A Study of Factors Affecting Fume Hood Energy Consumption

Contents

1. Introduction

It is well known throughout the HVAC industry that laboratories and fume hoods are generally the largest consumers of energy in a facility. Volumes of information have been written and many studies have been performed outlining the substantial amounts of energy that labs and fume hoods consume over the lifetime of their operation. Various industry estimates put the energy consumed by a single fume hood in a year to be 1 to 3.5 times that of the average residential home. In most cases, the air required for the operation of the fume hood is totally exhausted out of the ventilation system due to the hazardous particles and/or gasses it may contain. This forces new makeup air to be introduced into the system, which requires a considerable amount of energy to condition. In regular HVAC ventilation systems designed for comfort, the system is typically designed so that a percentage of the air required by the system is "recycled" and the tempered return air is not being wasted to the atmosphere, thereby keeping energy costs lower.

The continuous operation of lab and fume hood exhaust fans and the speed at which they operate to maintain the desired static pressures and volumetric flow rates, is also an area where a reduction in energy consumption can be realized. Many lab and fume hood exhaust fans in industrial or research facilities operate 24 hours a day, 7 days a week. The ability to lower the design static pressure setpoints and employ various control strategies of these continuously operating labs and fume hoods, equates to potentially lower fan operating speeds and exhausted CFM.

Since recycling exhaust air and intermittent HVAC equipment operation are not luxuries afforded in the operation of many labs and fume hoods, it is necessary to take into account some specific areas when designing or retrofitting a lab and fume hood exhaust system. 1.) Lab and fume hood HVAC operational system static pressure requirements. 2.) Fume hood exhaust duct size. 3.) VAV vs. CAV operation of the fume hood exhaust. 4.) Control air valve selection.

1.1 System Static Pressure Considerations

Static pressure must be considered when looking at potential energy savings in the design and operation of labs and fume hoods. A Technical Bulletin outlining System Static Pressure Optimization[1], released in 2007 by Laboratories for the 21st Century (Labs21) in partnership with the U.S. Department of Energy states: "Standard design and operating practice for laboratory ventilation systems usually results in system static pressure setpoints that are higher than actually required. Dynamically optimizing system static pressure can reduce energy and improve airflow control in laboratories". Simply put, the less operating static pressure required, means less energy will be consumed both in the form of makeup air being exhausted through the lab and fume hoods, and the amount of energy in kW that the exhaust fan(s) requires for operation.

In the tests cases performed in this study, a 20% reduction in operational static pressure yielded 25% less fan kW usage. The possibility of designing a lab/fume hood HVAC system to operate at a static setpoint of -1.00 in. W.C. instead of -1.25 in. W.C. allows for a potential savings of 25% in fan energy consumption. Further reductions in fan energy as well as CFM consumption can be achieved if face velocity setpoints are reduced to 60 FPM, and system static pressure setpoints can be lowered, or "setback" when fume hoods are unoccupied – or the lab and fume hood ventilation system can be turned off altogether when not in use. These practices are particularly useful in universities with teaching labs, and where continuous operation of the lab and fume hoods is not always required. Use of direct digital controls (DDC) and/or building automation systems (BAS) to control the labs and fume hoods can facilitate scheduling or "setback" of the system to unoccupied conditions when possible.

1- *Static Pressure Optimization Technical Bulletin*, Laboratories for the 21st Century, 3 Feb. 2007

1.2 Duct Size

In new construction of a lab and fume hood exhaust system, initial capital expense has historically been the major consideration in system design. However, with annual energy costs rising exponentially and as owners and architects have become more educated and focused on energy conservation, or "sustainability" as it has become known, long-term operating costs of the system have also become a major factor in the design of lab and fume hood exhaust systems.

The possibility of designing a system that can employ the smallest diameter duct while meeting the lowest operational static pressure requirements is a recipe for not only saving energy on long-term operating costs, but enables the owner to save on initial capital expense by installing smaller size fume hood exhaust duct, and potentially smaller exhaust fans.

In the fume hood exhaust system examined in this study, where operational static pressure setpoints, 8" (20.32 cm) and 10" (25.4 cm) spiral duct arrangements, and various airflow valves were evaluated, it was determined that a VAV system with an operational system static pressure of -.65 in. W.C., utilizing 8" round duct, and an 8" closed loop butterfly airflow valve provided the potential for the greatest reduction in energy consumption, long-term operating cost and initial installation cost – while maintaining the desired target operational static pressure. However, it should be noted that operational static pressures should not only be designed around the fume hood exhaust, but the lab static pressure or volumetric flow requirements must be taken into consideration as well, if the fume hoods are in a controlled lab space.

1.3 VAV and CAV Operation

There are typically two widely employed methods for regulating fume hood exhaust air: Constant Air Volume (CAV) and Variable Air Volume (VAV) system design.

CAV control exhausts a specific or "fixed" amount of CFM based on the size, or "open area" of the fume hood and desired target face velocity, regardless of sash position. With a bypass fume hood, a CAV system fails to reduce the exhaust CFM when the fume hood sash is closed, causing it to consume substantial amounts of makeup air. In turn, more energy is required to condition the makeup air. In early designs, non-bypass fume hoods were specified in an attempt to reduce CFM consumption in a

CAV fume hood exhaust system. But this practice is typically no longer recommended since the face velocity of the fume hood is inversely proportional to the sash position. That is, the lower the sash's position in a non-bypass fume hood, the higher the face velocity. "Traditional fume hoods use constant air volume (CAV) exhaust fans, which exhaust air from the hood at a constant rate, regardless of sash height. This simple design can result in unacceptably high air velocities at the face of the fume hood when the front sash is lowered and nearly closed. "[2] These unacceptable face velocities generated at lower sash positions in a non-bypass fume hood employing a CAV exhaust system, could possibly lead to poor containment and operator exposure.

VAV operation takes into account the actual measured fume hood face velocity or sash position to maintain the desired target face velocity at the inlet of the fume hood. When the sash is lowered, the VAV system permits less makeup air to make its way through the exhaust while maintaining the desired target face velocity - requiring less energy to meet conditioned makeup air requirements. When the sash is opened, more air is let in to the fume hood and exhausted to ensure no contaminated air and particles spill out of the fume hood. Airflow control valves placed in the duct system coupled with a method to measure either fume hood face velocity or sash position, provide the ability to control or "vary" the amount of exhaust air required to maintain the desired target face velocity.

Figure 1 illustrates the average CFM consumption of a VAV system employing closed loop butterfly or pressure independent airflow valves compared to a CAV system.

2 - www.fume-hoods.us, *Chemical Fume Hood Guide for Laboratory Designers*

4' Bypass Fume Hood Operating at -1.0 in. WC System Static Pressure
Average Sash Position = 62% Open

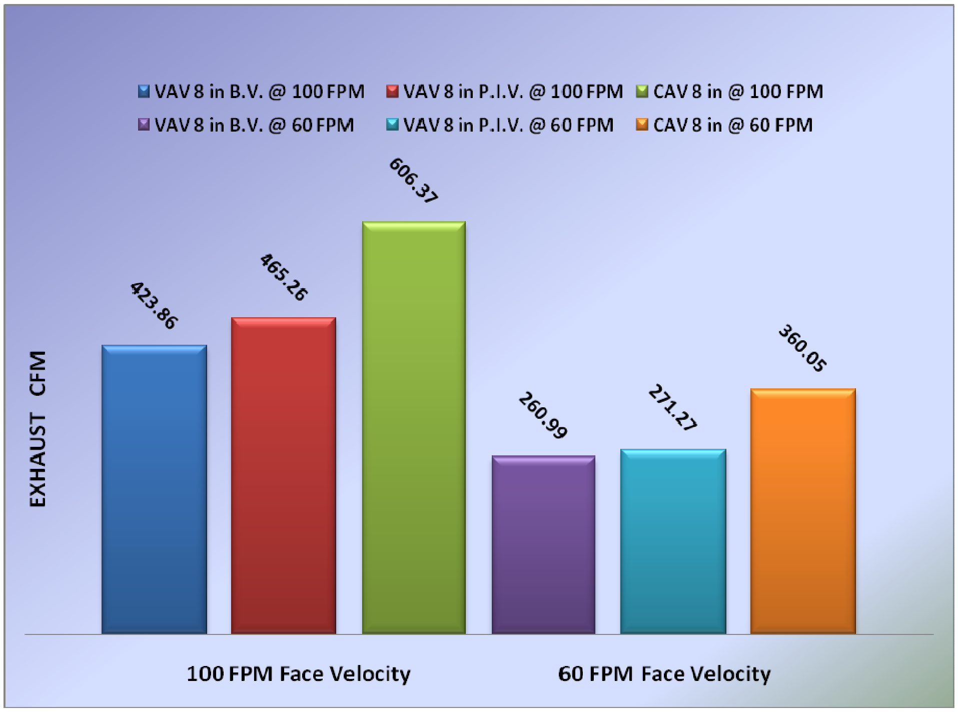

Figure 1

1.4 Control Air Valve Selection

Control airflow valve (damper) selection is another area that should be evaluated when looking to conserve energy in the operation of labs and fume hoods. While it is generally agreed upon that a VAV system is more economical to operate than a CAV system, different types and sizes of control air valves have different operating, performance, and control characteristics[3].

3 - In this study only closed loop butterfly and pressure independent airflow (venturi) valves were evaluated

Closed loop butterfly airflow valves have a simple design similar to butterfly valves used in a hydronic system. A disk turning on a diametrical axis (damper shaft) inside a duct is used to regulate or "throttle" airflow through the system. Butterfly valves are sized based on the amount of CFM required. They are relatively simple to specify and maintain, and require no factory calibration to operate in a specific system, or at a specific static pressure or airflow requirement.

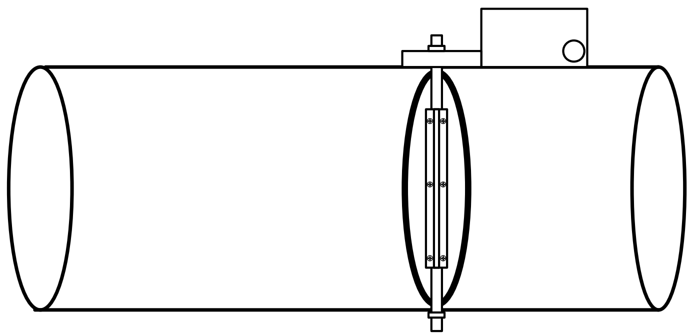

Figure 2 – Diagram Example of a Closed Loop Butterfly Airflow Valve

In most designs, pressure independent airflow or "venturi" valves ***(Figure 2)*** have a cone in the inlet. The cone rides on an engineered spring connected to the shaft of the damper. As the pressure in the ductwork increases or decreases, the pressure on this spring is either increased or decreased, causing the cone to move and vary the airflow. Selection of pressure independent airflow valves is a very precise process, and they typically need to be factory calibrated at a specific operating static pressure to meet the airflow requirements of the system where they are being installed.

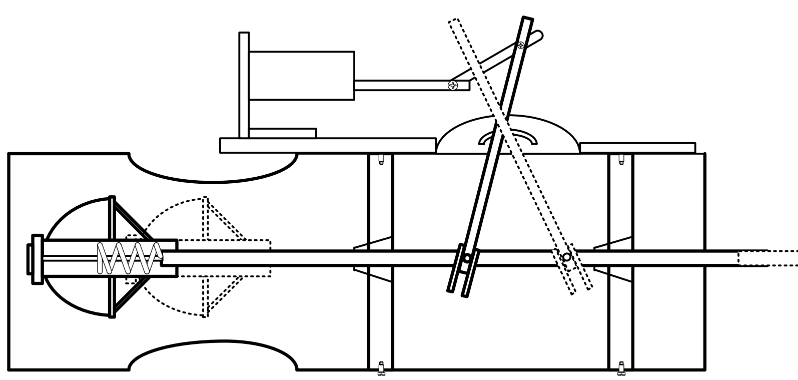

Figure 3 – Diagram Example of a Pressure Independent Airflow (Venturi) Valve

In tests performed on bypass and non-bypass fume hoods, it was determined in some cases that closed loop butterfly airflow valves and pressure independent airflow valves of the same size (dia.) performed similarly in the areas of energy consumption. However, the closed loop butterfly and pressure independent airflow valves performed quite differently depending on the system design static setpoint requirements and the duct diameter in which they were installed. While the performance characteristics between the 10" closed loop butterfly airflow valve and the 10" pressure independent airflow valve were comparable at the same duct static pressures in a 10" spiral duct, the 10" closed loop butterfly airflow valves were able to operate at significantly lower operating static setpoints and still maintain the desired target face velocity. It was also determined that certain closed loop butterfly airflow valves were able operate at static pressures as low as -.40 in. W.C., while maintaining an occupied fume hood face velocity of 100 FPM (+/- 2%).

In eight inch spiral duct, 8" pressure independent and closed loop butterfly airflow valves showed a significant difference in the amount of energy consumed based on exhaust CFM and fume hood desired face velocity requirements, specifically in the amount of kW required to operate the exhaust fan. In test cases performed in this study, an 8" closed loop butterfly airflow valve consumed about 60 % *less* exhaust fan energy (kW) than the 8" pressure independent valve in the same 8" diameter duct configuration, due to the fact it could operate at much lower static setpoints ***(Figure 4)***.

4' Bypass Fume Hood @ 100 FPM Face Velocity - 8" Exhaust Duct

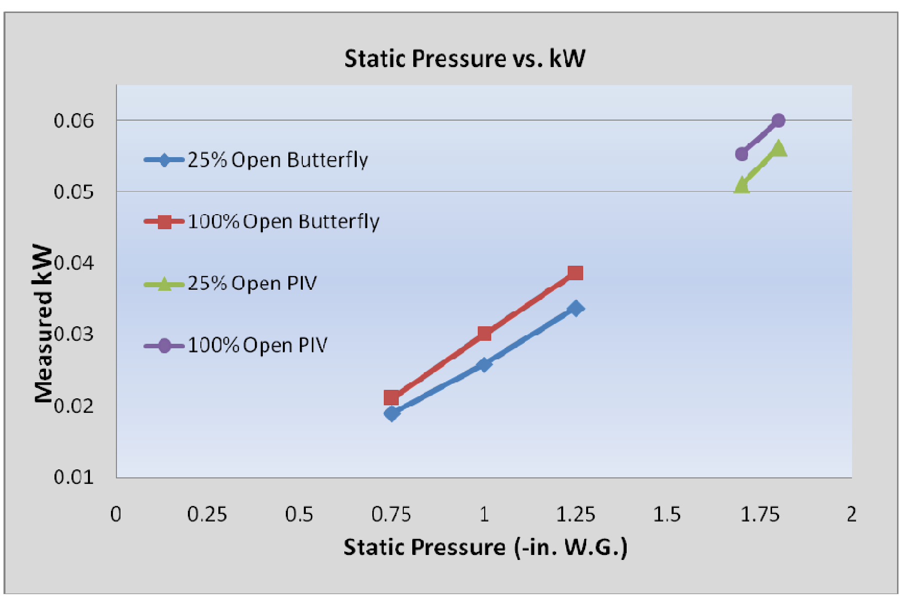

Figure 4 – 8" closed loop butterfly and pressure independent valves compared

2. Purpose

The primary purpose of the study was to measure the energy use (kW) of a fume hood exhaust fan under various design conditions. Fume hood exhaust energy consumption was measured over a range of design duct static pressures and desired fume hood target face velocities in 8” (20.32 cm) & 10” (25.4 cm) spiral duct with different exhaust airflow designs and control valve types. Tests were performed and comparisons were made between a CAV System and a VAV System utilizing common Pressure Independent Airflow Valves & standard Closed Loop Butterfly Airflow Valves in two size categories – 8” & 10”.

While the two airflow valves serve the same purpose in the operation of a VAV system, the drastic differences in airflow valve design show potential for a difference in energy usage. If one method uses less air to maintain static pressure in the ducts, it would mean lower exhaust fan operating requirements, less conditioned air is being exhausted into the atmosphere, and less makeup air needs to be reconditioned. In terms of energy use, this translates to less energy required to move the air in the duct, less energy required to maintain static pressure in the system, and less energy required to recondition the makeup air. Life cycle energy consumption projections were then analyzed based on the various control methods, system configurations and collected data. Life cycle energy projection falls in line with the Labs21 approach for using life cycle operating costs versus only evaluating initial costs, in the decision making process of laboratory design.

3. Test Environment

Test cases were conducted on a 4' wide (121.92 cm) bench top fume hood with a single vertical sash. The fume hood was tested in bypass and no bypass conditions.

A parallel duct system was the design for the fume hood exhaust. This allowed for various tests of different duct and airflow valve sizes to be performed on the same fume hood. 8" and 10" spiral duct were run parallel into the same common exhaust plenum. When not utilized, each duct run was blocked by the use of an isolation damper to prevent "air leakage" from one run of duct to the other.

The fume hood exhaust system was designed with a 3-phase/208 VAC 3-HP exhaust fan controlled by a variable frequency drive (VFD) to facilitate VAV operation with different types of airflow valves. CAV conditions were facilitated through locking the exhaust fan at specific speeds to maintain the desired system static pressure and face velocity requirements at the fume hood. It should be noted that less than 1 HP of the fan was used in any of the tests that were conducted.

Energy consumption tests were run with operational exhaust static pressures ranging from -.40 in. W.C. to -1.8 in. W.C. The focus of testing was primarily on the operation of the fume hood exhaust fan and its direct energy consumption at tested operating static pressures. Exhaust CFM was measured in all test cases; however energy consumption required for reconditioning makeup air was not an area of focus in this study, as the factors relating to the energy required to recondition makeup air are too varied based on diverse lab and fume hood operating specifications, regional environments (heating and cooling loads), and regional energy requirements/costs. Although it can safely be assumed that the less CFM that is exhausted out of the lab/fume hood, less energy will be consumed to condition makeup air.

Test environment temperature was in the range of 70°F (21°C) to 80°F (26.6°C). Humidity was in the range of 50% to 60% RH.

3.1 Exhaust Airflow Geometry

Although an atypical exhaust duct design configuration was utilized in the various tests ***(Figure 5)***, it should be noted that all comparative tests were run under the same conditions.

- All Tests employed identical Static Pressures – where valve operation allowed
- All Tests were conducted at the same Face Velocity Setpoints
- All Tests were conducted at the same Fume Hood
- All Tests utilized the same instrumentation
- Different Valve Types were substituted in the same duct configurations
- All Tests utilized the same duct configurations
    - 10” System had Smooth Transitions
    - 8” System had Abrupt Transitions

The atypical duct design and abrupt 8” duct transition allowed for the opportunity to evaluate how a non-standard duct configuration or poorly designed exhaust duct system would perform in relation to maintaining target face velocity at a fume hood, while operating at specific operating static pressure setpoints. In the tests performed in this study, little performance degradation was noticed. However, while the 8” Tee or “abrupt” transition maintained the desired target face velocities during testing, the face velocity measured across the opening of the fume hood at various points were somewhat inconsistent depending on the system operating static pressure. An exhaust duct design with smooth duct transitions as was employed in the 10” duct arrangement used in this study is recommended to achieve more consistent desired target face velocities measured across the opening of the fume hood.

3.2 Fume Hood Exhaust Airflow Diagram (As Tested)

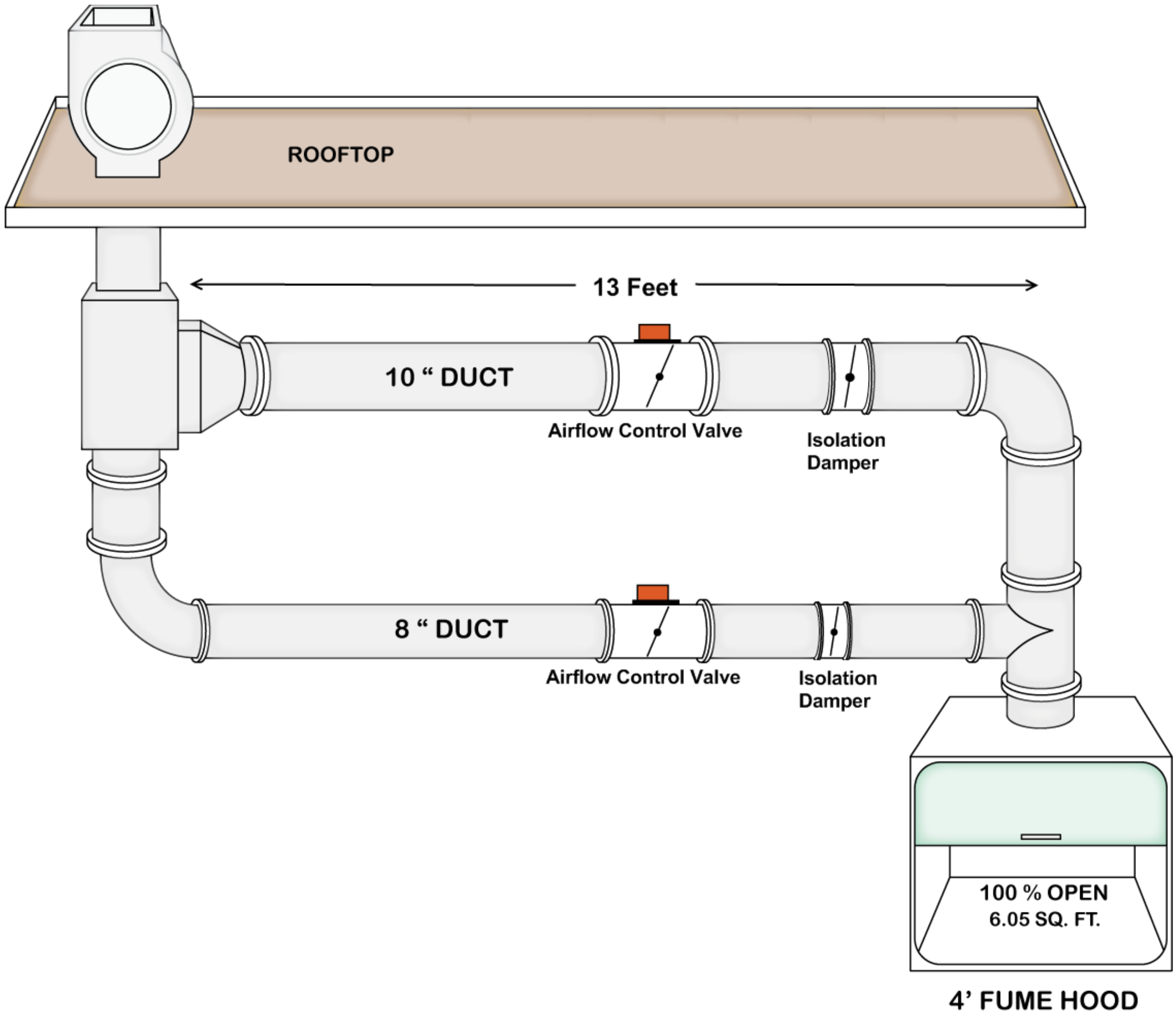

Figure 5 – Diagram of the fume hood exhaust system test environment

4. Equipment

4.1 Lab Equipment

4.1.1 Fume Hood

The fume hood used in this study was a 4’ wide (121.92 cm) bench top fume hood, with a single vertical sash. 10” round exhaust duct leaving the fume hood.

Fume hood with bypass - operational opening

Sash Width:	40"	(101.6 cm)
Max Open Height:	21.750"	(55.25 cm)
Min Open Height:	1.935"	(4.91 cm)
Bypass Height:	11"	(27.94 cm)
Max Sash Open Area:	6.05ft^2	(.56 m^2)
Min Sash Open Area:	3.05ft^2	(.28 m^2)

Fume hood with no bypass - operational opening

Sash Width:	40"	(101.6 cm)
Max Open Height:	21.750"	(55.25 cm)
Min Open Height:	1.935"	(4.91 cm)
Bypass Height:	0"	(0 cm)
Max Sash Open Area:	6.05ft^2	(.56 m^2)
Min Sash Open Area:	.5375ft^2	(.05 m^2)

4.1.2 Actuators

High speed over-shaft gear train actuators were employed to drive the airflow valves
Shaft position feedback provided

Rotation Time thru 90 degree Travel:	1.5 seconds
Operation Voltage:	2 - 10 vdc
Torque:	25 in-lb (2.88 m-kg) at rated voltage

4.1.3 Pressure Independent Airflow Valve

Eight and ten inch Variable Air Volume pressure independent airflow valves were used in this study. 8" and 10" airflow valves were used respectively in the 8" and 10" duct. The valves were of aluminum construction, designed for a horizontal flow and had the following specifications:

8" Pressure Independent Valve

Calibrated Pressure Range:	High	1" - 6" W.C. Delta P.D.
Calibrated CFM Range:	71 - 650 CFM (2.01 – 18.41 m^3-min)	

10" Pressure Independent Valve

Calibrated Pressure Range:	Low	.3" - 3" W.C. Delta P.D.
Calibrated CFM Range:	36 - 741 CFM (1.01 – 20.98 m^3-min)	

4.1.4 Closed Loop Butterfly Airflow Valve

Eight and ten inch Variable Air Volume closed loop butterfly airflow valves were also used in this study. 8" and 10" airflow valves were used respectively in the 8" and 10" duct. The closed loop butterfly airflow valves were of schedule 40 PVC construction. The valves contain a stainless steel blade and were mounted for horizontal operation.

4.2 Test Equipment

4.2.1 Data Acquisition Components

LabVIEW 7 Express© software & Data Acquisition Module – NI-DAQ 6009

The following conditions were recorded during testing:

1. Fume Hood Face Velocity
2. Exhaust Fan kW Consumption
3. Fume Hood Exhaust CFM
4. Airflow Valve Static Pressure Drop (VAV only)
5. System Operating Static Pressure
6. Airflow Valve Operating Position (VAV only)
7. Fume Hood Sash Position

4.2.2 Air Velocity Meter – Fume Hood Face Velocity Measurement

A calibrated NIST certified Shortridge Airdata Multimeter model ADM-860 was used to ensure target fume hood face velocity was achieved. Accuracy: +/- 3% @ 50-2500 FPM

4.2.3 Energy Meter – Exhaust Fan kW Consumption

A Veris Industries energy meter, model H8044-100-2 was used to measure kW consumption. Accurate to +/- 1% @ readings from 10% to 100% of the rated current.

Mfgr:	Veris Industries
Input Voltage:	208 to 480 VAC
Frequency:	50 - 60 Hz
Accuracy:	+/- 1%

4.2.4 Pressure / Flow Sensors

Fume Hood Exhaust Airflow (CFM) Measurement

Mfgr:	Ashcroft©
Pressure Range:	0 - 0.25" WC
Output:	4 - 20 mA
Accuracy:	within 0.25%

Airflow Valve Static Pressure Drop Measurement

Mfgr:	Setra©
Pressure Range:	-2.50 – 2.5" WC
Output:	0-5 VDC
Accuracy:	within 0.25%

Exhaust System Operational Static Pressure Measurement

Mfgr:	Setra©
Pressure Range:	-5.0 – 5.0" WC
Output:	4-20 mA
Accuracy:	within 0.25%

5. Test Cases

For the evaluation of fume hood energy consumption, over seventy individual test cases were developed for this study. VAV and CAV system exhaust CFM conditions were recorded, as were various system operating static pressures and fume hood face velocities, while employing closed loop butterfly and pressure independent airflow valves in 8” and 10” round duct. Two individual tests per case were performed during the study. Each individual test recorded pre-determined measured variables with the fume hood sash at 25% and 100% open. In the case of VAV evaluation, each individual test was run for a minimum of three minutes. For CAV evaluation, each test was run for a minimum of two minutes as the fluctuation in exhaust CFM based on the sash position of the bypass fume hood was virtually non-existent. Data collected through the use of LabVIEW software was retrieved and logged every second.

The tables on the following pages represent the data collected in each of the test cases. The collected data displayed in the tables was averaged for the purpose of evaluation and presentation.

Where possible, the CAV system, pressure independent, and closed loop butterfly airflow valves were evaluated at the same operational system static pressure. There were cases however where target face velocities could not be achieved by the pressure independent airflow valve or CAV system when compared to the closed loop butterfly airflow valves at the same operational static pressures. Because of the operational characteristics of the pressure independent airflow valves versus the closed loop butterfly airflow valves, this led to the pressure independent airflow valves not being tested directly against the closed loop butterfly airflow valve at the same static pressures in particular instances. Therefore, the data collected will show a significant difference in operating static pressures – and energy consumption – between the airflow valves in specific conditions.

5.1 10" Spiral Duct - 10" Closed Loop Butterfly Valve - 100 FPM Face Velocity SP

Environment		Case#_Test#	Sash Position	CFM	kW	Valve SP Drop	Damper Pos % (Open)	Face Velocity (FPM)
4' Bench Top Fume Hood – Bypass								
-0.40	**"WC Static SP**	C45_T1	25% Open	263.09	0.011209	-0.40241	45.50	100.25
		C45_T2	100% Open	599.29	0.012105	-0.14492	75.50	100.40
-0.50	**"WC Static SP**	C46_T1	25% Open	269.97	0.013372	-0.50901	43.30	100.70
		C46_T2	100% Open	601.26	0.014891	-0.29998	69.80	99.60
-0.75	**"WC Static SP**	C1_T1	25% Open	243.66	0.019610	-0.78935	38.90	101.11
		C1_T2	100% Open	613.87	0.021536	-0.60820	62.90	100.30
-1.00	**"WC Static SP**	C2_T1	25% Open	250.38	0.026188	-1.02635	36.50	99.55
		C2_T2	100% Open	612.69	0.028873	-0.89707	57.28	101.40
-1.25	**"WC Static SP**	C3_T1	25% Open	239.05	0.033995	-1.27140	33.40	99.40
		C3_T2	100% Open	604.97	0.037870	-1.18732	53.70	99.67
4' Bench Top Fume Hood – No Bypass								
-0.40	**"WC Static SP**	C47_T1	25% Open	158.50	0.010784	-0.39463	35.50	99.25
		C47_T2	100% Open	599.29	0.012105	-0.14492	75.50	99.00
-0.50	**"WC Static SP**	C48_T1	25% Open	151.75	0.012519	-0.49810	32.00	100.00
		C48_T2	100% Open	601.26	0.014891	-0.29998	69.00	99.30
-0.75	**"WC Static SP**	C4_T1	25% Open	156.74	0.019099	-0.74286	30.30	100.63
		C4_T2	100% Open	613.87	0.021536	-0.60820	62.50	100.75
-1.00	**"WC Static SP**	C5_T1	25% Open	147.76	0.025590	-0.98235	27.30	100.10
		C5_T2	100% Open	612.69	0.028873	-0.89707	57.28	101.20
-1.25	**"WC Static SP**	C6_T1	25% Open	153.60	0.033529	-1.22462	25.50	99.35
		C6_T2	100% Open	604.97	0.037870	-1.18732	54.29	101.24

5.2 10" Spiral Duct - 10" Closed Loop Butterfly Valve - 60 FPM Face Velocity SP

Environment		Case#_Test#	Sash Position	CFM	kW	Valve SP Drop	Damper Pos % (Open)	Face Velocity (FPM)
4' Bench Top Fume Hood - Bypass								
-0.40	**"WC Static SP**	C49_T1	25% Open	165.86	0.010240	-0.40562	33.10	59.75
		C49_T2	100% Open	363.09	0.010797	-0.37067	53.70	60.10
-0.50	**"WC Static SP**	C50_T1	25% Open	173.18	0.011933	-0.49349	31.50	61.20
		C50_T2	100% Open	363.93	0.012899	-0.46533	50.20	59.90
-0.75	**"WC Static SP**	C7_T1	25% Open	144.54	0.018964	-0.75225	29.32	59.75
		C7_T2	100% Open	363.95	0.020474	-0.76478	47.45	60.66
-1.00	**"WC Static SP**	C8_T1	25% Open	152.84	0.025390	-0.98849	26.60	60.22
		C8_T2	100% Open	366.77	0.027314	-1.04007	44.15	60.83
-1.25	**"WC Static SP**	C9_T1	25% Open	152.79	0.033660	-1.23155	25.20	59.40
		C9_T2	100% Open	363.83	0.035532	-1.31030	41.80	60.25
4' Bench Top Fume Hood – No Bypass								
-0.40	**"WC Static SP**	C51_T1	25% Open	87.97	0.010128	-0.38833	26.10	59.30
		C51_T2	100% Open	363.09	0.010797	-0.37067	53.00	60.00
-0.50	**"WC Static SP**	C52_T1	25% Open	101.78	0.012068	-0.47282	23.00	61.70
		C52_T2	100% Open	363.93	0.012899	-0.46533	50.20	59.85
-0.75	**"WC Static SP**	C10_T1	25% Open	98.63	0.018780	-0.72990	21.60	61.70
		C10_T2	100% Open	363.95	0.020474	-0.76478	47.60	60.66
-1.00	**"WC Static SP**	C11_T1	25% Open	95.41	0.025059	-0.96892	20.50	60.65
		C11_T2	100% Open	366.77	0.027314	-1.04007	44.22	60.50
-1.25	**"WC Static SP**	C12_T1	25% Open	93.05	0.033893	-1.23482	18.50	61.20
		C12_T2	100% Open	363.83	0.035532	-1.31030	41.40	59.65

5.3 10" Spiral Duct - 10" Pressure Independent Valve - 100 FPM Face Velocity SP

Environment	Case#_Test#	Sash Position	CFM	kW	Valve SP Drop	Damper Pos % (Open)	Face Velocity (FPM)

4' Bench Top Fume Hood - Bypass

-0.40 "WC Static SP	C59_T1	Could not achieve 100 FPM Face Velocity @ -0.40" WC Duct Static					
-0.50 "WC Static SP	C60_T1	Could not achieve 100 FPM Face Velocity @ -0.50" WC Duct Static					
-0.75 "WC Static SP	C13_T1	25% Open	305.26	0.019959	-0.84273	63.11	100.50
	C13_T2	100% Open	594.73	0.020111	-0.49794	89.14	99.10
-1.00 "WC Static SP	C14_T1	25% Open	319.59	0.026957	-1.21789	63.10	102.20
	C14_T2	100% Open	607.60	0.028915	-0.85891	89.15	101.00
-1.25 "WC Static SP	C15_T1	25% Open	314.33	0.034868	-1.40286	63.11	103.45
	C15_T2	100% Open	617.20	0.038571	-1.09500	89.03	102.15

4' Bench Top Fume Hood – No Bypass

-0.40 "WC Static SP	C61_T1	Could not achieve 100 FPM Face Velocity @ -0.40" WC Duct Static					
-0.50 "WC Static SP	C62_T1	Could not achieve 100 FPM Face Velocity @ -0.50" WC Duct Static					
-0.75 "WC Static SP	C16_T1	25% Open	143.28	0.018755	-0.75652	39.10	101.00
	C16_T2	100% Open	599.14	0.021592	-0.48304	89.15	99.30
-1.00 "WC Static SP	C17_T1	25% Open	145.50	0.025760	-1.11127	39.66	100.25
	C17_T2	100% Open	607.60	0.028915	-0.85891	89.10	101.00
-1.25 "WC Static SP	C18_T1	25% Open	145.64	0.034018	-1.26859	39.52	99.60
	C18_T2	100% Open	617.20	0.038571	-1.09500	89.15	102.15

5.4 10" Spiral Duct - 10" Pressure Independent Valve - 60 FPM Face Velocity SP

Environment	Case#_Test#	Sash Position	CFM	kW	Valve SP Drop	Damper Pos % (Open)	Face Velocity (FPM)

4' Bench Top Fume Hood - Bypass

Environment	Case#_Test#	Sash Position	CFM	kW	Valve SP Drop	Damper Pos % (Open)	Face Velocity (FPM)
-0.40 "WC Static SP	C63_T1	Could not achieve 60 FPM Face Velocity @ -0.40" WC Duct Static					
-0.50 "WC Static SP	C53_T1	25% Open	191.18	0.012677	-0.51867	47.20	61.90
	C53_T2	100% Open	366.59	0.013225	-0.45092	68.80	61.00
-0.75 "WC Static SP	C19_T1	25% Open	190.58	0.019478	-0.81007	47.23	62.15
	C19_T2	100% Open	361.46	0.020455	-0.81899	69.15	59.55
-1.00 "WC Static SP	C20_T1	25% Open	182.24	0.026930	-1.07170	47.23	60.80
	C20_T2	100% Open	366.66	0.027232	-1.11484	69.15	61.25
-1.25 "WC Static SP	C21_T1	25% Open	187.32	0.033788	-1.30741	47.23	61.20
	C21_T2	100% Open	365.83	0.035187	-1.41273	69.15	60.50

4' Bench Top Fume Hood – No Bypass

Environment	Case#_Test#	Sash Position	CFM	kW	Valve SP Drop	Damper Pos % (Open)	Face Velocity (FPM)
-0.40 "WC Static SP	C64_T1	Could not achieve 60 FPM Face Velocity @ -0.40" WC Duct Static					
-0.50 "WC Static SP	C54_T1	25% Open	92.10	0.012861	-0.48789	25.40	61.20
	C54_T2	100% Open	366.59	0.013225	-0.45092	68.50	61.00
-0.75 "WC Static SP	C22_T1	25% Open	98.18	0.018959	-0.73787	25.60	61.55
	C22_T2	100% Open	361.46	0.020455	-0.81899	69.15	59.65
-1.00 "WC Static SP	C23_T1	25% Open	95.69	0.025509	-0.96846	25.40	62.52
	C23_T2	100% Open	359.95	0.027320	-1.12291	69.15	59.40
-1.25 "WC Static SP	C24_T1	25% Open	99.71	0.033466	-1.22983	25.40	63.50
	C24_T2	100% Open	365.83	0.035187	-1.41273	69.15	60.75

5.5 8" Spiral Duct - 8" Closed Loop Butterfly Valve - 100 FPM Face Velocity SP

Environment		Case#_Test#	Sash Position	CFM	kW	Valve SP Drop	Damper Pos % (Open)	Face Velocity (FPM)

4' Bench Top Fume Hood - Bypass

-0.65	**"WC Static SP**	C55_T1	25% Open	268.89	0.018009	-0.65856	50.20	100.70
		C55_T2	100% Open	608.53	0.019614	-0.09689	91.30	100.30
-0.75	**"WC Static SP**	C25_T1	25% Open	251.58	0.018971	-0.64304	50.50	99.60
		C25_T2	100% Open	610.15	0.021092	-0.12661	85.20	99.60
-1.00	**"WC Static SP**	C26_T1	25% Open	244.39	0.025846	-0.89514	48.10	99.70
		C26_T2	100% Open	603.33	0.030015	-0.51685	73.50	100.50
-1.25	**"WC Static SP**	C27_T1	25% Open	237.57	0.033695	-1.13641	45.70	98.75
		C27_T2	100% Open	603.84	0.038652	-0.79097	67.50	100.20

4' Bench Top Fume Hood – No Bypass

-0.65	**"WC Static SP**	C56_T1	25% Open	150.27	0.017452	-0.69429	40.40	101.20
		C56_T2	100% Open	608.53	0.019614	-0.09689	91.30	99.50
-0.75	**"WC Static SP**	C28_T1	25% Open	149.67	0.018324	-0.67666	40.80	99.70
		C28_T2	100% Open	609.88	0.022058	-0.15762	85.20	100.75
-1.00	**"WC Static SP**	C29_T1	25% Open	143.65	0.025253	-0.92835	40.80	97.00
		C29_T2	100% Open	607.34	0.030133	-0.51920	73.10	100.50
-1.25	**"WC Static SP**	C30_T1	25% Open	143.24	0.033781	-1.19465	35.20	98.80
		C30_T2	100% Open	604.93	0.038201	-0.83013	67.60	99.25

5.6 8" Spiral Duct - 8" Closed Loop Butterfly Valve - 60 FPM Face Velocity SP

4' Fume Hood - Bypass

-0.65	**"WC Static SP**	C57_T1	25% Open	158.83	0.017174	-0.69626	38.60	59.30
		C57_T2	100% Open	360.73	0.018183	-0.61106	56.50	59.25
-0.75	**"WC Static SP**	C31_T1	25% Open	145.43	0.019283	-0.69040	40.60	59.74
		C31_T2	100% Open	368.61	0.020624	-0.58078	60.33	60.30
-1.00	**"WC Static SP**	C32_T1	25% Open	144.71	0.025571	-0.91976	38.60	59.80
		C32_T2	100% Open	377.27	0.027593	-0.82945	56.80	61.20
-1.25	**"WC Static SP**	C33_T1	25% Open	142.18	0.032306	-1.18574	35.10	59.00
		C33_T2	100% Open	372.62	0.035401	-1.08312	54.10	61.60

4' Fume Hood – No Bypass

-0.65	**"WC Static SP**	C58_T1	25% Open	91.83	0.016966	-0.71101	28.30	59.80
		C58_T2	100% Open	360.73	0.018183	-0.61106	57.20	60.10
-0.75	**"WC Static SP**	C34_T1	25% Open	90.19	0.019037	-0.70506	31.50	59.60
		C34_T2	100% Open	376.46	0.020713	-0.56354	60.41	61.20
-1.00	**"WC Static SP**	C35_T1	25% Open	84.42	0.026119	-0.95269	26.30	59.38
		C35_T2	100% Open	378.98	0.028013	-0.84436	57.30	60.40
-1.25	**"WC Static SP**	C36_T1	25% Open	88.28	0.033661	-1.21260	26.40	59.40
		C36_T2	100% Open	358.92	0.035262	-1.08535	53.60	61.75

5.7 8" Spiral Duct - 8" Pressure Independent Valve - 100 FPM Face Velocity SP*

Environment		Case#_Test#	Sash Position	CFM	kW	Valve SP Drop	Damper Pos % (Open)	Face Velocity (FPM)

4' Fume Hood - Bypass

Environment		Case#_Test#	Sash Position	CFM	kW	Valve SP Drop	Damper Pos % (Open)	Face Velocity (FPM)
-1.70	**"WC Static SP**	C37_T1	25% Open	311.90	0.051034	-1.96451	59.70	102.30
		C37_T2	100% Open	618.62	0.055324	-0.95700	91.70	102.20
-1.80	**"WC Static SP**	C38_T1	25% Open	309.59	0.056189	-2.13692	59.60	100.30
		C38_T2	100% Open	609.34	0.059927	-1.12435	91.70	101.00

4' Fume Hood – No Bypass

Environment		Case#_Test#	Sash Position	CFM	kW	Valve SP Drop	Damper Pos % (Open)	Face Velocity (FPM)
-1.70	**"WC Static SP**	C39_T1	25% Open	148.61	0.049832	-1.82445	30.20	99.85
		C39_T2	100% Open	617.60	0.055142	-1.00589	91.70	102.10
-1.80	**"WC Static SP**	C40_T1	25% Open	151.65	0.055220	-1.92701	30.50	100.00
		C40_T2	100% Open	624.13	0.060928	-1.11809	91.70	103.00

5.8 8" Spiral Duct - 8" Pressure Independent Valve - 60 FPM Face Velocity SP*

4' Fume Hood - Bypass

Environment		Case#_Test#	Sash Position	CFM	kW	Valve SP Drop	Damper Pos % (Open)	Face Velocity (FPM)
-1.70	**"WC Static SP**	C41_T1	25% Open	182.62	0.049446	-1.91464	39.17	60.10
		C41_T2	100% Open	359.93	0.049915	-1.96511	65.12	60.10
-1.80	**"WC Static SP**	C42_T1	25% Open	178.26	0.054677	-2.02474	39.17	58.80
		C42_T2	100% Open	362.43	0.056377	-2.03029	65.12	60.40

4' Fume Hood – No Bypass

Environment		Case#_Test#	Sash Position	CFM	kW	Valve SP Drop	Damper Pos % (Open)	Face Velocity (FPM)
-1.70	**"WC Static SP**	C43_T1	25% Open	89.19	0.049148	-1.74174	6.70	59.15
		C43_T2	100% Open	365.10	0.052118	-1.86544	65.12	61.50
-1.80	**"WC Static SP**	C44_T1	25% Open	92.45	0.053648	-1.86167	6.58	60.85
		C44_T2	100% Open	363.14	0.056359	-2.02077	65.12	60.00

* In the test cases performed for this study, an 8" Pressure Independent Airflow Valve installed in 8" spiral duct was unable to maintain desired target fume hood face velocities at comparable operating static pressures as the 8" Closed Loop Butterfly Valve. -1.7 in. WC operating system static pressure in the 8" duct was the lowest the 8" pressure independent valve could effectively operate and maintain the desired target fume hood face velocities.

5.9 CAV System - 10" Spiral Duct - 100 FPM Face Velocity SP

4' Fume Hood - Bypass

Environment	Case#_Test#	Sash Position	CFM	kW	Face Velocity (FPM)
-0.75 "WC Static SP	CAV_T1	Various	606.12	0.022314	100.00
-1.00 "WC Static SP	CAV_T2	Various	598.48	0.031979	99.60
-1.25 "WC Static SP	CAV_T3	Various	595.16	0.036122	100.20

5.10 CAV System - 10" Spiral Duct - 60 FPM Face Velocity SP

4' Fume Hood - Bypass

-0.75 "WC Static SP	CAV_T4	Various	354.13	0.020761	59.50
-1.00 "WC Static SP	CAV_T5	Various	366.67	0.028700	61.25
-1.25 "WC Static SP	CAV_T6	Various	362.56	0.035776	60.00

5.11 CAV System - 8" Spiral Duct - 100 FPM Face Velocity SP

4' Fume Hood - Bypass

-0.75 "WC Static SP	CAV_T7	Could not achieve 100 FPM @ -.75" WC Duct Static			
-1.00 "WC Static SP	CAV_T8	Various	606.37	0.030545	99.75
-1.25 "WC Static SP	CAV_T9	Various	600.60	0.039909	99.00

5.12 CAV System - 8" Spiral Duct - 60 FPM Face Velocity SP

4' Fume Hood - Bypass

-0.75 "WC Static SP	CAV_T10	Various	363.78	0.020473	61.25
-1.00 "WC Static SP	CAV_T11	Various	360.05	0.028536	60.00
-1.25 "WC Static SP	CAV_T12	Various	361.33	0.036496	60.60

6. Yearly kWh Consumption Analysis Examples

Fume Hood Exhaust Fan Energy Consumption Projections – 10" Spiral Duct

4' Bypass Fume Hood

Operation:
128 Hrs. / Week @ 60 FPM (.3048 m/sec) Face Velocity
40 Hrs. / Week @ 100 FPM (.508 m/sec) Face Velocity

Environment	Operating Static in. WC	kWh/yr. @ 60 FPM	kWh/yr. @ 100 FPM	Total kWh/Yr. (Per Exhaust Fan)
VAV – Butterfly Valve	-1.0	175.40	57.26	232.66
VAV – Press. Ind. Valve	-1.0	180.25	58.11	238.36
CAV	-1.0	189.74	63.90	253.64

Fume Hood Exhaust Fan Energy Consumption Projections – 8" Spiral Duct

4' Bypass Fume Hood

Operation:
128 Hrs. / Week @ 60 FPM (.3048 m/sec) Face Velocity
40 Hrs. / Week @ 100 FPM (.508 m/sec) Face Velocity

Environment	Operating Static in. WC	kWh/yr. @ 60 FPM	kWh/yr. @ 100 FPM	Total kWh/Yr. (Per Exhaust Fan)
VAV – Butterfly Valve	-1.0	176.93	58.10	235.03
VAV – Press. Ind. Valve	-1.7*	330.67	110.61	441.28
CAV	-1.0	189.94	63.53	253.47

** In the test cases performed during this study, an 8" Pressure Independent Airflow Valve installed in 8" spiral duct was unable to maintain desired target fume hood face velocity at a comparable -1.0 in. WC static pressure. -1.7 in. WC operating system static pressure in the 8" duct was the lowest the 8" pressure independent valve could effectively operate and maintain the desired target fume hood face velocity.*

7. Conclusions

1. As Expected, More Power is Required to Exhaust Higher Air Volumes when the Hoods are Fully Open
2. Use of Either Closed Loop Butterfly or Pressure Independent Airflow Valves in a VAV System, Regardless of Duct Size, Facilitates Lower Energy Consumption in the form of Exhaust CFM Compared to a CAV System at the Same Operational Static Pressures
3. 10" Duct/Valve Size – Little Difference in Energy Consumption between Valves at Comparable Static Pressures, but Closed Loop Butterfly Airflow Valves Could Control at *Lower* Operational Static Pressures
4. 8" Duct/Valve Size – Substantial Difference in Energy Consumption between Valves. *Higher* Operational Static Pressures must be Generated when Using the Pressure Independent Valve in and 8" Duct System
5. The Possibility of Controlling at Lower System Operational Static Pressure Enables System Design with Smaller Diameter Exhaust Ducting & Lower Energy Consumption Overall

Organizations such as the US Department of Energy, International Institute of Sustainable Laboratories (I^2SL), Labs21, US Environmental Protection Agency and the US Green Building Council have focused attention on energy conservation issues relating to the design and operation of laboratories. As owners and designers have become more aware of sustainability in the design of laboratory and fume hood HVAC ventilation systems, the technology and best design practices have been brought to the forefront to meet this need of building more sustainable systems and facilities.

Smaller Duct Size & Lower Operating Static Pressure

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Lower Initial Cost, Lower Life Cycle Operating Cost & Lower Energy Consumption

8. References

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