparing the pre- and post-mitigation results to determine the effectiveness of the project.

THE ASHRAE 110-1995 TEST METHOD (MODIFIED)

Flow Visualization (Smoke Testing)

Low-Volume Smoke Test. A small amount of white smoke was produced by using a glass smoke tube/bulb arrangement and/or a swab of titanium tetrachloride. This smoke source was moved around the perimeter of the sash opening while observing the flow patterns. The hoods passed this test if no flow-reversals or eddy currents were detected and if no smoke escaped from the hood into the laboratory. "Flow reversals" and "eddy-currents" are localized phenomena in which the direction of flow is contrary to the prevailing streamlines, and they are often characterized by turbulence and vortices.

High-Volume Smoke Challenge. Copious amounts of smoke were generated using a theatrical smoke generator. The smoke was released at a low velocity into the fume hood from the end of a flexible hose, and the flow patterns were observed. The hood passed this test if no smoke escaped from the hood without being immediately recaptured.

Real-Time Face Velocity Analysis

Hardware. The test was performed using a hot-wire type of velocity transducer that produces an analog signal proportional to the air velocity at the probe. This transducer signal was used as the input to a proprietary data acquisition system that performs signal conditioning and analog to digital conversion. These digital data were scaled and offset to produce velocity data in engineering units and then collected using a computer running proprietary software for analysis.

Calibration and Accuracy. The transducer was factory calibrated using instrumentation whose accuracy was traceable to National Institute of Standards and Technology (NIST) standards at STP (standard temperature of 21.1°C and pressure of 760.00 mm Hg). The velocity instrument was accurate to ±1.5% of reading or ±1.5 fpm at 100 fpm (±.008 m/s at 0.51 m/s). The accuracy of the signal conditioning equipment and analog to digital conversion hardware was 1/2 bit of an 8-bit word (one part in 256), or 0.4%. Aggregate system errors were expected to be less than 2% or 2 fpm at 100 fpm (0.01 m/s at 0.51 m/s).

Procedure. The sash opening was divided into an imaginary grid of approximately one-foot dimensions, and the probe was placed in the center of each grid box. The velocity probe was positioned at the desired traverse point in the plane of the hood opening. Velocity readings were taken five times per second over a 30-second period per traverse point. The probe was then moved to another location until the entire sash opening had been surveyed. For each position, the mean, maximum, minimum, and standard deviation were calculated and recorded.

Error Reduction. Investigator-induced error caused by improper location, orientation, or movement of the velocity probe during the traverse was reduced or eliminated by clamping the velocity transducer to a ring stand that could be accurately positioned in the plane of the sash opening of the hood. Instrument reading error was eliminated by having the computer read the output of the instrument.

ASHRAE 110 Tracer Gas Containment Testing

Hardware. This test was performed using a electron capture detector type of tracer gas analyzer. It has a digital LCD display reading out in ppm and an analog signal output that goes to a proprietary data acquisition system that performs signal conditioning and analog to digital conversion. These digital data were then scaled and offset to produce tracer gas concentration data in engineering units and then collected using a computer running proprietary software for analysis.

The mannequin used for the test is a clothing display mannequin that meets the height and width requirements of ASHRAE 110. The feet were modified (removed) so that the mannequin could be mounted on an elevated mobile platform yet still maintain the height required by the standard. This modification is not expected to affect the test results when used testing benchtop and distillation fume hoods and is expected to have little effect when testing walk-in fume hoods.

The tracer gas flow rate to the ASHRAE standard ejector was measured and controlled to 4.0 L/min using a gas flowmeter and a pressure gauge.

Calibration and Accuracy. The electron capture cell detection limit in the particular configuration used in this test was 0.01 ppm. The accuracy of the signal conditioning equipment and analog to digital conversion hardware was 1/2 bit of an 8-bit word (one part in 256), or 0.4%. The unit was field calibrated several times each day using a calibration gas of 0.9 ppm. The calibration gas was assayed using NIST traceable standards and is expected to be accurate within 0.01 ppm. The instrument is linear within 10% below 2.6 ppm. Nonlinear response was experienced above this range. Aggregate system errors were expected to be less than 0.02 ppm at the control level of 0.1 ppm. Tracer gas levels recorded as 0.00 do not indicate the total absence of tracer gas but concentrations less than the detection limits of the detector. The instrument was normally operated so that the detector range was between 0.01 ppm and 2.00 ppm with a target control level of 0.10 ppm. If higher tracer gas levels were present, the detector range may be increased one decade to 0.1-20.0 ppm or, if necessary, 1.0-200 ppm. Data on the test reports reading 2.00 or 20.0 indicate that the tracer gas levels probably exceeded the range of the detector and were actually higher than indicated.

The accuracy of the pressure gauge/flowmeter arrangement was expected to be within 10% given the accuracy of the calibrator of ±0.1% and the repeatability of the pressure gauge and flowmeter. The flow rate through this system was calibrated using an electronic flow calibrator, which was a primary standard.

Procedure (Benchtop Fume Hoods). The centering of the tracer gas ejector (see Figure 2) was positioned 12 in. (30 cm) from the left wall of the fume hood. The front edge of the ejector diffuser ring was placed 6 in. (15 cm) back from the plane of the sash. The tracer gas block valve was opened and, if necessary, the flow rate was adjusted. The mannequin was placed in front of the fume hood with the vertical centerline of the mannequin in line with the vertical centerline of the ejector and with the nose of the mannequin 3 in. (7.6 cm) in front of the place of the sash. The detector was inserted into the head of the mannequin with the probe protruding approximately one-half inch from the mouth. Tracer gas levels were then recorded for four to five minutes. The average tracer gas concentration for this survey was calculated for this position and was called the "positional control level." The ejector and mannequin were then moved laterally to the center of the hood, and the tracer gas levels were monitored again for four to five minutes. A second positional control level was calculated. Next, the ejector and mannequin were moved to the right side of the hood so that the centerline of the ejector and mannequin were 12 in. (30 cm) from the right wall of the hood. Tracer gas readings were taken for an additional four to five minutes in this position. A third positional control level was calculated. The control level for the entire fume hood was the maximum of the three positional control levels. The minimum, maxi-

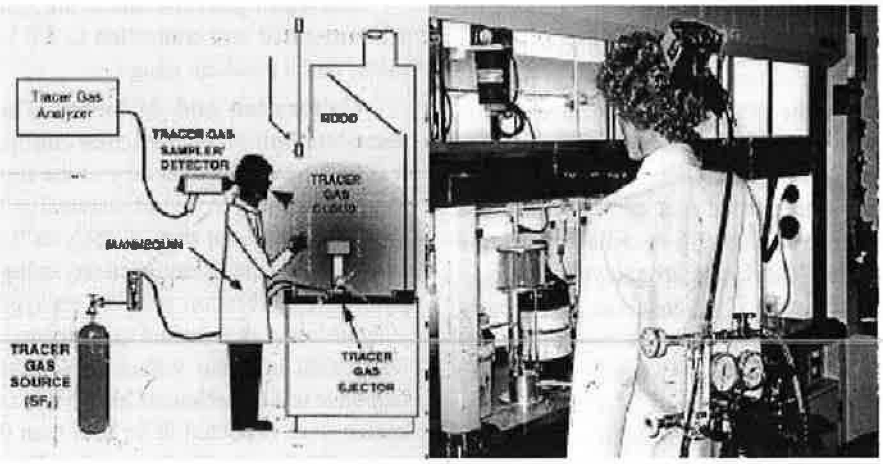

***Figure 2** The ASHRAE 110 tracer gas test schematic and setup.*

mum, mean, and standard deviation of the data for each position were recorded. Finally, the ejector was moved back to the center of the hood, the mannequin was removed, and the detector probe was moved by hand around the perimeter of the sash opening. The maximum tracer gas concentration between each perimeter/grid intersection was noted in the test report. Variations in the placement of the tracer gas ejector were sometimes necessary to accommodate equipment within the fume hood and were carefully documented.

Distillation and Walk-in Fume Hoods. The procedure was the same as noted above for benchtop hoods except that the tracer gas ejector was mounted on a stand and elevated so that the bottom of the ejector was approximately 30 inches above the floor.

PERFORMANCE IMPROVEMENT PROJECT SCOPE

The initial fume hood testing and detailed investigation phase revealed many hoods performing outside the specified velocity limits, many hoods exhibiting high turbulence and wide velocity fluctuations across the face (profile), and very high average tracer gas leakage. It is important to note that if the traditional face-velocity-only test had been used to determine "performance," more than half of the hoods requiring mitigation would have escaped detection.

There were two major directions that the project could have taken at this point. The first was a comprehensive, targeted mitigation project designed to address individual problems at a relatively low cost of approximately $200,000. The second was a wholesale laboratory renovation including the fume hoods and mechanical systems, which was estimated at approximately $2,000,000. It was decided, due to budget constraints and the desire not to disturb laboratory operations required by the FDA as part of the pharmaceutical manufacturing process, that the first proposal would be implemented. The following probable causes and recommendations were then generated and included in the mitigation plan that was executed.

Hood Repairs. Several hoods were missing one or both piping access panels located in the interior sidewalls of the hood. This allowed large volumes of air to be drawn into the hoods through these openings in the sidewalls, thereby bypassing the sash opening. Not only does this lower the average face velocity, but the stray air entering the hood perpendicular to the face caused considerable turbulence inside the hood, which was clearly shown during the smoke tests. The access panels were replaced. Several hoods required repairs to the sash mechanisms to restore proper movement. The baffles on several hoods were replaced or repaired to allow control of the face velocity profile.

Hood Baffle Optimizations. The baffles on most of the hoods tested were improperly adjusted and exhibited much higher velocity at the top of the opening than near the bottom. Adjustments were made to optimize the profile (see Figure 3).

Design Sash Position/Volume Optimizations. Most of the hoods tested had extremely large maximum sash heights. By installing sash stops, the maximum design openings of the hoods were reduced from 35 in. to 24 in (89 cm to 61 cm). The fan motor speeds were then adjusted to restore the desired face velocity at the lower sash positions.

Supply Air Delivery Upgrade. ASHRAE 110 testing has demonstrated that air blowing across or into the face of a fume hood (from traffic, windows, doors, supply air diffusers, etc.) at velocities exceeding 30%-50% of the hood face velocity can cause loss of containment (Caplan and Knutson 1977, 1978). In several locations, the slot diffusers used in the original cafeteria located in the building prior to its conversion to a laboratory still remained above the fume hoods. The slot velocity in one of the locations exceeded 3,000 fpm (15 m/s) and produced cross-drafts at the hood greater than 800 fpm. In several other locations, long-throw office-type diffusers were producing cross-drafts between 50 and 120 fpm (0.25 and 0.61 m/s). The offending supply air diffusers were removed or disconnected, and low-velocity, low-throw, non-aspirating supply air diffusers were installed in strategic locations near affected fume hoods (see Figure 4).

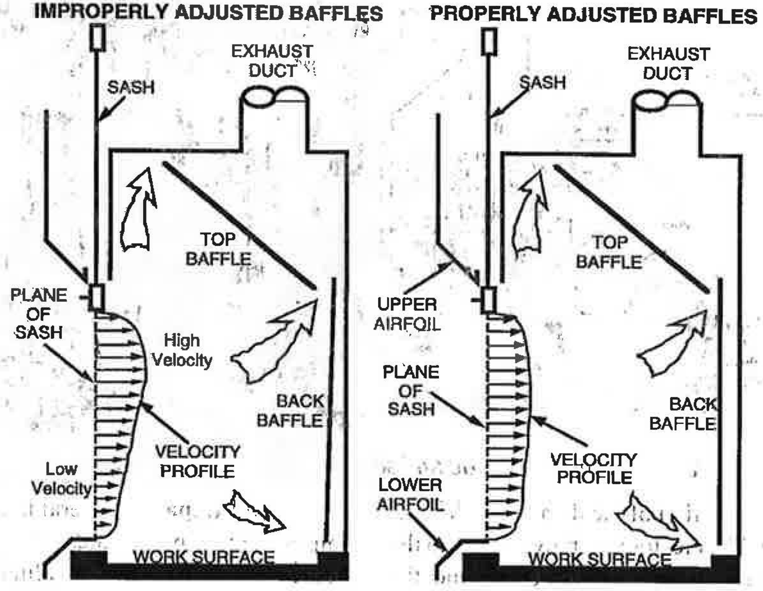

Figure 3 *Baffle optimization.*

Testing and Balancing of Supply Air Systems. Since changes were made to both the supply and exhaust systems, the supply side was balanced to restore negative laboratory differential pressures with respect to the corridors.

Installation of Specific Exhausts. Several hoods had large pieces of equipment in them that were blocking airflow into the hood and impairing performance. These were removed from the hoods and placed on the benchtops nearby. Special exhaust systems were designed and installed to ventilate each piece of equipment. Figure 5 shows a typical booth-type hood suitable for a lab oven. Figure 6 shows the method used for ventilating gas chromatographs. Figure 7 shows the method used for ventilating an atomic absorption spectrophotometer (A-A Spec).

Fabrication of Reagent Bottle Racks. This operation uses large numbers of one-gallon bottles of reagents and solvents that were stored in the hoods and blocked airflow. Custom racks were designed and fabricated, and installed, allowing elevation and separation of the bottles and improved hood performance (Figure 8).

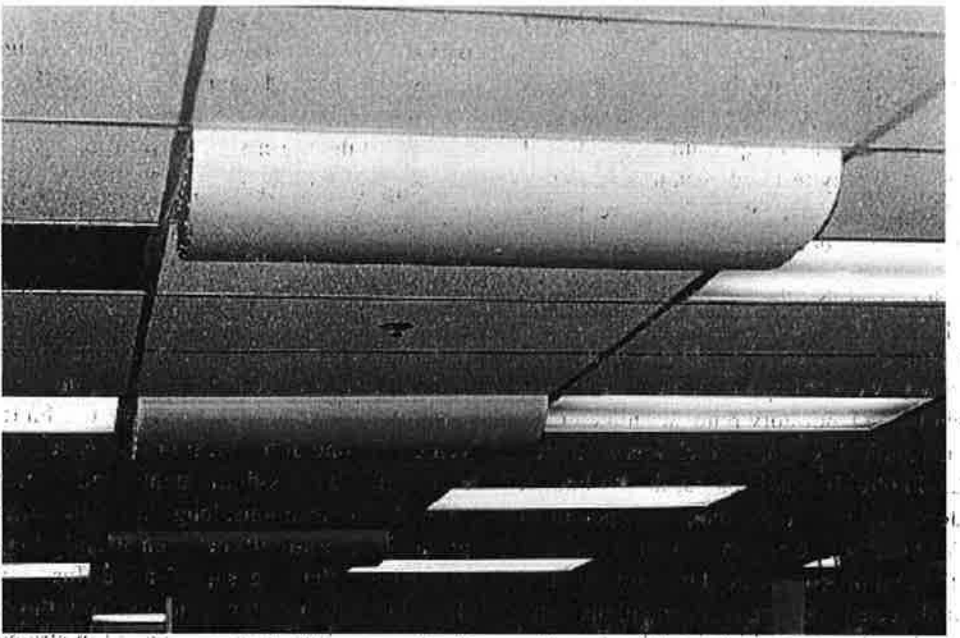

Figure 4 *Supply diffuser replacements.*

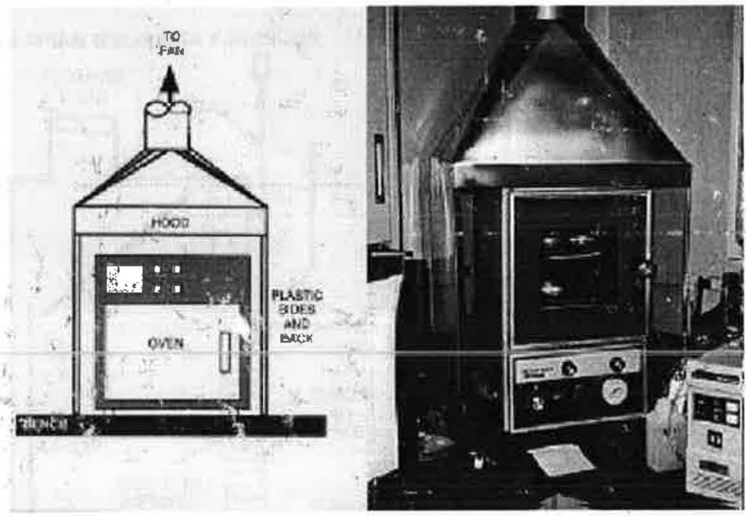

Figure 5 *Typical oven hood.*

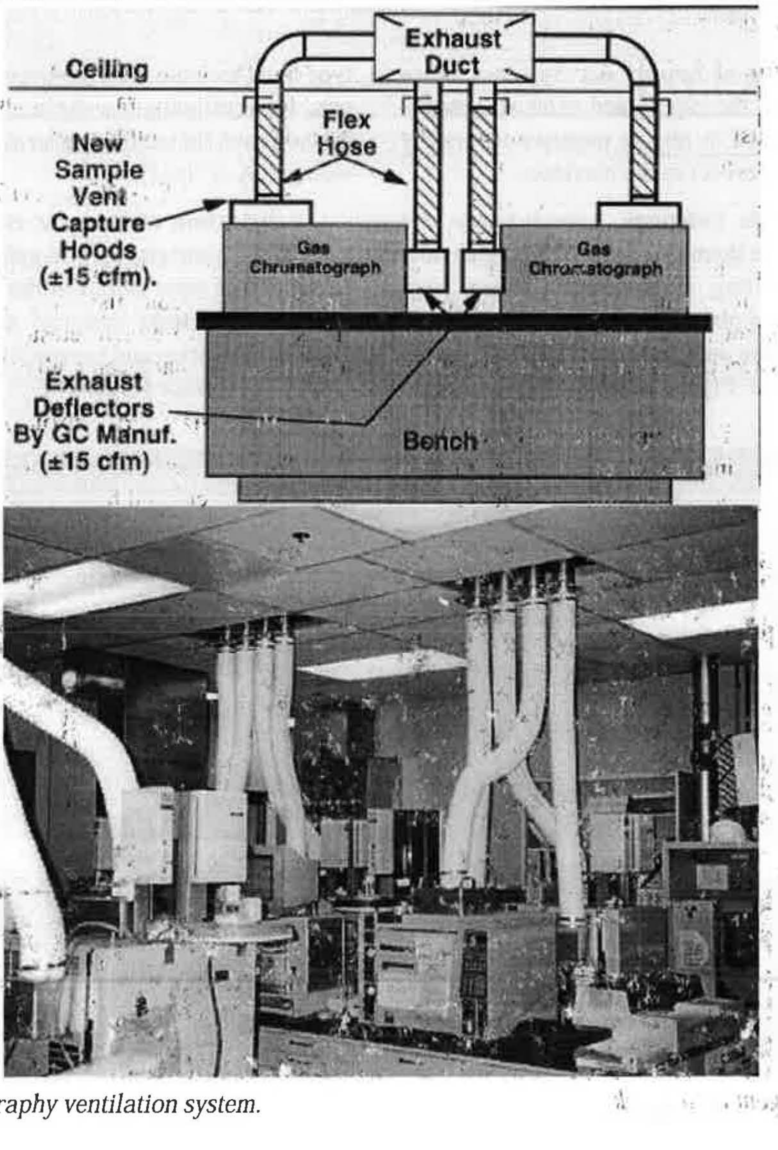

Figure 6 *Gas chromatography ventilation system.*

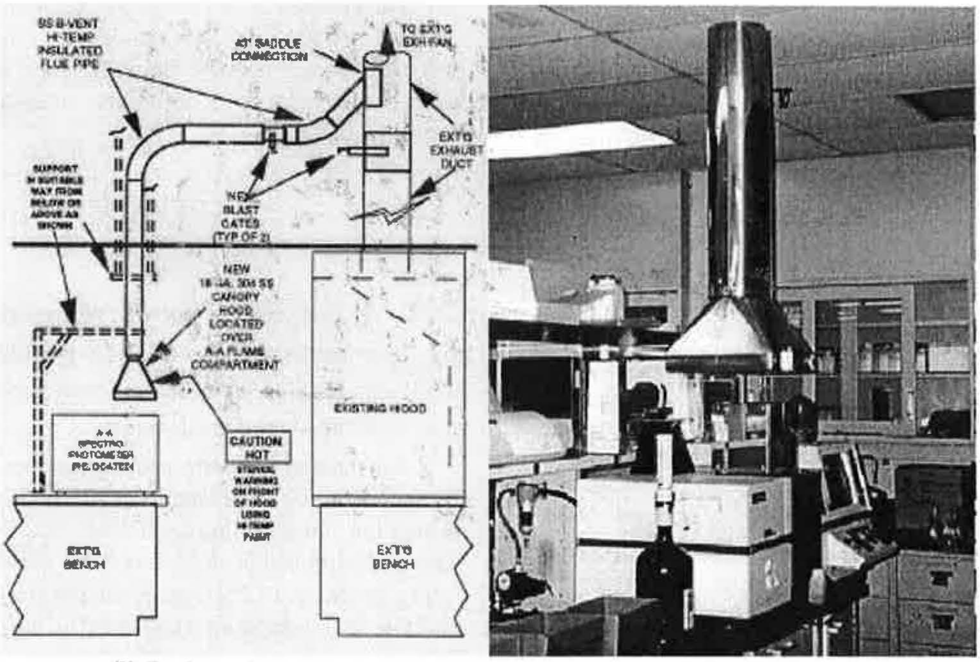

Figure 7 *Atomic absorption spectrophotometer hood.*

Fabrication of Equipment Stands. Several pieces of equipment that could not be removed from the hoods were elevated and separated using custom-built stands. This improved airflow around, under, and between them.

Exhaust Stack Enhancements. Reingestion of contaminated air back into the building supply air was occurring. Exhaust stack heights and discharge velocities were increased using nozzles attached the top of the stacks (see Figure 9). Note that normally this is not a good design practice for an initial installation, but it is acceptable for a retrofit application such as this.

Fume Hood Operator Training. Since even the best-designed laboratories operating under optimum conditions can be rendered useless by poor operating procedures, the project team agreed that the laboratory workers in this building should receive training in the function, purpose, and safe use of laboratory fume hoods.

PRE- AND POST-MITIGATION PERFORMANCE RESULTS

During the mitigation process outlined above, several hoods were decommissioned, leaving 39 operating hoods. These hoods were then retested to determine if performance improvements had been realized.

Flow Visualization (Smoke) Test Results

The number of fume hoods passing the low-volume smoke test increased from 23 (59%) to 38 (97%) after mitiga-

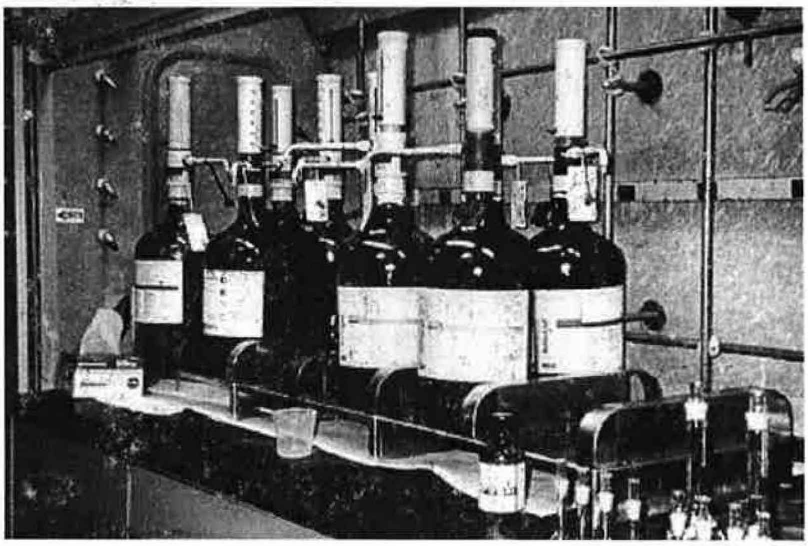

Figure 8 *Typical reagent bottle rack.*

Figure 9 Exhaust stack enhancements.

tion, for an improvement of 65%. The number of hoods passing the high-volume smoke test increased from 30 (77%) to 38 (97%) after mitigation, for an improvement of 27%. This information is summarized in Table 1.

Real-Time Face Velocity Test Results

The company criteria for fume hood face velocity is a range between 85 and 115 fpm (0.43 and 0.58 m/s). This was the range used in this face velocity analysis. Table 2 shows the summarized statistical information about this test.

Part of the project scope involved volume optimization of the fume hoods. Actually, this procedure involved face velocity optimization at new sash positions. Since face velocity was adjusted to meet a 100 fpm (0.51 m/s) ±10% specification, all the hoods passed the face velocity test well within the 100 fpm (0.51 m/s) ±15% specification.

TABLE 1
Flow Visualization (Smoke) Test Results

For All 39 Hoods Tested:	Before	After	Improvement
Number passing low-volume smoke test	23 (59%)	38 (97%)	15 (65%)
Number passing high-volume smoke test	30 (77%)	38 (97%)	8 (27%)

TABLE 2
Face Velocity Test Results

For All 39 Hoods Tested:	Before	After	Improvement
Mean face velocity	97 fpm (0.49 m/s)	101 fpm (0.51 m/s)	N/A
COV of mean velocities	22%	6.3%	71%
Number meeting specifications	23 59%	39 100%	16 69%

The coefficient of variation (COV) of mean velocities in Table 2 is simply the standard deviation of the average face velocity of each hood in the population normalized by the average face velocity of the population as shown in the following equation:

$$COV = \left(\frac{\sigma_{\bar{v}_n}}{\bar{V}}\right) \qquad (1)$$

where

COV = coefficient of variation of average face velocity,
$\sigma_{\bar{v}_n}$ = standard of deviation of average hood face velocities,
$\bar{V}$ = mean face velocity of tested population,
n = number of hoods tested.

The number of hoods meeting the company's face velocity specifications increased from 23 (59%) to 39 (100%) after mitigation, for an improvement of 69%. The COV of mean velocities dropped from 22% to 6.3% after mitigation, for an improvement of 15.7%. Again, face velocity was a dependent variable and was controlled directly during the mitigation project.

Face Velocity Variation Test Results

COV of Velocity Over Time (Turbulence). This is the coefficient of variation of the face velocity or the statistical average of the standard deviations of the velocity over time data for each traverse point normalized by the mean velocity. It is used as a measure of the turbulence or temporal variation experienced at the face opening of the hood and is calculated using the following formula:

$$Turbulence = \frac{\left(\frac{\Sigma\sigma_n}{n}\right)}{\bar{V}} \qquad (2)$$

where

Turbulence = coefficient of variation of velocity over time,
σ_n = standard of deviation of velocity at traverse point n,
n = number of velocity traverse points,
$\bar{V}$ = mean face velocity of the fume hood.

The maximum *Turbulence* figure recommended by the authors is 15% of the mean face velocity. The number of hoods with *Turbulence* below this criteria increased from 17 (44%) to 38 (97%) after mitigation, for an improvement of 124%. The average *Turbulence* decreased from 15.1% to 10.3% of the mean velocity after mitigation, for an improvement of 32%. The primary assignable cause for improvements in *Turbulence* is supply air modifications reducing high-velocity air vectors impinging on the hood opening and cross-draft reduction. These data are summarized in Table 3.

COV of Velocity by Position (Profile). This is the coefficient of variation of the mean velocities at each traverse point or the standard deviation of the average face velocities of each of the traverse points normalized by the mean face velocity. It

TABLE 3
Face Velocity Variation Over Time (Turbulence) Test Results

For All 39 Hoods Tested:	Before	After	Improvement
Number meeting 15% *Turbulence* recommendations	17 44%	38 97%	21 124%
Average *Turbulence*	15.1%	10.3%	32%

is used as a measure of the flatness of the face velocity profile or spatial variation and is calculated using the following formula:

$$Profile = \frac{\sigma_{v_n}}{\bar{V}} \tag{3}$$

where

Profile = efficient of variation (VOC) of the mean velocities at each traverse point,

$\sigma_{\bar{v}_n}$ = standard deviation of the mean velocities at each traverse point *n*,

$\bar{V}$ = mean face velocity of tested population.

The maximum *Profile* figure recommended by the authors is 20% of the mean face velocity. The number of hoods with *Profile* below this criteria increased from 10 (26%) to 33 (85%) after mitigation, for an improvement of 230%. The average *Profile* decreased from 26.1% to 15.4% of the mean velocity after mitigation, for an improvement of 41%. The assignable causes for improvement in *Profile* are, listed in order of importance, (1) baffle optimization, which optimizes the profile, and (2) reduced sash positions, which tend to compress the range between the highest and lowest velocity reading at the hood opening. These data are summarized in Table 4.

TABLE 4
Face Velocity Variation By Position (Profile) Test Results

For All 39 Hoods Tested:	Before	After	Improvement
Number meeting 20% *Profile* recommendations	10 26%	33 85%	23 230%
Average *Profile*	26.1%	15.4%	41%

TRACER GAS CONTAINMENT TEST RESULTS

The number of fume hoods meeting the ACGIH-recommended maximum control level of 0.10 ppm increased from 5 (13%) to 28 (72%) post-mitigation for an improvement of 460%. The most revealing statistic, however, is that average tracer gas control levels were reduced from 24.2 ppm to 0.13 ppm after mitigation, representing a reduction of potential chemical exposures of 99.5%. These data are summarized in the top of Table 5.

Of the 11 hoods still failing to meet the 0.10 ppm criteria after mitigation, none exhibited control levels exceeding 0.86 ppm. The average tracer gas control levels of these 11 hoods were reduced from 19.8 ppm to 0.37 ppm post-mitigation, representing a reduction of 98.1%. These data are summarized in the bottom of Table 5.

Informal piloting (i.e., trial-and-error experimentation) of the mitigation activities was done to reveal the efficacy of each of the individual types of hood mitigation activities outlined here, but only records of the final results for each hood were retained. No attempt was made to assess the synergistic effects of multiple mitigations for a particular hood. Based on this information, it is estimated that approximately 66% of the reductions in potential exposures described above were achieved by lowering the maximum sash heights and installing sash stops to enforce this. The (approximate) balance was due to the other mitigation activities in the following order of importance: replacing missing access panels, reducing supply air interference, and relocating/elevating equipment. This is an overall estimate. Obviously, for fume hoods that received only the sash position reduction and no other improvements, the entire reduction in potential exposures can be attributed to this improvement.

TABLE 5
ASHRAE 110 Tracer Gas Containment Test Results

For All 39 Hoods Tested:	Before	After	Improvement
Number meeting ACGIH recommendations (0.1 ppm)	5 13%	28 72%	23 460%
Average tracer gas control levels	24.2 ppm	0.13 ppm	99.5%

For 11 Failures:	Before	After	Improvement
Average tracer gas control levels	19.8 ppm	0.37 ppm	98.1%

Energy Conservation

By reducing the maximum operating sash heights of most of the fume hoods from 35 in. (89 cm) to 24 in. (61 cm), reductions in exhaust flow rates were possible. Building supply and exhaust system flow rates were reduced by approximately 19,000 cfm (8,970 L/s.). An analysis of building energy use and costs reveals that this represents approximately $57,000 savings per year in facility operating costs to condition make-up air.

CONCLUSION

A classic TQM approach was used to define, solve, and verify laboratory fume hood performance problems. ASHRAE 110 testing was chosen as the appropriate diagnostic tool to determine quantitative hood performance. A comprehensive yet cost-effective array of different mitigation techniques was used to improve hood performance. Significant improvements in fume hood performance were realized, including a 99.5% average reduction in tracer gas control levels.

If traditional face velocity testing alone had been used to determine performance, more than half of the hoods exhibiting high leakage and, therefore, high exposure potential would have been overlooked.

These results, as well as those from several thousand other ASHRAE 110 tests, reveal that 30% to 50% of the hoods tested that meet industry standard face velocity specifications of 80-120 fpm (0.4-0.6 m/s) have leakage rates that exceed industry guidelines outlined in *ANSI-AIHA Z9.5, American National Standard for Laboratory Ventilation* (AHIA 1992), *Prudent Practices in the Laboratory* (NRC 1995), and *Industrial Ventilation—A Manual of Recommended Practice* (ACGIH 1995).

Based on this, the conclusion that traditional face velocity testing is a very poor indicator of fume hood performance—as it is not a measure of containment and the hood-related and environmentally related factors that affect containment—is unavoidable. The authors recommend that this method be discontinued as the primary hood performance measurement and that it be replaced with the ASHRAE 110 test.

It is recommended that all fume hoods be tested using the ASHRAE 110 method *as installed* or *as used* once to establish containment parameters. If containment fails to meet required specifications, modifications should be made to the exhaust/supply systems to achieve desired performance as determined by retesting. Containment has now been demonstrated under actual conditions and at a specific benchmark face velocity. In the future, face velocity testing (using accurate methods similar to those described here) can be used for the periodic testing required by the OSHA laboratory standard (OSHA 1990). If no substantive changes have been made to the supply system, exhaust system, or the hood itself, then one may reasonably assume continued containment performance as long as the face velocity remains in a reasonable range of ±10% about the benchmark.

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