

Using Extended Surface Air Filters in Heating Ventilation and Air Conditioning Systems: Reducing Utility and Maintenance Costs while Benefiting the Environment

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ABSTRACT

Air filter manufacturers have recently begun marketing premium air filters that provide very high particle capture efficiencies with very low initial static pressure drops. This is accomplished with proprietary filter designs incorporating at least twice the media surface area of traditional filters.¹ The increased media reduces the initial pressure drop of air filters while dramatically increasing their dust holding capacity. In addition, their useful lives are extended and prefilter use may be eliminated.

Physical principals governing airflow in fan systems predict available energy savings from using premium air filters. This energy savings may offset the additional cost of the premium filters. In fact, premium filter investments can payback in six months to three years depending on airflow and number of hours of fan operation. Additional benefits of using premium air filters include longer filter life, lower installation and disposal costs, elimination of prefilters and the ability to increase effective filter efficiency in buildings without reducing ventilation effectiveness.

A case study was conducted in an office building with two nearly identical VAV systems to determine if premium air filters are good investments for building owners and managers. This paper presents performance characteristics including fan energy use and static pressure drops across both premium and typical air filters. The performance data were used to test the validity of one manufacturer's claim concerning their premium filters, fan energy reduction and improved indoor air quality. Results of this study demonstrated purchase and use of the premium air filters might be good investments for building owners and managers.

Introduction

Heating, ventilation, and air conditioning (HVAC) systems are used to control temperature, humidity and promote good indoor air quality. Air filters are an integral part of an HVAC system. Cleanliness and ventilation requirements of a space determine the number and type of air filters needed, as well as the size and location of ductwork and ultimately the size and type of fan required to move the air throughout the system. Since air filters capture particulates, their life is finite and they must be replaced periodically. The air filter's useful life depends on its type and size as well as the installed environment. The maintenance costs associated with the purchase, installation and disposal of air filters are fixed. Unfortunately,

¹ When compared to earlier air filter manufacturing practices.

there is a hidden cost associated with air filter use that is more difficult to quantify and is often overlooked. This is the cost of the energy required to move air across the filter.

Whether filters are manufactured from paper, fiberglass or synthetic materials, they cause a pressure drop in the ventilation system that must be overcome to deliver adequate ventilation to a space. This pressure drop increases as the filter loads with contaminants. Thus, the energy required to maintain the ventilation rate increases. Conversely, if the energy remains constant, the ventilation rate decreases.

The purpose of this case study was to determine whether reducing an HVAC system's total fan static pressure, by using air filters with lower initial static pressure drops than industry-typical air filters, would lower the energy consumed by fan motors. In addition, this study investigated the purported benefits of premium air filters including extended life, air quality improvement and subsequent reductions of fixed maintenance costs.

The study investigated the use of premium air filters in variable air volume (VAV) fan systems. Two nearly identical VAV systems were selected. One system, the control group, operated with standard bag-type air filters. The other system operated with premium bag-type air filters. The manufacturers of the air filters were Quality Filters, Inc. and Viledon respectively. Viledon claims their filters save energy since they have very low initial static pressure drops and consequently lower average static pressure drops over the life of the filter. In theory, this is true. In practice, however, if total fan static pressure is decreased from the baseline design, power consumption could actually increase.²

Background

Air handling units (AHUs) are used to heat and cool occupied spaces in commercial, institutional and in most industrial markets. AHUs are designed and built primarily for the ventilation requirements of a space. Specific system pressurization and required airflow determine the size of fans, motors, coils, air filters and ductwork. Figure 1 below shows a schematic of a typical air handling unit.

System Pressurization

Supply fans convert rotational kinetic energy from a motor to a combination of static pressure and velocity pressure in a duct system. Total fan pressure is the sum of static pressure and velocity pressure. Fans can be classified by either of the two types listed below.

- Axial Fan-air flows parallel to the fan shaft through the fan
- Centrifugal Fan-air flows radially through the fan wheel

Static pressure is a measure of the amount of potential energy (potential flow) within a ventilation system. It is measured in inches of water gauge either above or below atmospheric pressure.³ Conversely, velocity pressure is a measure of the airflow (kinetic

² In a constant volume system, if system pressure was decreased, air volume would increase resulting in greater power consumption by the motor. The fan would have to be resheaved to keep airflow and power baselined.

³ One pound per square inch equals 2.703 inches of water.

energy) within a ventilation system. It is also measured in inches of water gauge above atmospheric pressure. In real air systems, there is always a combination of static and velocity pressure throughout the duct network. By adding the magnitudes of static and velocity pressure anywhere in the system, total system pressure (total energy content of the air stream) is obtained.

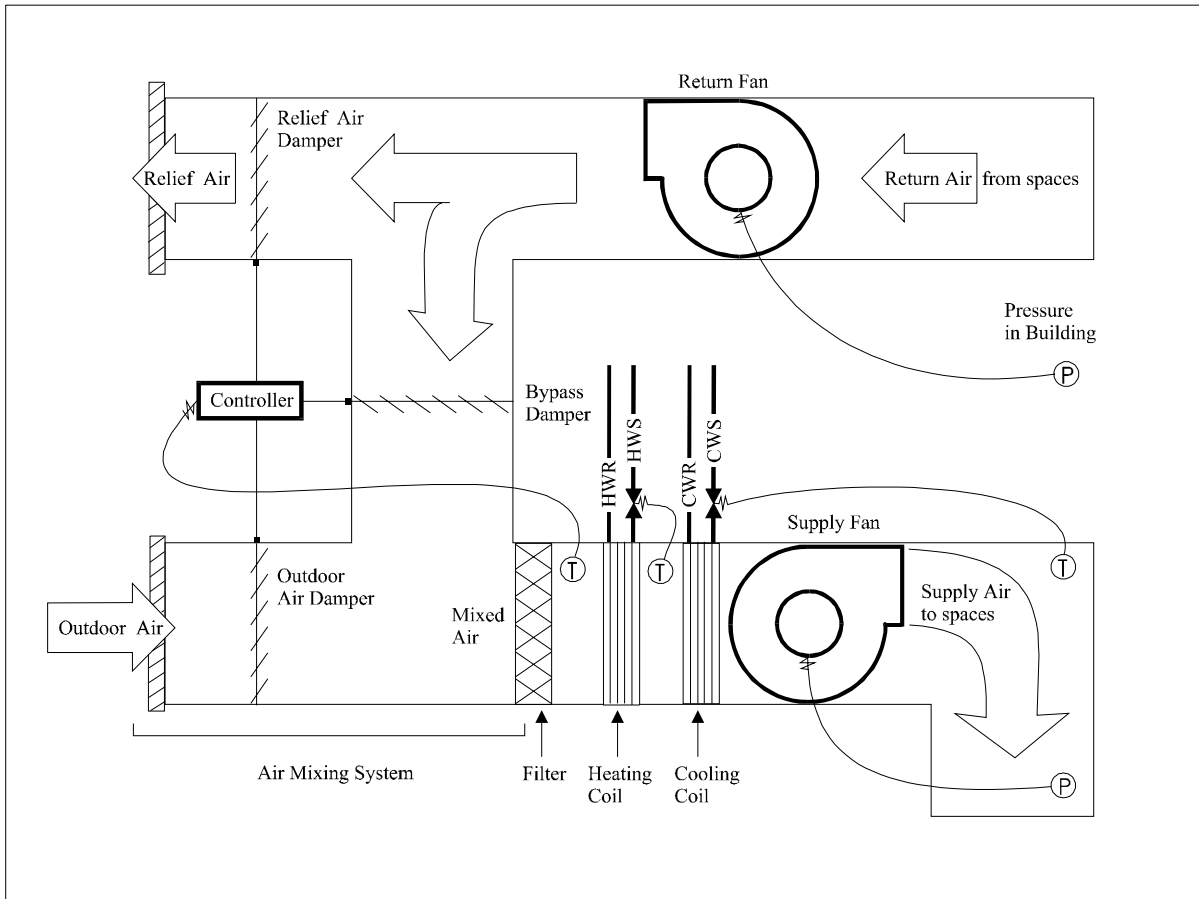


Figure 1. Ventilation System Schematic

System Curves and Fan Curves

Each component in a ventilation system exhibits a pressure drop as air is moved across it. The sum of all these pressure drops (including friction losses and ductwork pressure drops) make up the total pressure that must be supplied by the fan. For any fixed system, the relationship between airflow and system pressure is a quadratic relationship as presented in equation 1.

$$P_{New} = P_{Old} \times (Flow_{New}/Flow_{Old})^2 \quad (\text{Equation 1})$$

Where

P_{New} = the new static pressure requirement in consistent units

P_{Old} = the original static pressure requirement in consistent units

$Flow_{New}$ = the new flow rate in consistent units
 $Flow_{Old}$ = the original flow rate in consistent units

If you reduce the air flow by a factor of one half, the pressure required to produce that air flow in the system will only be one quarter of what was required at full air flow. If you plot the results of this equation, the resulting parabola is called a system curve. Any change to the system (moving a balance damper, a VAV terminal throttling, a filter loading, etc.) will change this flow to pressure drop relation ship and therefore will change the system curve for the system. System curves, when combined with other information such as the cooling requirements for a space answer the questions, “how much air does the space require and how much pressure will the fan need to produce to deliver this air in a given system?”

Conversely, fan curves answer the question, “how much air can the system provide.” All fans are tested in an apparatus similar to the one depicted in Figure 2 below. Fans are tested from blocked tight static pressure (BTSP) to wide-open flow (WOCFM) at different fan speeds. This is accomplished by blocking the duct with a throttling device and measuring pressure and horsepower consumption, which establishes the Blocked Tight Static Pressure point (BTSP), then moving the throttling device away from the duct exit in a series of iterations while continuing to measure pressure and horsepower. This is continued until the throttling device is removed from the test duct, which establishes the Wide Open Cubic Feet Per Minute point (WOCFM). When fan tests are completed, fan performance curves are generated.

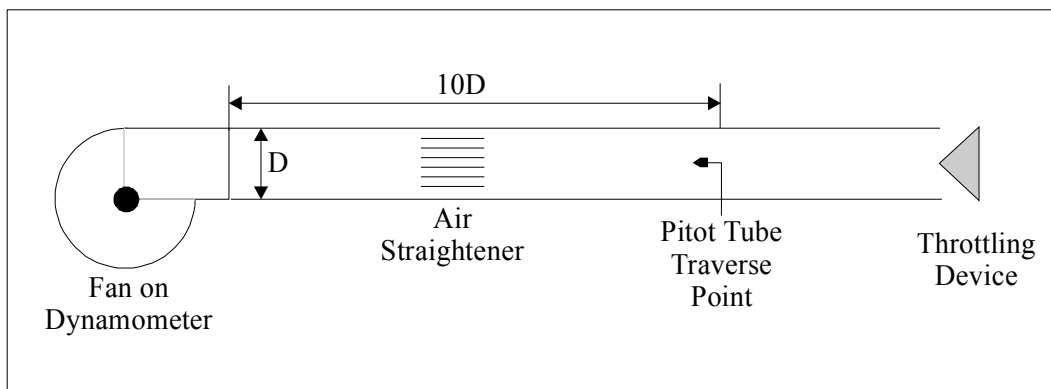


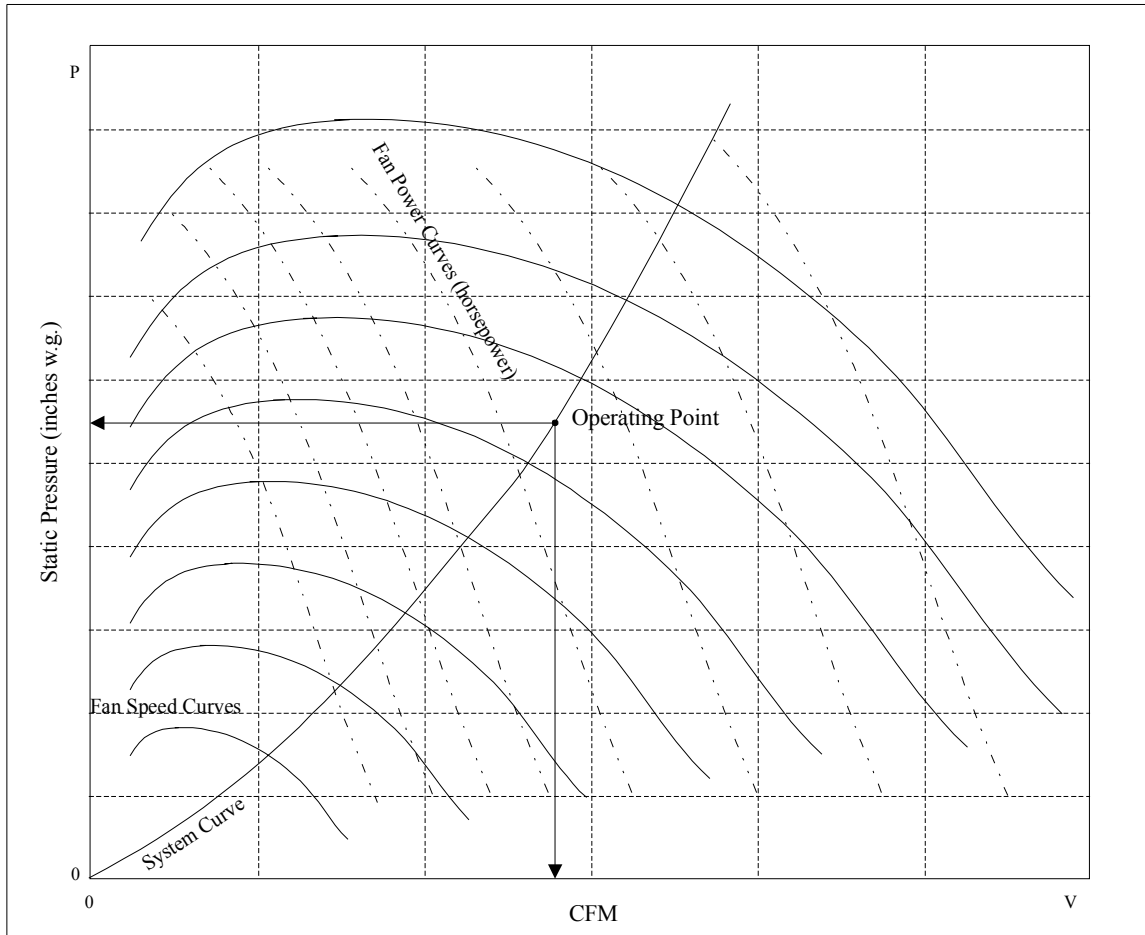
Figure 2. Fan Test Stand

Operating Point

Superimposing the fan curves onto the system resistance curve yields the *operating point*. In practice, to determine where the system curve intersects the fan curve, one must accurately determine the total airflow of the fan with a Pitot-tube traverse, a flow hood, or an anemometer, and the speed of the fan with a stroboscope or tachometer. Where the airflow intersects with the fan speed, the operating point exists. The operating point determines the required motor horsepower for the system. If the system characteristics change, then the system curve will change. This will shift the operating point on the fan curve and the motor horsepower could also change. Figure 3 shows a sample family of fan performance curves with a system curve and depicts an example of an operating point.

The operating point is not constant. It changes as the pressure characteristics of the system change. For example, on a hot and humid day the cooling coil would be wetted because the coil would be condensing moisture as it cools the supply air. The pressure drop across the coil would increase and the system characteristics would change. This is known as “riding the fan curve.” This same phenomenon occurs as filters capture contaminants from the air. Most real fan systems actually operate on a family of system curves that are related to the variations in system pressure requirements associated with these operational changes.

Figure 3. Fan Curves Showing Operating Point



Air Filtration

The role of air filters is to protect occupants and equipment from contamination introduced from the outside air or generated within the space. There are many types of air filters but the most common types are impingement filters and extended surface filters.

Impingement filters are usually used as prefilters in an air filter system. In some cases (e.g. some packaged rooftop units), impingement filters may be the only air filters in the system. Categories of impingement filters are panel filters (e.g. spun-fiberglass or synthetic material in cardboard frame), roll filters and washable metal filters. The ASHRAE efficiencies of these air filters are less than 20 percent. Impingement air filters are relatively

inexpensive and have an average useful life of 30 to 90 days depending mainly on the outdoor environment (Avery, Et al 1996).

Extended surface filters are used where increased capture efficiencies are needed. They include filters made of mat-type media (fiberglass or synthetic materials) or paper media (Avery, et al. 1996). Examples of mat-type filters include pleats, cubes, bag filters and rigid cell filters. Paper media filters are typically pleated-type filters with corrugated separators or close-pleated filter designs. ASHRAE efficiencies of extended surface filters range from 30 to 98 percent. Extended surface filters are more costly than their prefilter equivalents, however, their life is typically four to six times that of a prefilter.

Building owners/managers who use extended surface air filters in their air handling units usually place an impingement filter upstream to protect the more expensive final filter. In these instances, the prefilters are used to extend the life of the higher efficiency final filters. Prefilters capture coarse dusts and allow the final filter to be exposed to smaller concentrations of finer dusts. The lives of prefilters and final filters are typically determined by comparing the measured static pressure drop across the air filters at rated airflow,⁴ to a variety of standards. Some of these standards include pressure drops selected by the design engineer who specified the equipment, air filter manufacturers' recommended final pressure drop or final pressure drops determined by field experience. Typically, the manufacturers recommended final pressure drops are related to the structural capacity of the filter; i.e. how much pressure drop can the filter handle before either the framing begins to fail or the media begins to blow through. Final filter pressure drops specified by designers often take the overall capabilities of the air handling system into account in addition to the manufacturers recommendations. Often, the designers criteria is not well documented and the facilities engineers and operators find themselves juggling the various parameters in an effort to minimize system energy costs while maximizing filter life and maintaining indoor air quality.

Some air filter manufacturers are marketing high efficiency extended surface air filters under the trade names LUWA, Viledon and Optiflow that exhibit extremely low initial static pressure drops. They claim these premium filters will last two to three times longer than typical air filters and will supply the lowest initial static pressure drop in the industry. If true, the life cycle costs⁵ of these air filters would be lower than typical extended surface air filter types. Use of these filters would also make the air handling process in a facility more sustainable due to the reduction in size of the filter resource and waste stream.

Air Filter Efficiency

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has created a standard for measuring the efficiency and arresstance of air filters.⁶ Air filter manufacturers are allowed to advertise "ASHRAE" efficiencies if they have had their air filters tested in an ASHRAE air filter test duct in accordance with the testing procedures outlined in ASHRAE 52.1-1992. ASHRAE allows the nomenclature "less than

⁴ Typically 400-500 feet per minute.

⁵ Including first cost, maintenance costs, disposal costs and cost of moving the air through the filter.

⁶ Standard 52.1-1992, where efficiency refers to the ASHRAE Average Dust Spot Efficiency.

20 percent ASHRAE efficiency” to be used for any untested filter. This reference is usually used for prefilters.

While Standard 52.1 deals with average efficiencies, the next generation of air filter testing, Standard 52.2, will address fractional efficiency tests where air filters will be tested over a spectrum of particle sizes. This information will dramatically increase the comparative nature of air filter specifications.

Even the most efficient air filter is suspect in a system with a poorly maintained air filter housing. The integrity of the air filter housing is as important as the selection of the air filters themselves since air always follows the path of least resistance. It is impossible to maintain good indoor air quality with a poorly designed or poorly maintained set of air filter frames. In addition, it is very likely the air filters will not perform at the level identified in their respective testing report.

Case Study

Since air filters are maintenance items and must be replaced periodically (eliminating them is not an option), there is a potential to save fan energy by replacing existing air filters with high efficiency, low initial static pressure drop air filters. The purpose of this case study⁷ was to validate energy savings professed by air filter manufacturers and provide life cycle economic analyses concerning the use of these high efficiency, low static pressure drop air filters by commercial and institutional end users. The case study was conducted at a commercial building in Hoffman Estates, Illinois that had variable air volume fan systems.

The air filters used for comparative purposes in this study are listed in Table 1 below, which contains all pertinent air filter performance data. These filters were selected by the end user and were not exclusive to the market. The Viledon air filter represents a final bag-type air filter exhibiting uniquely low initial static pressure drop. This is considered a high-end product with unit costs equal to 2 to 4 times that of a typical bag-type air filter.

The Quality air filters represent a generic (standard) final bag-type air filter whose construction is typical of several other U.S. manufacturers. They are considered representative bag-type air filter products (Hardt 1998).

VAV System Description

The building’s air handling systems, labeled AHU-1 and AHU-2, were located on the fifth floor of the building. These units supplied 100 percent of the heating and cooling to the building. The fan systems operate on this typical office building occupancy:

Monday-Friday:	6:00 am to 7:00 pm
Saturday:	7:00 am to 3:00 pm
Sunday:	As needed for limited scheduled occupancy.

⁷ Funded by the Illinois Department of Commerce and Community Affairs (DCCA) Bureau of Energy and Recycling

AHU-1 and AHU-2 contained one Joy Series 1000 Axivane Fan Model 48-26-1770 driven by a Reliance 125hp motor. Each AHU served half the building and had a two-stage filtration system. The prefilters used in the study were 40-24x24 inch 3-ply polyester panel air filters. These were graduated density polyester filters sewn around a wire ring with an estimated Average ASHRAE Dust Spot Efficiency of 25-30%. Identical prefilters were used if both air handling units.

Table 1. Case Study Air Filter Specifications

Trade name	Viledon	Quality
Air Filter Model	T60	65% Average ASHRAE Dust Spot Efficiency Bag
Air Filter Size	24x24x26 8 pocket	24x24x15 12 pocket bag
ASHRAE Dust Spot Efficiency	60%	65%
Initial Fractional Efficiency	98% on 2 micron particles	Not Available
Initial Pressure Loss at 2000 CFM (in. w.g.)	0.18	0.30
Benefits	<ul style="list-style-type: none"> • Immediate High Efficiency • Non-Shedding Media • High Particulate Retention • Moisture Resistant • Structural Integrity • Particle Retention During Filter Change • 100% Synthetic Material • Long Service Life • Will Not Leak up to 2.4 in. w.g. 	<ul style="list-style-type: none"> • Non-Shedding Media • Moisture Resistant • Inexpensive to produce • 100% Synthetic Material
Disadvantages	<ul style="list-style-type: none"> • Expensive First Cost 	<ul style="list-style-type: none"> • Prone to Racking • Prone to Leaking • Bag/Frame Separation
Manufacturer	Viledon (USA)	Quality Filters, Inc. (USA)

Downstream of the prefilters in AHU-1 were 40-24x24x15 inch, 12-pocket 65% air filters manufactured by Quality Filters, Inc. of Robertsdale, Alabama. Downstream of the prefilters in AHU-2 were 40-24x24x22 inch T60 air filters manufactured by Viledon Air Filtration Division, Chelmsford, Massachusetts. Both AHUs were balanced prior to the case study with pertinent data listed in Table 2. Airflows and motor horsepower were verified prior to the start of the study and compared with data from the test and balance reports.

Table 2. AHU-1 and AHU-2 Fan and Motor Data

Fan Manufacturer	Joy
Model No.	48-26-1770
Motor Manufacturer	Reliance
Motor Horsepower	125
Supply CFM	70,000
Total Fan Static Pressure (TFSP)	6.5 inches
Motor RPM	1780
Motor Draw (kW)	69 kW

Theoretical Predictions

The manufacturers of the Viledon air filters predicted a filter life of at least two times that of typical air filters in any given application (Fries 1998). Based on that assumption, the following equation was derived that predicts the theoretical electrical savings between two identical fan systems containing different air filters.

$$kW = \frac{CFM * (SP_t - SP_p)}{8520 * SE} \quad (\text{Equation 2})$$

Where:

kW = reduced electric demand (kilowatts)

CFM = volumetric airflow in cubic feet per minute

SP_p = average pressure drop across the premium air filter over the air filter's life

SP_t = average pressure drop across the typical air filter over the air filter's life

8520 = conversion constant

SE = system efficiency (motor efficiency * fan efficiency * drive efficiency)

The motor and fan efficiencies were assumed to be 80 percent, while the drive efficiency was 100 percent (direct drive). Table 3 below demonstrates the theoretical savings by using the Viledon air filters over a two-year timeframe accounting for energy to move the air through the air filter exclusively. The Quality air filters were expected to last one year based on past air filter longevity at the building (Cowgill 1998).

Though Equation 2 can be used to predict energy savings in any fan system, it may overestimate predicted savings in VAV systems, since it assumes a constant load profile. In reality, the total savings should account for hourly variances in fan capacity and static pressure drop across the filters. This theoretical information was not available during this case study; therefore the simplified model was used.

Field Measurements

Power consumed by the supply fan motors was monitored for 40 weeks starting on April 30, 1998. Power consumption was monitored on each AHU with Elite-4 Poly Phase

Power Loggers,⁸ using a time interval step of 10 minutes. The meters were connected to each fan’s motor control center and periodically downloaded to ensure data integrity. In addition, static pressure drop measurements across the air filters were monitored periodically to document the pressure drop rise of the air filters as a function of time. Pressure drop readings were taken with a digital manometer⁹. All instrumentation was calibrated by the instruments’ manufacturers prior to the study.

Table 3. Predicted Energy Savings Using Viledon Air Filters (Fries, 1998)

Given: CFM=70,000 Electricity Cost-ComEd Rate 6T		Viledon	Quality
		Final Filter	Final Filter
	Units	T60	12P 65% Bag
Operating Life	months	24	12
No. of Replacements	n/a	1	2
Number of Full Size Filters	n/a	40	80
Initial Static Pressure Drop	("w.g.)	0.17	0.4
Final Static Pressure Drop	("w.g.)	1	1.25
Average Static Pressure Drop	("w.g.)	0.59	0.83
Total Fan Operation Time	hours	7,091	7,091
Average Power Consumption	kW	7.51	10.59
Total Energy Use	kwh	53,255	75,104
Energy Cost	\$	\$2,187	\$3,084
Demand Cost	\$	\$1,096	\$1,546
Theoretical Savings:	Viledon	Quality	Savings
Total Energy Usage (kwh)	53,255	75,104	21,848
Total Energy Cost	\$3,283	\$4,630	\$1,347
Total Filter Cost	\$4,240	\$3,160	-\$1,080
Total Dollar Savings			\$267
IRR (2 year)			8.1%

In addition to the instrumentation, the building’s DDC controller was programmed to monitor the positions of the inlet vane dampers and supply static pressure for both fans. This was conducted to verify that each fan had approximately 50 percent of the building load and to validate the power readings by comparing them to inlet vane damper position.

Data Analysis

The power data was analyzed for load trends, peak demand and total power consumption. The shapes of the power curves for both fans were similar, however, the total electric consumption of AHU2 (the Viledon system) was approximately 21percent lower than that of AHU1 (the Quality system). The cyclic nature of the power draw was due predominantly to weather fluctuations and load variations within the building. Peak ventilation loads varied with the seasons. The metering equipment also verified that the fans were off during the weekends and holidays. As expected, the inlet vane damper position was shown to be directly proportional to motor draw. The data summary is presented in Table 3.

⁸ Manufactured by Pacific Science and Technology, Bend Oregon.

⁹ ALNOR Micromanometer 530

Table 3. Results of Data Analyses

	AHU-1 (Quality filters)	AHU-2 (Viledon filters)
Maximum Power (kW)	74.1	67.2
Minimum Power (kW)	0.0	0.0
Average Power (kW)	21.6	17.1
Standard Deviation (kW)	20.6	22.3
Electric Use (kWh)	60,487	47,884

During the study, AHU-1 used 12,603 more kWh than AHU-2. Normalizing the data for 24 months would yield an estimated electricity savings of 32,768 kWh. Using electric use rate data from ComEd (the local electric utility), the expected savings would be \$1,345.¹⁰ Assuming the Quality air filters and other similar air filters would last only one year as claimed in the theoretical predictions, the purchase of Viledon air filters would yield a simple payback of approximately 10 months. A more conservative model would be to assume the Quality air filters would last as long as the Viledon air filters. The simple payback of this investment would be 2.0 years. In either case, the purchase of Viledon air filters seems appropriate in this application.

The static pressure drop across the filters was also monitored to determine how the pressure relationship changes as a function of time. It was not possible to isolate the pressure drop across the prefilters and final filter; therefore, the measurements represented a total air filter system pressure drop. The relationship of filter loading versus time was nearly linear for both air filter types. Though most of the loading was on the prefilter, it was evident after changing the prefilter six months into the study that both final filters were capturing significant amounts of air contaminants. The air filter systems had a 50 percent difference in static pressure drop at the beginning of the study. This magnitude remained relatively constant throughout the case study.

Post Inspection of Air Filters

After approximately 40 weeks of service, one Viledon and one Quality air filter were removed and inspected to determine any significant performance-related issues. The media in the Quality air filter did not load evenly as indicated by its inconsistent coloring throughout the depth of the filter. When a filter does not load evenly, building owners and managers do not receive a good value for their investment.

Many of the stitch holes of the Quality air filter were not covered with glue. Perhaps this is a manufacturing quality control issue. Large channels remain open for particles to pass through the media and contaminate occupied areas. The value of this product is suspect considering the filter should be designed for virtually 100% particle retainment. In addition, because of the holes in the filter, it would likely never reach its recommended final pressure drop. This is problematic for maintenance programs relying on this information for air filter change intervals.

Conversely, the Viledon filters loaded evenly as demonstrated by the consistent color of the air filter pockets throughout their depth. The Viledon air filter was specifically

¹⁰ Demand savings were considered insignificant and therefore not included in the analysis.

designed with self-supporting pockets that keep them open in varying airflows. Perhaps this characteristic allows for the decreased initial static pressure drop. The Viledon bags are heat-sealed at the ends of the pockets ensuring 100 percent particle retainment. In addition, the fronts of the bag pockets are molded into the polyurethane header for added filter integrity.

Conclusions

Physical laws that govern pumping fluids (including the fan laws) predict some savings in ventilation systems by reducing the total pressure within the system. In this study, premium air filters with dramatically lower initial static pressure drops were compared to standard air filters with typically higher initial static pressure drops. The cost of the Viledon bag-type air filter was 2.7 times the cost of the Quality air filter. The manufacturers of premium bag-type air filters purport the incremental filter cost can be recovered with the subsequent savings in electric costs due to the lower average pressure drop of the filters. In theory, this is irrefutable.

The case study of a VAV system demonstrated both air handlers had similar demand consumption curves, however the energy consumption of AHU2 was approximately 21 percent less than AHU1 when the power meter data was compared. VAV systems are inherently self-regulating as static pressure fluctuates in the supply system. The static pressure drop of the Viledon filter was clearly lower than the Quality filter. A two-year payback was demonstrated for the retrofit of one AHU with the Viledon air filters. Though this is a very respectable payback, it did not include benefits of reduced installation and disposal costs and other ancillary benefits that would reduce the payback to less than two-years.

Based on this case study, the Viledon air filter is a good investment for VAV systems. In addition, building managers could upgrade their filter system's ASHRAE efficiency by using a premium air filter. Finally, the economic viability of this type of investment was proven on a building where the variable air volume AHUs operated approximately 10 hours/day. Buildings with variable air volume AHUs that operate at least 16 hours/day¹¹ will find this investment extremely desirable.

Epilogue

Last year the host of the case study replaced the Quality air filters in AHU-1 with Viledon T60 air filters. The air filters in AHU-2 have been in use nearly two years. During the last prefilter change, the static pressure drop was measured across the Viledon air filters. The reading was approximately 0.7 inches of water. The engineer anticipates using the original filters another year (Cowgill 1999). If he does and if all the other variables remain constant, the effective simple payback of the investment becomes 1.5 years.

This study considered energy and air filter cost exclusively. The other benefits to using premium air filters instead of typical air filters were not considered, however, advocates of improved indoor air quality would clearly benefit from their use.

Recommendations for supplemental studies include:

¹¹ E.g. hospitals, manufacturing facilities, etc.

- Benefits of using premium air filters in constant-velocity fan systems
- Comparing fractional efficiencies of premium and typical air filters in the field
- Exploring the relationship of decreasing system pressure and its effect on system efficiency
- Determining the effect of eliminating prefilters on the life of final filters, on the energy consumption of the system, and on the over-all life cycle cost for the filter system when energy costs, filter costs and disposal costs are all taken into account.
- Explore the relationship between filter dust load, pressure drop, and time at constant flow rates for different filter types.

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