Development of the Labconco Protector® XStream® High Performance Laboratory Fume Hood

Safety is the primary purpose of any laboratory hood. Facility managers and laboratory planners desire fume hoods that can conserve energy without compromising safety. Exhausting less air through a hood can result in substantial energy savings. For example, typical supply air costs for a 6-foot by-pass hood operated at 100 fpm (1180 CFM) is estimated at $6,000 to $9,000.* At the same time, safety officers are concerned about hood performance when they are operated below accepted guidelines and standards.

Laboratory fume hood manufacturers continue to reconcile this conflict between "energy savings" and "safe containment" using a variety of approaches. Restricting the sash opening with sash stops or horizontal-sliding sashes is one example. Another approach is to use sash position and airflow sensors that control the opening and closing of mechanical rear baffles. Yet a third scenario uses small fans to introduce air near the operator's breathing zone to create a barrier to contaminants inside the hood. This paper focuses on Labconco's alternative approach to the development of a high performance or low flow laboratory fume hood that does not rely on user training, restricted sash openings, airflow sensors and electronic control, mechanical components, or additional fans.

Labconco's Approach

Engineers at Labconco Corporation, Kansas City, Missouri, have taken a new and different approach to high performance fume hood design. Labconco engineers postulated that if all areas, from top to bottom behind the open sash, could be kept as free of contaminants as possible, then even at lower face velocities, the risk of contaminants escaping the hood would be virtually eliminated. That basic concept resulted in an approach with critical design initiatives.

**Based on average annual dollars per CFM usage of $5.00, fume hood operating 24 hours per day and 5 days per week (6240 hours per year). Average annual dollars per CFM can range from $5.00 to $12.00 depending on geographic location. To determine the energy costs of using a traditional fume hood in selected locations, visit http://fumehoodcalculator.lbl.gov.*

First, Labconco engineers researched ways to minimize and counteract the traditional "roll" or "vortex" that causes chemical fumes generated inside from migrating to the front of the hood. Second, they looked at ways to purge the area behind the sash of any contaminants. Third, they tested ways to reduce turbulence at the bottom edge of the sash by providing velocity and direction. Finally, engineers focused on increasing the strength at which the air foil and work surface are swept by the air coming into the hood. The result of these initiatives was a fume hood design that has airflow moving in uniform streams towards the rear of the hood, more laminar-like in pattern than any other laboratory fume hood currently available. Labconco has named this patented** high performance hood the Protector® XStream® after these parallel air streams.

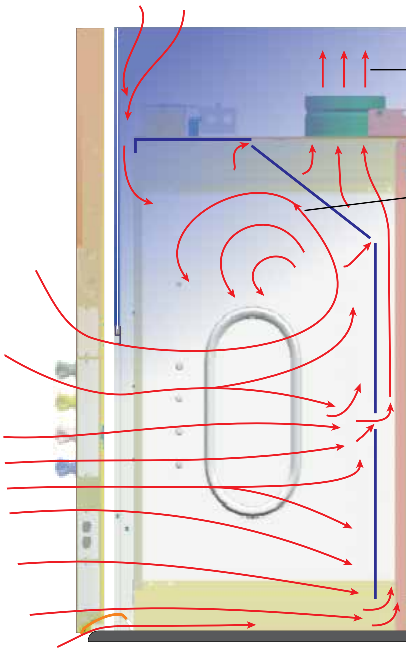
The design features of the Protector XStream Hood that contribute toward its high performance include the following:

1. ***Rear Downflow Dual Baffle*** – By integrating a pattern of variable-sized slots, the inclined rear baffle provides laminar "directional" flow through the hood. This exclusive feature is designed to capture contaminants in the hood in a single pass, greatly minimizing the forward rolling vortex that is typical of traditional by-pass fume hoods. The Protector XStream Hood's unique baffle drastically limits the amount of contaminated air that can initially make its way to the top area of the hood. To further oppose the natural tendency for a vortex to be created in the hood, a secondary baffle is located behind the slotted rear baffle. The secondary baffle forces all air exhausted through the hood to travel downward behind the primary baffle before it is exhausted. This horizontal to downward redirection of air is key to opposing the vortex action of traditional by-pass style laboratory fume hoods.

Smoke released inside the hood moves in a horizontal stream to the primary baffle slots.

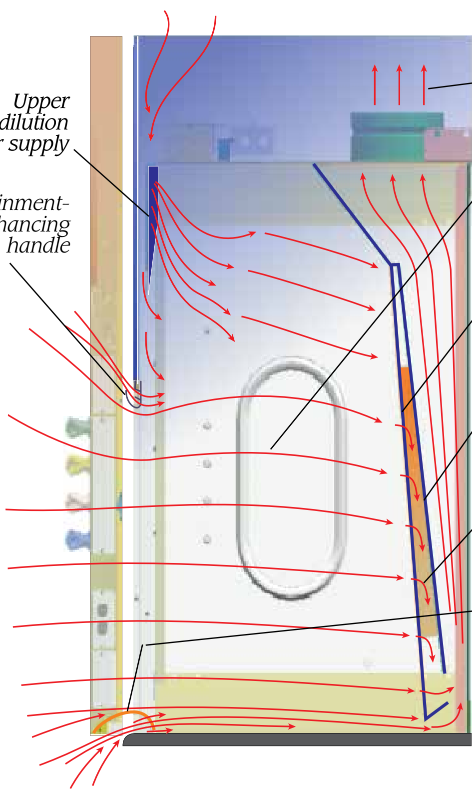
***U.S. Patent No. 6,461,233*

Traditional Hood Design



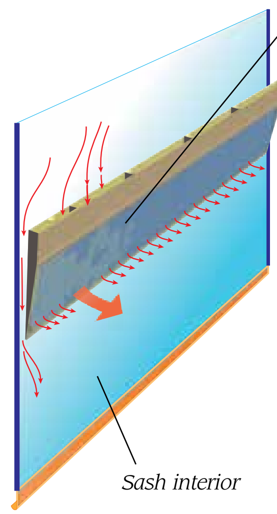
Smoke tests on traditional hoods show the tendency for contaminants generated in the interior to roll forward producing high concentrations of contaminants behind the sash in close proximity to the user's breathing zone.

Protector XStream Hood Design

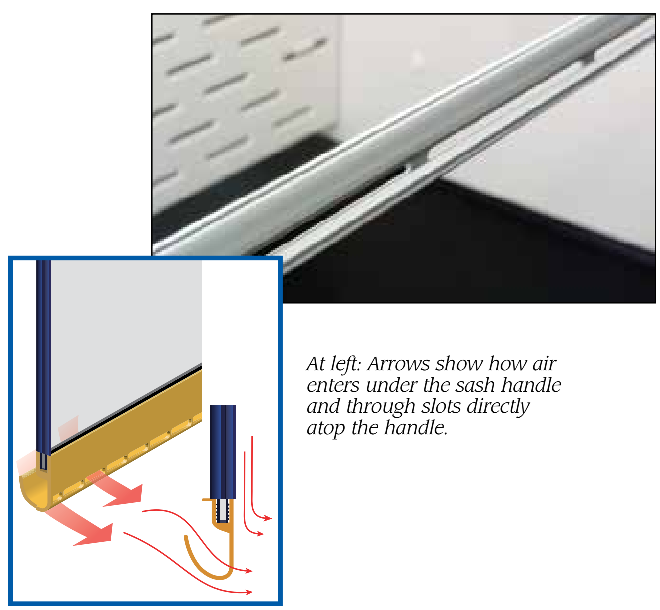


In contrast, smoke tests on Protector XStream Hoods show contaminants removed in a single pass and a remarkable lack of turbulence. Horizontal laminar air flowing toward the baffle forces contaminants to the rear interior, away from the user. The upper dilution air supply sweeps the upper interior to eliminate stagnant pockets of air and to prevent contaminants in the area behind the sash.

2. ***Upper Dilution Air Supply*** – In the upper plenum of the Protector XStream Hood, the internal dilution supply is designed to provide 5-7% of the fume hood's total airflow volume requirements when the sash opening is between 18 and 28 inches. This exclusive diffuser is proportionally split to provide a stream of clean air in two directions. First, there is a 2-inch curtain of clean air directed downward between the back of the sash and any contaminated air inside the fume hood. Second, the backside of the dilution supply plenum is perforated to uniformly distribute clean air, which continually purges the top portion of the hood interior, preventing contaminants from accumulating in this area of the hood. No additional blowers are required to perform this function.



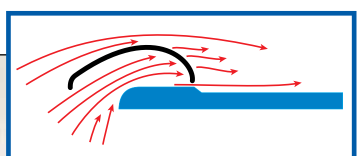
3. ***Sash Handle*** – In laboratory hoods with typical vortex "roll," contaminated air flows down the back of the sash. That contaminated air is only held inside the hood by the continual movement of air through the sash opening. As face velocities are reduced to conserve energy, the ability to contain this contaminated air at the bottom of the sash is compromised.



At left: Arrows show how air enters under the sash handle and through slots directly atop the handle.

The exclusive sash handle of the Protector XStream Hood was developed to enhance containment directly at the bottom plane of the sash. The bottom of the sash handle incorporates a large radius surface to promote smooth entry of air to sweep the bottom of the handle and push the contaminated air further back into the fume hood cavity. Slots between the sash glass and the radiused surface provide high velocity air to break up by-pass air coming down the backside of the sash, assisting in pushing any contaminants straight back into the fume hood cavity. Both the large radius and integral high velocity slots have been proven to perform two functions. First, the slots disrupt the flow of air down the backside of the sash so it is less likely that contaminants can escape during use. Second, the large radius and slots contribute to the parallel nature of the air stream in the hood by diminishing the turbulent rolls at the bottom edge of the sash handle.

4. ***Air Foil*** – The exclusive air foil with Clean-Sweep™ openings enhances the containment capabilities of the hood at the work surface. The air foil's unique shape works in concert with the perforated hole pattern that extends the length of the air foil. The aerodynamic shape promotes airflow acceleration, enhancing sweeping action across the hood's work surface. The perforated hole pattern promotes a continuous flow of clean air through and across the air foil, even when an operator partially blocks the front of the air foil. This constant flow of air through and across the air foil results in unsurpassed containment in the lower regions of the fume hood. A large radius on the front edge of the accessory epoxy work surface further enhances airflow into the hood and overall containment. No additional blowers are required to aid performance.



Above: Side view illustrates airflow entering over, through and under the air foil.

When the operator blocks the front of the air foil, air is still able to enter from under the air foil so "dead-air" zones are minimized and containment maintained.

ASHRAE 110 Test Data

The ANSI/ASHRAE 110 gives a relative and quantitative determination of the efficiency of a hood to capture contaminants under a set of strict conditions. The overriding question is how forgiving is the fume hood's ability to contain when subjected to common occurrences that fall outside these strict conditions such as:

- Movements outside the sash opening,
- User working too close to the air foil,
- Equipment creating obstacles inside the hood,
- External air currents including those from HVAC and open doors,
- Pressure and temperature fluctuations within the lab,
- Shorter lab personnel,
- Heat-producing equipment within the enclosure,
- Sash movements and varying sash heights.

The Protector XStream Laboratory Hood has been rigorously tested beyond the ANSI/ASHRAE 110 Standard. To ensure that containment was "robust" under adverse conditions, Labconco engineers developed variations of the ANSI/ASHRAE 110 Standard to challenge the Protector XStream Hood. Tracer gas was used as a tool to test the hood's performance. Design features were modified based on tracer gas test results until performance was optimized. The height of the gas ejector was varied from 2 to 24 inches above the work surface simulating various chemical procedures. Likewise, the sampling sites on the mannequin positioned in front of the hood were varied. Sampling was not limited to the center or at a single distance from the hood. Containment was challenged by changing temperatures, differing sash heights and adding interior obstructions, walk-bys and door movements.

Test data is listed on pages 4 and 5. Results for standard ASHRAE 110 tests and variations of ASHRAE tests show detected tracer gas amounts in parts per million (ppm). All are below the accepted ASHRAE level of less than 0.05 ppm.

The Interior Obstructions Test simulates a typical fume hood used for chemical and equipment storage.

Testing was performed on a 6-foot Protector XStream Laboratory Hood, model 9840600. Sash opening height was at 28" except where noted. All units of measure in ppm.

A. Standard ASHRAE 110 with Cross Drafts

Airflow (CFM)	Avg. Face Velocity (fpm)	Avg. Cross Draft (fpm)	Mannequin Test Positions Left	Center	Right	ASHRAE Test
1150	100	24	0.00	0.00	0.00	Standard
690	60	15	0.00	0.00	0.00	Standard
460	40	14	0.00	0.00	0.00	Standard

B. Standard ASHRAE 110 vs. Heat Effect

Airflow (CFM)	Avg. Face Velocity (fpm)	With Two Hot Plates*	Mannequin At Center**	ASHRAE Test
1150	98	Off	0.00	Standard
1150	100	On	0.01	With Heat
930	81	Off	0.00	Standard
930	85	On	0.03	With Heat
700	62	Off	0.00	Standard
700	65	On	0.04	With Heat

C. Standard ASHRAE 110 with Sash Movement Effect

Airflow (CFM)	Avg. Face Velocity (fpm)	Sash Movement Effect with Mannequin at Center**	ASHRAE Test
1150	100	0.00	Standard
930	80	0.00	Standard
700	60	0.02	Standard

D. Standard ASHRAE 110 vs. 300 fpm Walk-By Pace

Airflow (CFM)	Avg. Face Velocity (fpm)	With Walk-By	Mannequin At Center**	ASHRAE Test
1150	100	No	0.00	Standard
1150	100	Yes, 1 per minute	0.00	With Walk-B
700	60	No	0.00	Standard
700	60	Yes, 1 per minute	0.00	With Walk-By
460	40	No	0.00	Standard
460	40	Yes, 1 per minute	0.00	With Walk-By

E. Standard ASHRAE 110 vs. Doors Opening and Closing

Airflow (CFM)	Avg. Face Velocity (fpm)	With Door Movement	Mannequin At Center**	ASHRAE Test
1150	100	No	0.00	Standard
1150	100	Yes, 1 per minute	0.00	With Door Movement
700	60	No	0.00	Standard
700	60	Yes, 1 per minute	0.00	With Door Movement
460	40	No	0.00	Standard
460	40	Yes, 1 per minute	0.00	With Door Movement

F. Standard ASHRAE 110 with Mannequin Breathing Location 19" above work surface

Airflow (CFM)	Avg. Face Velocity (fpm)	Mannequin Test Positions Left	Center	Right	ASHRAE Test
1150	100	0.00	0.00	0.00	With Lower Mannequin
920	80	0.00	0.00	0.00	With Lower Mannequin
700	60	0.00	0.00	0.00	With Lower Mannequin

**One hot plate with 1200 watts; one hot plate with 1118 watts.*
***Center position is typically considered the most challenging mannequin position.*

G. Standard ASHRAE 110 with 18" Sash Opening

Airflow (CFM)	Avg. Face Velocity (fpm)	Mannequin Test Positions Left	Center	Right	ASHRAE Test
720	100	0.00	0.00	0.00	Standard
430	60	0.00	0.00	0.00	Standard
290	40	0.00	0.00	0.02	Standard

H. Standard ASHRAE 110 with Interior Obstructions* (see page 3)

Airflow (CFM)	Avg. Face Velocity (fpm)	Mannequin Test Positions Left	Center	Right	ASHRAE Test
1150	100	0.00	0.00	0.00	With Obstructions
920	80	0.00	0.00	0.00	With Obstructions
700	60	0.00	0.00	0.01	With Obstructions

I. Standard ASHRAE 110 with Interior Obstructions* & 200 fpm Walk-By

Airflow (CFM)	Avg. Face Velocity (fpm)	Mannequin Test Positions Left	Center	Right	ASHRAE Test
1150	100	0.00	0.01	0.00	With Obstructions and Walk-By
920	80	0.00	0.01	0.00	With Obstructions and Walk-By
700	60	0.01	0.01	0.01	With Obstructions and Walk-by
460	40	0.00	0.01	0.01	With Obstructions and Walk-By

**An interior obstructions test simulates a fume hood used for chemical and equipment storage. A cluttered work surface does not adhere to good safety practices, but is used to challenge the fume hood beyond the normal scope of the ASHRAE 110 test.*

Despite successful ASHRAE testing at 40 FPM, Labconco recommends that the fume hood be operated at a minimum of 60 FPM, which complies with all applicable government standards from ACGIH and OSHA.

CFD – Computational Fluid Dynamics

The science of fluid dynamics explores the patterns of air or liquids that flow. Using the concepts of fluid dynamics, Labconco researchers engineered the Protector XStream Hood with horizontal laminar airflow to overcome the tendencies for turbulence. Labconco used computational fluid dynamics (CFD) to build a model of the Protector XStream Hood and validate the successful ASHRAE test results. CFD predicts fluid flow behavior and provides a means of visualizing the fluid flow. Like the tracer gas in ASHRAE testing, CFD was used as a tool to test the hood's performance. Design features were modified based on CFD test results until performance was optimized. Some of the CFD outputs from the computer model are provided with explanations to illustrate the Protector XStream Hood's high performance. The first CFD output shows the Protector XStream velocity vectors at 60 FPM on a plane through the center of the hood (Figure 1). Notice the horizontal laminar air vectors that turn downward as they reach the rear perforated baffle. Also note the Protector XStream Hood's diminished vortex roll, which reduces turbulence and instability in the fume hood.

Side View – velocity vectors on a plane through center of hood.

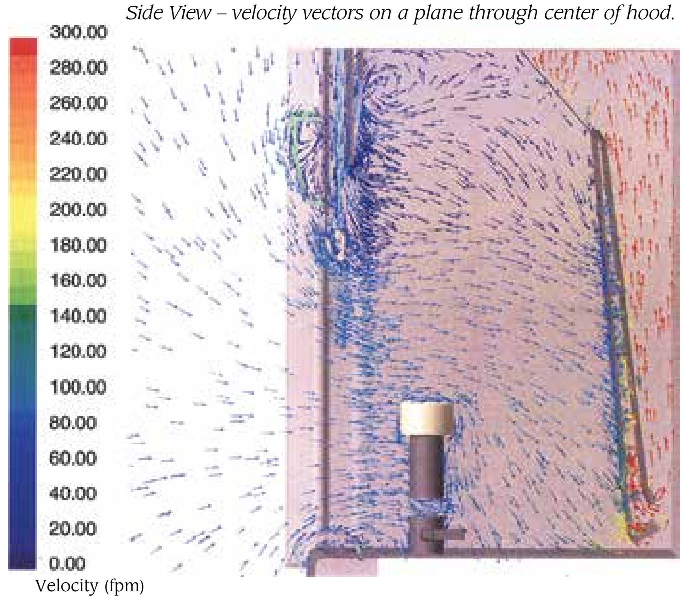


Figure 1

The second CFD output shows sulfur hexafluoride (SF_6) gas concentrations emitted from the ejector on a plane through the center of the hood at 4 liters per minute (LPM), the hood operated at 60 fpm and sash fully open (Figure 2). Notice the dark blue area free of contaminants near the sash plane where the operator stands and works. Also, notice how the concentrations are contained deep into the interior of the hood so the contaminants can be exhausted in a single pass.

Side View – SF_6 concentrations on a plane at center of hood

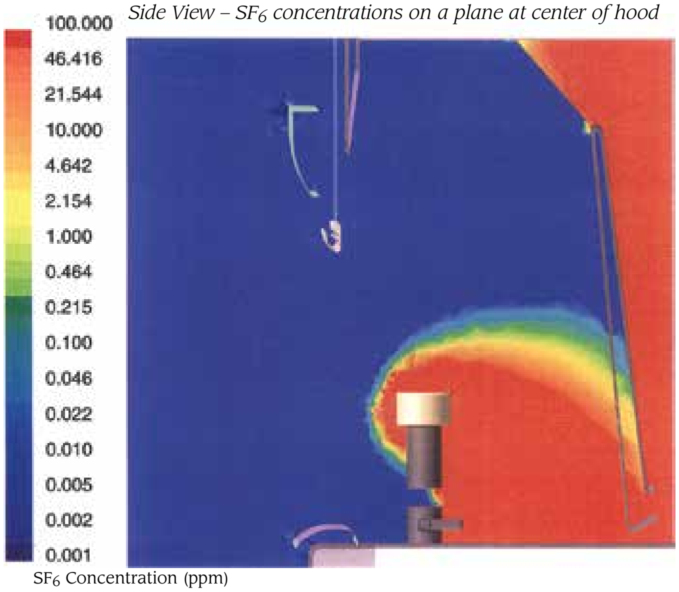


Figure 2

The third CFD output shows streak line airflows through the hood when operated at 60 fpm face velocity (Figure 3). These streak lines validate the horizontal laminar airflow pattern.

Side View – Streak lines colorized by air speed

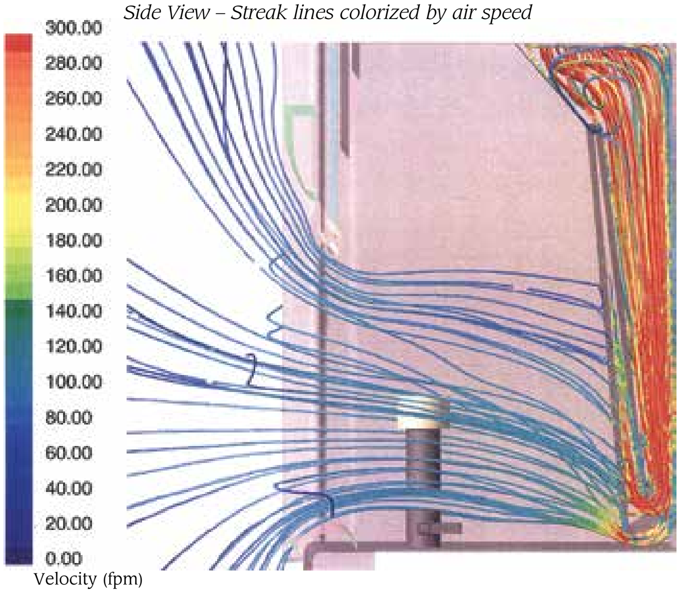


Figure 3

The final CFD output shows an isometric view of the Protector XStream Hood operating at 60 fpm with sash fully open, which validates the containment of SF_6 gas concentrations displaced to the rear of the fume hood and removed in a single pass (Figure 4).

Isometric View – Clipped isosurfaces of SF_6 concentration

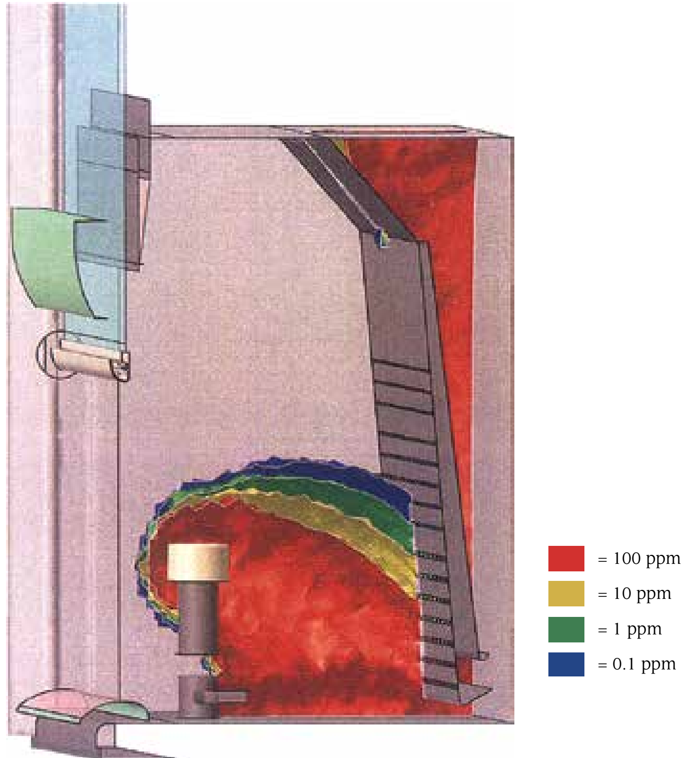


Figure 4

Concentration Testing Using Propylene Gas

To further confirm the performance of the Protector XStream Laboratory Hood, 3.3 liters per minute of propylene gas were released through a 24″ high ASHRAE ejector inside the fume hood and a photo ionization gas detector was used to measure concentrations at specific points inside the hood. These gas concentrations were confirmed by CFD. With the Protector XStream Hood design, the gas concentrations were redistributed from the front and upper portion of the fume hood to the rear of the fume hood, which greatly reduced the risk of contaminants escaping. These average concentrations were used to optimize the fume hood and are listed in the table on page 7.

In summary, when compared to a conventional fume hood, the average gas concentrations were at least 400 times smaller behind the sash and 3-8 times smaller through the middle of the fume hood. The conclusion drawn from the propylene gas testing is that the high performance Protector XStream Fume Hood nearly eliminated gas concentrations at the critical user-breathing zone and greatly reduced fume concentrations throughout the hood cavity.

Propylene Gas Concentration Data

6′ Protector XStream Laboratory Hood, model 110610000 with 18″ Sash Opening Height, 24″ Gas Ejector Height

Depth	Height from Work Surface	Average Concentration (ppm) 6′ Protector XStream Hood	6′ Traditional By-Pass Hood
1″ Behind Sash	21″	0.2	80
	26″	0.1	95
	34″	0.1	52
	42″	0.0	16
12″ Behind Sash	26″	155	519
	34″	32	251
	42″	9	45

Energy Savings, CAV, VAV, Combination Sashes, and Airflow Design Requirements

The patented* Protector XStream Hood offers unsurpassed containment of chemical fumes and vapors while conserving energy when operated at OSHA approved "low flow" velocities as low as 60 fpm. Reducing the face velocity for a fume hood saves energy, but can reduce the margin of error for providing containment. Labconco has tested the Protector XStream Hood at 40 fpm with excellent results, but still recommends the hood operate at 60 fpm to provide a comfortable safety margin and to comply with governmental standards. While energy savings is important, the primary concern is protecting those who use a fume hood. The Protector XStream Hood was designed to be used in either a constant air volume (CAV) or variable air volume (VAV) exhaust system. The unique features of the Protector XStream Hood demand an initial price premium, but the long-term energy savings provide an attractive cost-to- benefit ratio resulting in an excellent economic payback. The economic payback from a constant volume system at 60 fpm is illustrated in the tables below. For even greater savings, a VAV system can be added. As illustrated in the example on the following page, the Protector XStream Hood at constant volume offers the best economic payback, but the Protector XStream Hood with VAV controls has the lowest annual operating costs. For those users who prefer combination A-style sashes in lieu of a single vertical-rising sash, the Protector XStream Hood is available with optional sash configurations.

Total Exhaust CFM and Static Pressure @ 18″ Sash Opening (60% open)

Nominal Width	100 fpm	s.p.	80 fpm	s.p.	60 fpm	s.p.	CFM Savings at 60 fpm vs. 100 fpm	Total Average Annual Dollars Savings at 60 fpm vs. 100 fpm**	Economic Payback Period†
4 feet	440	0.10″	350	0.06″	265	0.04″	175	$1400	1.25 years
5 feet	580	0.12″	465	0.08″	350	0.05″	230	$1840	1.25 years
6 feet	720	0.16″	575	0.10″	430	0.06″	290	$2320	1.25 years
8 feet	1000	0.11″	800	0.07″	600	0.04″	400	$3200	1.25 years

Total Exhaust CFM and Static Pressure @ 28″ Sash Opening (100% open)

Nominal Width	100 fpm	s.p.	80 fpm	s.p.	60 fpm	s.p.	CFM Savings at 60 fpm vs. 100 fpm	Total Average Annual Dollar Savings at 60 fpm vs. 100 fpm**	Economic Payback Period†
4 feet	705	0.26″	565	0.17″	425	0.9″	280	$2240	0.8 year
5 feet	930	0.30″	745	0.20″	560	0.12″	370	$2960	0.8 year
6 feet	1150	0.41″	920	0.26″	690	0.15″	460	$3680	0.8 year
8 feet	1600	0.29″	1280	0.19″	960	0.10″	640	$5120	0.8 year

* *U.S. Patent No. 6,461,233*

** *Based on average annual dollars per CFM usage of $8.00, fume hood operating 24 hours per day and 5 days per week (6240 hours per year). Average annual dollars per CFM can range from $5.00 to $12.00 depending on geographic location. To determine the energy costs of using a traditional fume hood in selected locations, visit http://fumehoodcalculator.lbl.gov.*

† *Period when the savings in energy costs equals the price difference between the Protector XStream Laboratory Hood and a traditional fume hood.*

Example: 6′ Protector XStream Hood with VAV @ 28″ Sash Opening (100% open)

Hood Type Notes	Exhaust System	Average Airflow Volume	Average Annual Operating Costs	Additional First Cost	Additional Controls Cost	Annual Savings	Economic Payback Period	Note
6′ Traditional Hood	CAV	1180 CFM	$9440	0	0	0	—	1
6′ Protector XStream Hood	CAV	690 CFM	$5520	$1800	0	$3920	0.6 year	2
6′ Traditional Hood	VAV	440 CFM	$3520	0	$6000	$5920	1.2 years	3
6′ Protector XStream Hood	VAV	345 CFM	$2760	$1800	$6000	$6680	1.3 years	4

Average Annual Operating Costs are based on $8.00 per CFM usage. Average annual dollars per CFM can range from $5.00 to $12.00 depending on geographic location. To determine the energy costs of using a traditional fume hood in selected locations, visit http://fumehoodcalculator.lbl.gov. Additional first cost is the price difference between the hood type and a 6′ traditional hood with constant air volume. Annual savings is the difference between operating costs the hood type and a 6′ traditional hood with constant air volume. Economic payback period is when the annual savings equals the first cost.

Note 1: Traditional Hood with constant air volume is operating at 100 fpm, 1180 CFM, 5 days per week, 6240 hours per year.
Note 2: Protector XStream Hood with constant air volume is operating at 60 fpm, 690 CFM, 5 days per week, 6240 hours per year.
Note 3: Traditional Hood with variable air volume controls is operating at 100 fpm, 6240 hours per year, with an average 440 CFM computed from usage at 1180 CFM for 1000 hours, 550 CFM for 1000 hours, and 240 CFM for 4240 hours for idle conditions.
Note 4: Protector XStream Hood with variable air volume controls is operating at 60 fpm, 6240 hours per year, with an average 350 CFM computed from usage at 690 CFM for 1000 hours, 450 CFM for 1000 hours, and 240 CFM for 4240 hours for idle conditions.

Conclusion

The Protector XStream Laboratory Fume Hood offers a serious yet practical approach to energy-saving laboratory ventilation. As a result of aggressive research and testing, its patented* features combine to ensure maximum containment under less than favorable external conditions. When considering savings over the life of the investment, the XStream Hood provides reliable service since it is not dependent upon complex controls, mechanical components, or additional fans. Finally, since the hood does not require operation with a reduced sash opening to achieve its energy savings, user compliance is assured. With its patented* unique features working together to achieve energy savings and outstanding containment, the Protector XStream Laboratory Hood merits its high performance designation.

Fume Hood Standards

Federal Register 29 CFR Part 1910
Non-mandatory recommendations from "Prudent Practices"
- Fume hoods have a continuous monitoring device
- Face velocities should be between 60-100 linear feet per minute (lfpm)
- Average 2.5 linear feet of hood space per person

Occupational Health and Safety
U.S. Department of Labor
200 Constitution Avenue N.W.
Washington, DC 20210
(202) 523-1452
www.osha.gov

Industrial Ventilation-ACGIH
- Fume hood face velocities between 60-100 lfpm
- Maximum of 125 l fpm for radioisotope hoods
- Duct velocities of 1000-2000 fpm for vapors, gasses and smoke
- Stack discharge height 1.3-2.0 x building height
- Well designed fume hood containment loss, <0.10 ppm

Industrial Ventilation, A Manual of Recommended Practice.
24th Edition, 2001
American Conference of Governmental Industrial Hygienists
1330 Kemper Meadow Drive
Cincinnati, OH 45240-1634
(513) 742-2020
www.acgih.org

ASHRAE 110 Method of Testing Performance of Fume Hoods
Evaluates fume hood's containment characteristics
- Three part test: Smoke generation, Face velocity profile, Tracer gas release @ 4 liters per minute
- Rated As Manufactured (AM), As Installed (AI) and As Used (AU)

American Society of Heating, Refrigerating, and Air Conditioning Engineers
1791 Tullie Circle N.E.
Atlanta, GA 30329
(404) 636-8400
www.ashrae.org

ANSI Z9.5 Laboratory Standard
Covers entire laboratory ventilation system.
- Vertical stack discharge @ 2000-3000 fpm
- New and remodeled hoods shall have a monitoring device
- Ductless hoods should only be used with non-hazardous materials
- Fume hood face velocities between 80-120 fpm

American Industrial Hygiene Association
2700 Prosperity Avenue, Suite 250
Fairfax, VA 22031
(703) 849-8888
www.aiha.org

SEFA 1 Laboratory Fume Hoods Recommended Practices
- Fume hood face velocities based on toxicity levels of chemicals
  Class A— materials of extreme toxicity—125 to 150 fpm
  Class B—standard lab chemicals—80 to 100 fpm
  Class C—materials of low toxicity—75 to 80 fpm
- Test Method—face velocity profile and smoke generation

SEFA
Scientific Equipment & Furniture Association
World Headquarters
1205 Franklin Avenue, Suite 320
Garden City, NY 11530
(515) 294-5424
www.sefalabs.com

Reference

Mills, E. and Sartor, D. 2005. "Energy Use and Savings Potential for Laboratory Fume Hoods." *Energy* 30 (2005): 1859-1864.

Protecting your laboratory environment
LABCONCO®

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**U.S. Patent No. 6,461,233*

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