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 begun target 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 principles 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 with cleanliness and ventilation requirements determining the number and type of air filters needed. Since air filters capture particulates, their life is finite and they must be replaced periodically. The air filter's useful life depends on it's type and size as well as the installed environment. The maintenance costs associated with the purchase, installation and disposal of air filters are generally fixed. Unfortunately, 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.

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[1] When compared to earlier air filter manufacturing practices.

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 over the filter life.

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 as either an *axial fan*, where air flows parallel to the fan shaft, or a *centrifugal fan*, where air flows radially through the fan wheel.

Static pressure is a measure of the amount of potential energy (potential flow) within a ventilation system. Conversely, velocity pressure is a measure of the airflow (kinetic energy) within a ventilation system. They are measured in inches of water gauge either above or below atmospheric pressure.[3] Total system pressure is obtained by adding the magnitudes of static and velocity pressure anywhere in the ventilation system.

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[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 27.7 inches of water.

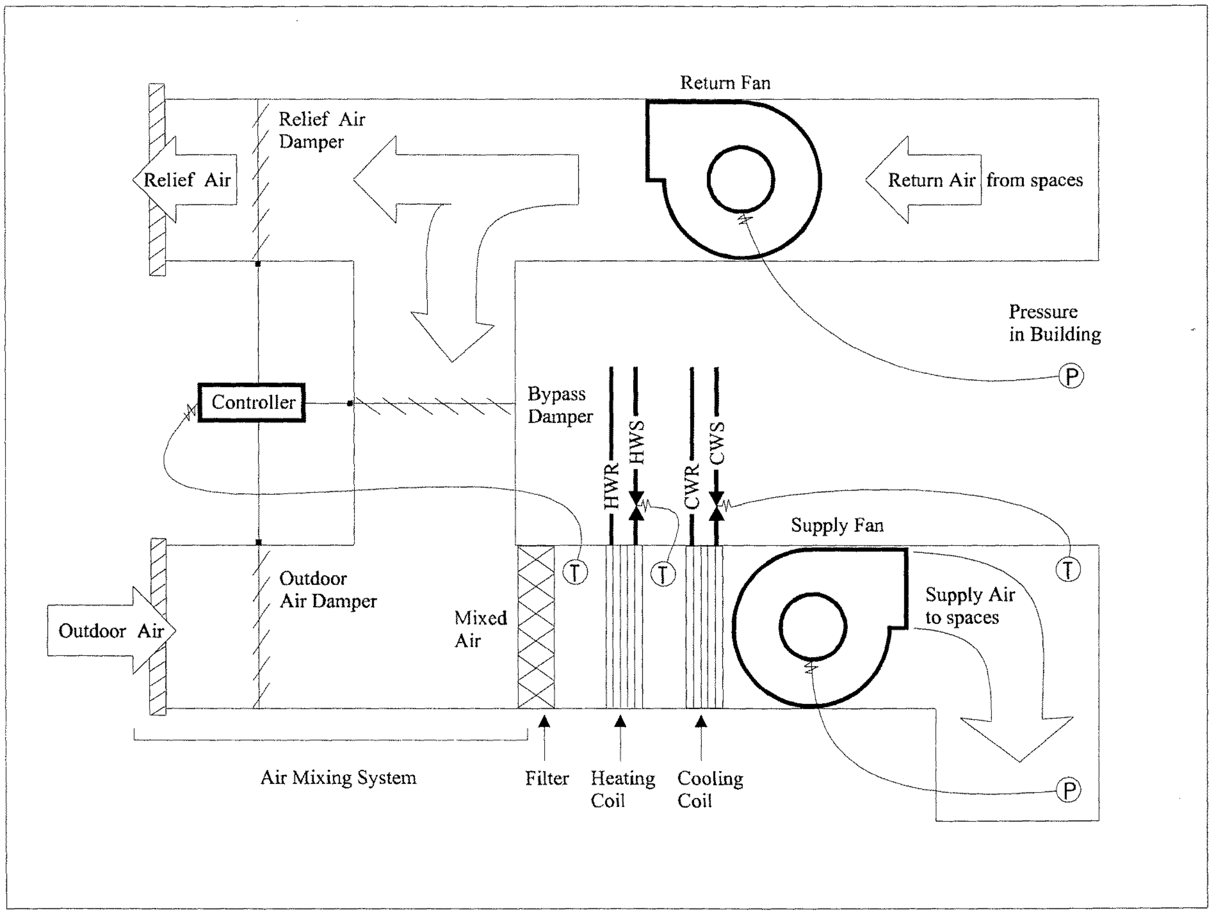

Figure 1. Ventilation System Schematic

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 follows a quadratic relationship as presented in equation 1.

$P = k * Q^2$ Equation 1

Where
P = system pressure (inches of water)
k = constant based on measured airflow and pressure
Q = system flow (cubic feet per minute)

If you reduce the air flow by a factor of one half, the pressure required to produce that airflow in the system will be one quarter of what was required at full airflow. If you plot the results of this equation, the resulting parabola is called a system characteristic curve. Any change to the system (moving a balance damper, VAV terminal throttling, filter loading, etc.) will change this flow to pressure drop relationship and therefore will change the system curve. 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 Cubic Feet Per Minute (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 BTSP point, 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 WOCFM point. When fan tests are completed, fan performance curves are generated.

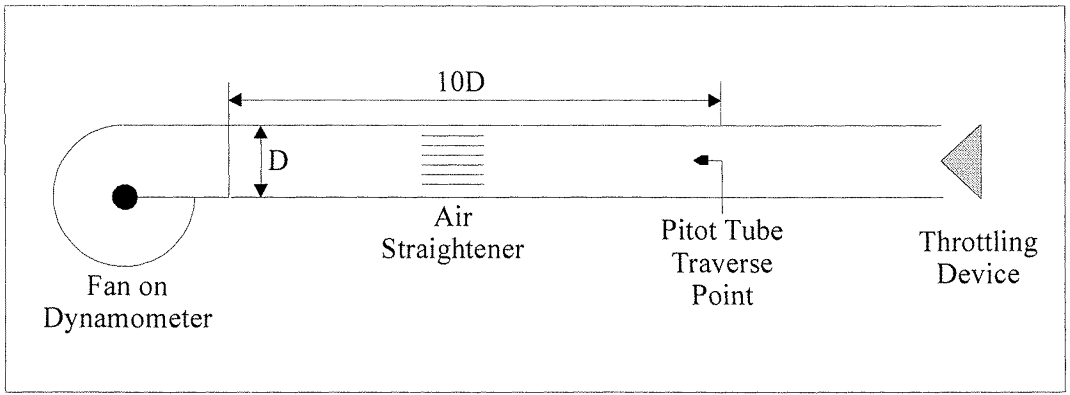

Figure 2. Fan Test Stand

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, exists the operating point. The operating point determines the required motor horsepower for the system. 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/flow characteristics of the system change. For example, on a hot and humid day the cooling coil would be wetted as the coil condenses moisture out of the supply air. The pressure drop across the coil would increase and the system characteristic curve and operating point 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.

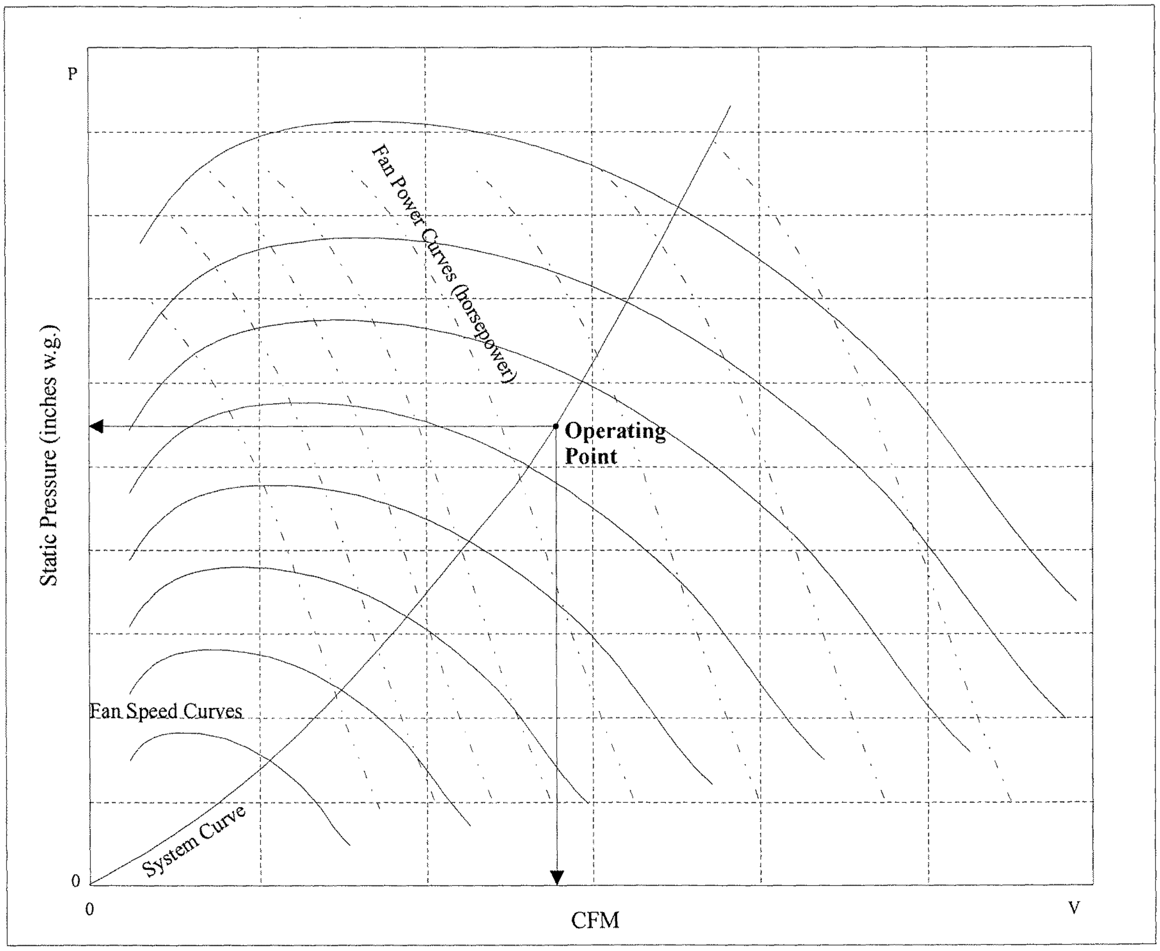

Figure 3. Fan Curves Showing Operating Point

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 used. Categories of impingement filters are panel filters (e.g. spun-fiberglass or synthetic material in cardboard frame), roll filters and washable metal filters. The American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) efficiencies of these air filters are classified as less than 20 percent[4]. 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 particle 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

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[4] See ASHRAE Standard 52.1-1992 *Gravimetric and Dust-Spot Procedures for Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter.*

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 prefilters, however, their life is typically four to ten 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,[5] to a variety of standards. Some of these standards include pressure drops selected by the design engineer who specified the equipment, air filter manufacturers' or final pressure drops determined by field experience. Typically, the manufacturer recommended final pressure drops are related to the structural capacity of the filter, while designers often take the over-all capabilities of the air handling system into account in addition to the manufacturers recommendations. The facilities engineers try to maintain good indoor air quality yet are often pressured to extend filter life so air filter budgets can be minimized.

Some air filter manufacturers are marketing high efficiency extended surface air filters under the trade names LUWA, Viledon, Optiflow, American Air Filter and others 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 costs[6] of these air filters could be lower than typical extended surface air filter types. Use of these filters could also make the air handling equipment in a facility more sustainable due to the reduction in size of the filter resource and waste stream.

Air Filter Efficiency

Historically, the ASHRAE standard for measuring the efficiency and arrestance of air filters has been ASHRAE 52.1.[7] 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 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 52.2-1999, addresses fractional efficiency tests where air filters are tested over a spectrum of particle sizes. This standard is new, however, it will dramatically increase the comparative nature of air filter specifications once it is implemented throughout the air filtration market.

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

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[5] Typically 400-500 feet per minute.

[6] Including first cost, maintenance costs, disposal costs and cost of moving the air through the filter.

[7] Efficiency refers to the ASHRAE Average Dust Spot Efficiency.

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 (premium filters). The purpose of this case study[8] was to validate energy savings professed by air filter manufacturers and provide life cycle economic analyses concerning the use of premium air filters by commercial and institutional end users. This case study was conducted at a commercial building in Hoffman Estates, Illinois that had two 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 two to four 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 required by the building. The fan systems operated on the following schedule:

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

AHU-1 and AHU-2 contained one Joy Series 1000 Axivane Fan Model 48-26-1770 driven by a Reliance 125hp motor. Each AHU supplied 70,000 CFM against 6.5 inches of static pressure (design) to their 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 in both air-handling units.

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

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[8] Funded by the Illinois Department of Commerce and Community Affairs (DCCA) Bureau of Energy and Recycling.

Filtration Division, Chelmsford, Massachusetts. Both AHUs were balanced prior to the case study. Airflows and motor horsepower were verified prior to the start of the study and compared with data from the test and balance reports.

Table 1. Case Study Air Filter Specifications

Trade name/Manufacturer	Viledon/ Viledon (USA)	Quality/Quality Filters, Inc. (USA)
Air Filter Model	T60	65% ASHRAE Dust Spot Efficiency
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 Cost ($)	$106	$39.50
Average Life (months)	24	12
Initial Pressure drop at 2000 CFM (in. w.g.)	0.18	0.40
Benefits	• Immediate High Efficiency • Non-Shedding Media • High Particulate Retention • Moisture Resistant • Structural Integrity • Particle Retention • 100% Synthetic Material • Long Service Life • Will Not Leak up to 2.4 in. w.g.	• Non-Shedding Media • Moisture Resistant • Inexpensive to produce • 100% Synthetic Material
Disadvantages	• Expensive First Cost	• Prone to Racking • Prone to Leaking • Bag/Frame Separation

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 demand 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 estimated at 80 percent,[9] while the drive efficiency was 100 percent (direct drive). Table 2 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).

Table 2. Predicted Energy Savings Using Viledon Air Filters (Fries, 1998)[10]

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

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 information was not available during this case study; therefore, the simplified model was used.

Field Measurements

Power consumed by the supply fan motors was continuously monitored for 40 weeks starting on April 30, 1998. Power consumption was monitored on each AHU with Elite-4 Poly Phase Power Loggers,[11] 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 rise in pressure drop rise of the air filters as a function of time.

[9] From motor nameplate and fan curve information.

[10] Rate 6T charges are: $14.24/kW (summer), $11.13/kW (winter), $0.05599/kWh peak time (9:00 a.m. to 10:00 p.m. M-F) and $0.02341 off-peak time (all remaining hours).

[11] Manufactured by Pacific Science and Technology, Bend Oregon.

Pressure drop readings were taken with a digital manometer[12]. All instrumentation were calibrated by the instruments' manufacturers prior to the study.

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 21 percent 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 proportional to motor draw. The data summary is presented in Table 3.

Table 3. Results of Data Analyses (40 Week Duration)

	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 over this time would be $1,345.[13] If the Quality air filter life was 12 months, the simple payback on the investment for the Viledon air filters would be 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

[12] ALNOR Micromanometer 530

[13] Demand savings were not considered but would decrease the overall payback.

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 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 (including the fan laws) predict some savings in ventilation systems by reducing the total pressure within the system. In this study, premium air filters (Viledon) were compared to standard air filters (Quality) with typically higher initial static pressure drops. The cost of the Viledon 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 curves with the energy consumption of AHU2 (Viledon) approximately 21 percent less than AHU1 (Quality). The static pressure drop of AHU2 was clearly lower than AHU1 resulting in a 10-month to two-year payback for the retrofit of one AHU with the Viledon air filters. Though this is a very respectable payback range, it did not include benefits of reduced installation and disposal costs and other ancillary benefits that could reduce the payback even further. 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/day could find this investment extremely desirable.

Reducing burden on our power plants by increasing energy efficiency in commercial buildings is beneficial to the environment. In addition, reducing waste streams by reducing air filter use could help ease the burden on already over-taxed landfills throughout the U.S.

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 Viledon filters another year (Cowgill 1999).

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:

- 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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