



Commercial HVAC Filters

Total Cost of Ownership Tool from 3M

Restricted budgets challenge facility owners and operators to seek solutions that help save energy and reduce operating costs, while maintaining appropriate indoor air quality.

Evaluation of HVAC filters should include a comparison of total cost of ownership to have the largest impact on reducing total cost, while maintaining indoor air quality. The initial filter purchase cost can be as low as 7% of the total operating cost for HVAC air filtration¹. Supply and return fans consume approximately 5% of all energy used in US commercial buildings.^{1,2} Utilizing HVAC air filters that have a low pressure drop over their life, can have a meaningful impact on this energy consumption. In addition, HVAC filters that last longer can be replaced less frequently, thereby reducing disposal and shipping costs, and potentially, saving labor and / or service costs.

Filtrete™ Commercial HVAC Filters from 3M have low total ownership and operating cost and can, therefore, potentially reduce the total ownership and operating cost for the building. The Total Cost of Ownership (TCO) tool from 3M was developed to compare various commercial HVAC filters with the Filtrete Commercial HVAC filter solutions and to quantify the TCO savings when using Filtrete Commercial HVAC filters.

There are five components of the total cost of ownership for HVAC filters:

- 1) cost to purchase the filters,
- 2) cost of the associated energy use,
- 3) cost of labor for installation and replacement,
- 4) cost of disposal and
- 5) cost of shipping filters to the facility.

In certain HVAC systems, the cost for the energy required to move air through the filters is often the greatest component of total operating cost. This energy cost is proportional to the average pressure drop of the filter over the time period assessed. The difference in energy cost of two different filter systems is proportional to differences in their respective average pressure drops.

There are several scenarios where tremendous reduction in energy may be achieved by using Filtrete Commercial HVAC filters:

- 1) when replacing filters with higher pressure drop,
- 2) when replacing filters which do not maintain low pressure drop over time and
- 3) when replacing a pre- and primary filter combination, wherein the combined pressure drop is much higher.

As an added benefit, the reduction in energy use from lower pressure drop filters results in a reduction of CO₂ emissions from power plants. The conversion of energy to CO₂ reduction is based on the Environmental Protection Agency's (EPA) Greenhouse Gas Equivalencies Calculator. The conversion is 6.9x10⁻⁴ metric tons CO₂ / kWh. This conversion can be found on the EPA website: <http://www.epa.gov/cleanenergy/energy-resources/refs.html>.

The cost associated with the labor of taking used HVAC filters out of the air handling unit (AHU), installing new filters, ensuring sealing of the individual filters to minimize air by-pass, and transporting the used filters to the disposal site, are referred to as labor cost. Filtrete Commercial HVAC Filters, which are often smaller and lighter than competitive products of the same efficiency, have integral gaskets that eliminate the need for a separate sealing step, and may last longer than alternative competitive products. In total, these factors may result in lower labor cost as a component of the total cost of ownership of the HVAC filters for the customer.

The cost of filter disposal is influenced by many factors including volume, weight, and metal content. Filtrete Commercial HVAC Filters from 3M are often smaller and lighter than competitive deep pleat, pocket, or box HVAC filters. Filtrete Commercial HVAC filters are 100% synthetic, hence, may often be incinerated, depending on federal, state, and local regulations.

The cost of shipping filters is partially determined by the key factors of filter volume and change-out frequency. Filtrete Commercial HVAC Filters provide an excellent combination of small size and long filter life.

The TCO tool from 3M analyzes each of the above components and projects costs over a defined assessment period, most often one year. The tool is based on published engineering principles and guidelines, product performance, and significant customer input about the specific building being analyzed. The tool contains two forms. The "Customer Information" form, that captures all required details of the facility, representative AHU and filter attributes for competitive filters and the 3M solution. The "Summary of Results" form contains projected annual TCO savings per filter, per AHU and for the entire building. Figure 1 and 2 show these two forms respectively.

HVAC Total Cost of Ownership Estimate Prepared for Account Name Here Date: Enter Here Page 1 of 2: Customer Information			
Customer Information		Air Handling Unit Information	
Name	Account Name Here Account Name (Line 2) 1111 Freedom Drive Dallas, TX 78866	Name	Supply Fan 1
Address		Location	Basement
Contact name	Joe Smith 651-789-5485	Configuration	VAV
Phone		Area(s) Served	
e-mail	jsmith@account.com	Average Filter Airflow (CFM)	2000
Square Footage	200,000	Number of Filter Slots (24 x 24)	1
Cost of labor (\$ / hr)	\$50.00	Fan Hours (per year)	8760
Energy cost (\$ / kWh)	\$0.15		
HVAC Filter Comparison			
Pre-filter	Current Product	3M Solution	
Manufacturer / Model Number	Filter Option A Prefilter	none	
Efficiency	MERV8	none	
Dimensions	24" x 24" x 2"	24" x 24" x 2"	
Change-out frequency (per year)	4	1	
Initial dp "w.c. (1970 CFM)	0.27	none	
Est. Change-out dp "w.c. (1970 CFM)	0.54	none	
Filter Cost	\$5.00	none	
Disposal Cost	\$1.00	\$1.00	
Primary Filter	Current Product	3M Solution	
Manufacturer / Model Number	Filter Option A Primary Filter	Filter Option B	
Efficiency	MERV 12	0	
Dimensions	24" x 24" x 2"	24" x 24" x 2"	
Change-out frequency (per year)	1	1	
Initial dp "w.c. (1970 CFM)	0.47	0.37	
Est. Change-out dp "w.c. (1970 CFM)	1.41	1.11	
Filter Cost	\$60.00	\$60.00	
Disposal Cost	\$4.00	\$1.00	
Total Annual Cost of Ownership Estimate for Air Handling Unit			
Filter Cost	Current Product	3M Solution	
Annual Filter Cost	\$80	\$60	
Energy Cost			
Estimated Electricity Consumed kW-H	3691	1991	
Estimated Annual Energy Cost	\$554	\$299	
Labor Cost			
Pre-Filter Labor Hours per Change-out	0.2	0.2	
Final-Filter Labor Hours per Change-out	0.4	0.4	
Annual Labor Cost	\$60	\$20	
Disposal Cost			
Annual Disposal Cost	\$6	\$1	
Filter Shipping Cost			
Pre-Filter Cost / Change-out	\$0.00	\$0.00	
Final Filter Cost / Change-out	\$0.00	\$0.00	
Annual Shipping Cost	\$0	\$0	
Total Estimated Annual Cost of Ownership	\$702	\$388	
Send completed electronic form to 3M Purification Inc. laboratory (jsnyder@mnm.com).			
Total Cost of Ownership Tool from 3M © Version.0R1G			

Figure 1: Customer Information Page

HVAC Total Cost of Ownership Estimate Prepared for Account Name Here Date: Enter Here Page 2 of 2: Summary of results			
Cost (per Filter)		Cost (for Entire Building)	
	Current Product	3M Solution	
Annual Filter Cost	\$80.00	\$60.00	Building Square Footage: 200,000 / 200,000
Annual Energy Cost	\$554.88	\$299.63	Estimated # Filters: 100 / 100
Annual Labor Cost	\$60.00	\$20.00	Annual Filter Cost: \$9,000 / \$6,000
Annual Disposal Cost	\$6.00	\$1.00	Annual Energy Cost: \$55,968 / \$29,963
Annual Shipping Cost	\$0.00	\$0.00	Annual Labor Cost: \$6,000 / \$2,000
Estimated Annual TCO	\$701.88	\$379.63	Annual Disposal Cost: \$600 / \$100
Difference		\$322.04	Annual Shipping Cost: \$0 / \$0
Electricity Consumed kWh	3691	1991	Estimated Annual TCO: \$70,188 / \$37,963
Difference		1700	Difference
Annual CO2 released (metric tons)	2.8	1.4	Electricity Consumed kWh: 369 / 199
Difference		1.2	Difference
			Annual CO2 released (metric tons): 255 / 138
			Difference
			Return on investment (Year 3M Solution) (months): 2
Total Cost Comparison			
Total Energy Use			
Total CO2 Use			
Total Projected Annual Cost Savings for Entire Building			
Energy Cost Savings	\$25,504		
Labor Cost Savings	\$4,000		
Filter Cost Savings	\$2,000		
Disposal Cost Savings	\$700		
Shipping Cost Savings	\$0		
TOTAL COST SAVINGS PER YEAR	\$32,204		
Assumptions:			
<p>The projections calculated by the TCO tool from 3M are only as valid as the accuracy of the data entered. Data that has the biggest impact on calculations, and at the same time, is of highest uncertainty, includes:</p> <ol style="list-style-type: none"> 1) pressure drop of the filter when replaced, 2) the airflow used to calculate the TCO (must be the average for all filter slots for the building over the time period) and, 3) hours of operation for the air handling unit for the projection period. <p>Total Cost of Ownership projections are only valid for fan drives that do not have fixed speeds. Examples of systems with variable fan speed are Variable Air Volume systems or systems where the fan speed is adjusted through a Variable Speed Drive. The projection is NOT valid for Constant Fan Speed systems.</p> <p>The validity of a projection for the entire building is based on equivalency of all AHUs.</p> <p>The projection calculated by the TCO tool from 3M assumes a fan/motor/system efficiency of 0.65. For details supporting this assumption see the accompanying TCO Technical Sheet.</p>			
Send completed electronic form to 3M Purification Inc. laboratory (jsnyder@mnm.com).			
Total Cost of Ownership Tool from 3M © Version.0R1G			

Figure 2: Summary of Results Page

The TCO is modeled for a single representative AHU where the input airflow and pressure drop data is the average per filter slot. Utilizing the facility square footage, these results are then scaled to the entire facility. The costs are highly dependent on key input including: 1) filter characteristics, 2) filter change-out frequency, 3) annual average airflow rate per filter slot, 4) number of filters, and 5) utility and labor rates.

The projections calculated by the TCO tool from 3M are only as valid as the accuracy of the data entered. Data that has the biggest impact on calculations, and at the same time, is of highest uncertainty, includes:

- 1) pressure drop of the filter when replaced,
- 2) the airflow used to calculate the TCO (must be the average for all filter slots for the building over the time period) and,
- 3) hours of operation for the air handling unit for the projection period.

TCO projections are only valid for fan drives that do not have fixed speeds. Examples of systems with variable fan speed are Variable Air Volume systems or systems where the fan speed is adjusted through a Variable Speed Drive. The projection is NOT valid for Constant Fan Speed systems.

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Electronic copies of all completed TCO forms submitted to customers shall be provided to the 3M Purification Inc. Laboratory for review.

Example Total Cost of Ownership Prediction

The total cost of ownership (TCO) can vary significantly, depending on the changes in filter characteristics and AHU operating characteristics.

The following example will help illustrate this variation. Three filter options, A, B and C are described below and listed in Figure 3. The filter option A is a pleated pre-filter in combination with a rigid box primary filter. The filter options B and C are both single mini-pleat filters with no pre-filter. Option C is a filter with a pressure drop that increases at twice the rate as option B. These options are evaluated at four different scenarios and are described below in Figure 4. The yearly difference in hours of operation is the difference between operating 12 hours for five days per week or operating continuously. The two values for average flow per filter slot over the year is calculated. This difference in airflow would be the difference in operating the typical 24 x 24 size filter at full or half capacity, where capacity is defined as airflow.

		Option A	Option B	Option C
Pre-filter	Efficiency	MERV 8		
	Dimensions	24 x 24 x 2		
	Frequency of Change (per year)	4		
	Initial dp "w.c. (1970 CFM)	0.27		
	Est. change-out dp "w.c. (1970 CFM)	0.54		
	Hours per change-out per filter	0.2		
	Filter Cost	\$5		
	Disposal Cost	\$1		
Primary filter	Efficiency	MERV 12	MERV 12	MERV 12
	Dimensions	24 x 24 x 12	24 x 24 x 2	24 x 24 x 2
	Frequency of Change (per year)	1	1	2
	Initial dp "w.c. (1970 CFM)	0.47	0.37	0.37
	Est. Change-out dp "w.c. (1970 CFM)	1.5	1.5	1.5
	Hours per change-out per filter	0.4	0.4	0.4
	Filter Cost	\$60	\$60	\$60
	Disposal Cost	\$4	\$1	\$1

Figure 3: Variation of Filter Characteristics

Scenario	One	Two	Three	Four
Hours of Operation (annually)	3120	3120	8760	8760
Average filter slot airflow (CFM)	1000	2000	1000	2000
Site Electric Costs \$ / kWh	\$0.15	\$0.15	\$0.15	\$0.15
Labor Rate \$/ hour	\$50	\$50	\$50	\$50

Figure 4: Variation of AHU Operation Conditions

Figure 5 shows that the variation in the TCO per filter can vary significantly with change in hours of use and flow rate. When systems run continuously at high airflow, energy is the driving factor in ownership cost. When systems run a fraction of the year at low airflow, energy becomes less important.

Basis and Calculations of the Total Cost of Ownership Tool from 3M

The following is a review of the tool, calculation procedures and the assumptions used.

The National Air Filtration Association (NAFA) has developed a Life Cycle Cost Analysis (LCCA-2007) tool for calculation of Total Cost of Ownership.³ Where appropriate, the improvements in the TCO tool from 3M are compared and contrasted to those in the NAFA calculations.

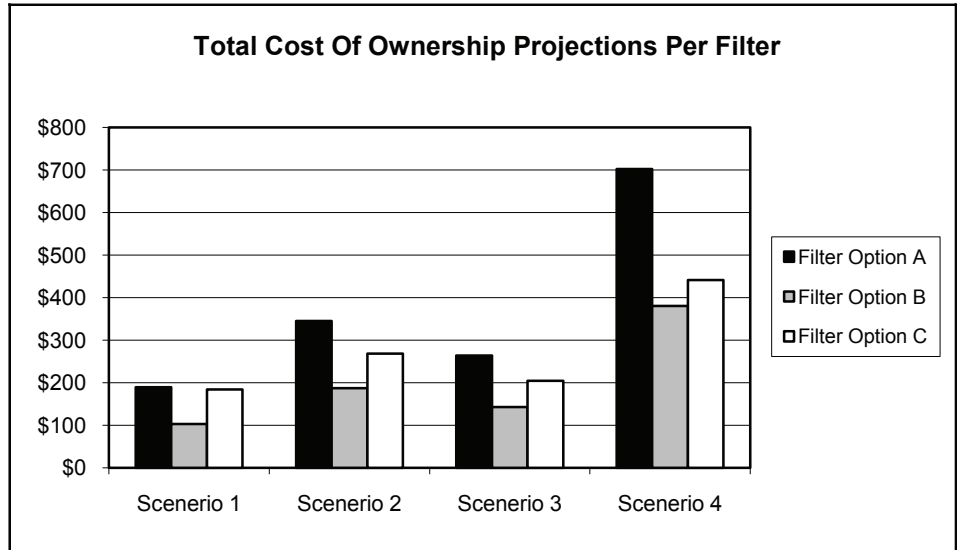


Figure 5: Variation in TCO based on different filters and AHU operation

Power and Energy

The power utilized by a fan motor is related to the pressure drop of system components, with the HVAC filter being one of those components. The power utilized by the fan motor for moving air through a filter is a function of airflow and pressure drop. The integration of power over time provides the energy utilized by the fan. The equations for fan power and energy cost are given in Equation 1 and Equation 2, respectively.^{3,4}

Equation 1:

$$\text{Fan Power} = \frac{Q \times \Delta P}{\eta_{\text{fan_system}}} \times \left(\frac{1}{8510} \right)$$

Equation 2:

$$\text{Cost} = \text{FanPower} \times \text{time (hr)} \times \text{ElecCost (\$/ kWh)}$$

Where FanPower = Power utilized by the fan motor

Q = airflow (CFM)

ΔP = avg. pressure drop (inches w.c.)

Δfan_system = fan system efficiency

t = time (hr)

Airflow

The average airflow through an HVAC filter is dependent on the specific AHU, the AHU control type, minimum ventilation requirements, and the nature of the heating and cooling loads. The largest determinant of HVAC design velocity is the cooling coil size. Cooling coils provide dehumidification. A limit of 600 FPM is recommended to prevent water carry-over.⁵ Because typical coil area is roughly equal to filter area, the velocity of the coil is also typical for filter face velocity.

In Constant Speed and Constant Volume configurations, the AHU has a relatively fixed airflow. This airflow is dependent on the design and installation of the HVAC equipment. For comfort applications, typical coil face velocity is in the range of 400-500 FPM.⁵

For Variable Air Volume configurations, the airflow is also dependent on whether an economizer mode of operation is in use. When economizer control is utilized, the airflow is generally higher. This increase is the result of outside air having a higher enthalpy than mechanically cooled air.⁶

Due to the cyclical nature of cooling loads, the airflow will vary depending on time of day and day of the season. Airflow is increased during the day and in the summer, and decreased at night and in the winter. This is particularly true if the heat source is heat gain from exterior surfaces. Estimating the average airflow in the case of VAV control requires continuous in-situ monitoring over significant time periods. This average airflow rate is very specific to the building. Therefore, a reasonable TCO prediction requires accurate customer input based on building information management system data.

Based on the above description, in the absence of specific facility data, a default value of 400 FPM is utilized in the TCO tool from 3M.

Filter Pressure Drop

Filter pressure drop is dependent on airflow across the filters, denoted dp . Filter dp is typically measured in inches of water column, denoted "w.c." To estimate the energy use related to the filter for a period of time, the average in-use filter pressure drop over the period of time being assessed must be estimated, or continuously measured, then averaged.

A simplified estimate of the average pressure drop is to utilize the average of the initial and final pressure drop of the filter. This is the method utilized by the NAFA LCCA tool and is shown in Equation 3, where the final dp is the final recommended pressure drop. The filter loading rate is based on an estimate of the replacement interval.

Equation 3:

$$dp_{avg} = (\text{initial } dp + \text{final } dp) / 2$$

A more detailed estimate is utilized in the TCO tool from 3M. The three improvements in this estimate include:

- 1) a method to account for the dependency of filter pressure drop with airflow,
- 2) a method to account for the fact that the filter pressure drop at change out is generally not the recommended final dp and is dependent on filter change out frequency, and
- 3) a method to determine the average pressure drop that takes into account the typical exponential pressure drop rise as the filter loads.

Estimating filter pressure drop dependency with airflow

Filter pressure drop varies with airflow. 3M has developed a mathematical equation for calculating filter dp as a function of airflow. This equation was developed by measuring and analyzing numerous HVAC filter types, both from 3M and from competitors. This equation has also been shown to be reasonable for loaded HVAC filters and is shown in Equation 4.

Equation 4:

$$dp_2 = dp_1 (Q_2 / Q_1)^{1.26}$$

Where Q_1 = airflow at measured pressure drop at state 1

dp_1 = measured differential pressure at state 1

Q_2 = specified airflow

dp_2 = projected pressure drop at specified airflow

Published data for pressure drop of new HVAC filters at the rated airflow is used for values in state 1. Likewise, when the pressure drop of the loaded filter is either estimated or measured, the values to establish the dependency of pressure drop with airflow for the loaded filter can be substituted in state 1.

An example use of the Equation 4 is shown in Figure 6. This figure shows data taken from an actual ASHRAE 52.2 test report for the Filtrete™ Commercial HVAC Filter MERV A13 Mini-Pleat with Gasket. The filter pressure drop was taken over a series of flow rates at initial and after four different loaded amounts. The actual measured data is shown as points on the graph. The projected values from Equation 4, based on the 2000 CFM data, are shown as a line series. The predicted values closely match the actual data for both the initial case and during filter loading.

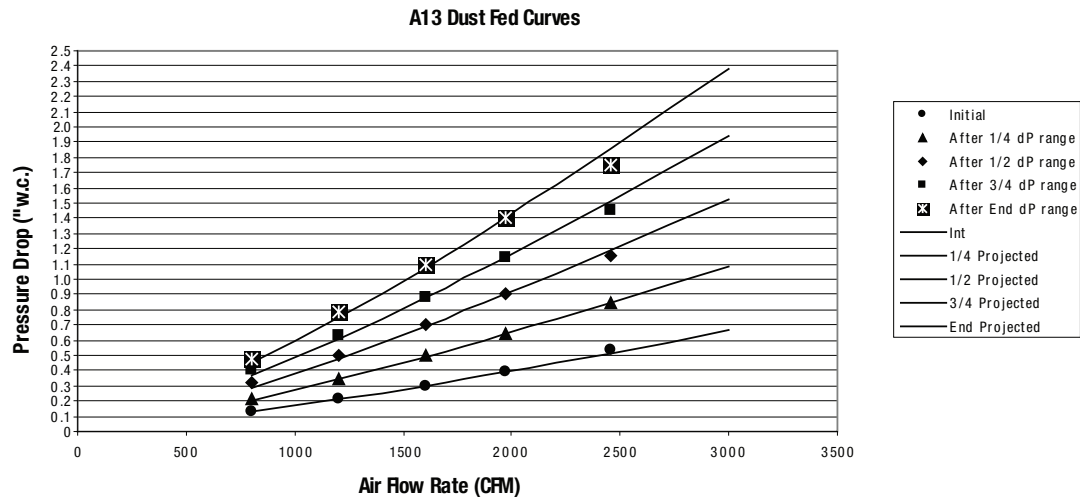


Figure 6: Example of Equation 4 Applied to An Actual Filter

Estimating Filter Pressure Drop At Change Out

To estimate the average filter pressure drop it is necessary to know or have a reasonable estimate of the pressure drop at change-out. The TCO tool from 3M utilizes the following estimates for the change-out pressure drop of the pre and primary filters, based on experience working with many building operators over numerous years. These estimates are based on change-out pressure drop at the rated filter airflow, which is generally 1970 CFM for a 24" x 24" filter, based on the ASHRAE 52.2-2007 standard.

- 1) Pre-filter: the change-out pressure drop is twice the initial pressure drop.
- 2) Primary filter: the change-out pressure drop is the lower of either three times the initial pressure drop or 1.5 "W.C.

Estimating Average dp

Utilizing the simplified NAFA estimate of average shown in Equation 3 does not account for the shape of the loading rate curve, and, therefore, reduces the importance of initial pressure drop. The TCO tool from 3M utilizes Equation 5 to better reflect the shape of filter loading curves.

Equation 5:

$$dp_{Avg} = dp_1 \times \frac{dp_{co} - dp_1}{3}$$

where dp_1 = initial pressure drop
 dp_{co} = change out pressure drop

Fan System Efficiency

The electricity required to operate a HVAC fan system is not perfectly converted to useful power (airflow rate x total pressure). Energy is lost in the fan, electric motor, fan motor belt, and adjustable speed drive. In addition, the specific HVAC system design reduces the fan performance. All these factors combined, cause an increase in the required electric power above the useful power of the fan.

The fan system efficiency is a fraction which accounts for the difference in output power to input electrical power and is defined in Equation 6.

Equation 6:

$$\eta_{\text{fan_system}} = \eta_{\text{fan}} * \eta_{\text{motor}} * \eta_{\text{belt}} * \eta_{\text{ASD}} * \text{PF}$$

Where	η_{fan}	=	fan efficiency
	η_{motor}	=	motor efficiency
	η_{belt}	=	belt efficiency
	η_{ASD}	=	adjustable speed drive efficiency
	PF	=	Power Factor

The default values utilized in the TCO tool from 3M are listed below.

η_{fan}	=	85%
η_{motor}	=	90%
η_{belt}	=	98%
η_{ASD}	=	95%
PF	=	0.9

These values are conservative and result in a system efficiency of 65%.

Efficiency Varies With Operating Condition

At a minimum the fan, electric motor and adjustable speed drive (ASD) efficiency vary with time. The fan peak, or optimal, efficiency only occurs at a specific fan operating point and decreases with either increasing or decreasing airflow rate.⁷ The electric motor efficiency is highest at higher torque and lower at partial load.⁸ The efficiency of variable frequency drives, a type of ASD, will vary as the output frequency varies. An example of how efficiency of the drive system varies follows based on an ASHRAE research project.⁹

“Furthermore, the efficiency of the motor and adjustable speed drive (ASD) will vary with speed and torque. In an ASHRAE-sponsored research project, values of 82% for an ASD-motor system were measured at full load. However, at 50% speed this efficiency declined to an average of 68% for mid-range torque levels”.

Fan And Motor Efficiency

The highest efficiency type centrifugal fans are backward-inclined and airfoil. Generally, the optimum of these types of fans can approach 90%.^{10,11} Large induction motor efficiency can be as high as 95% at full load, though 90% is more common.⁸

Power Factor

Because motors are inductive, they distort the ac phase angles of voltage and current. This effect causes some power to dissipate across the electric circuit. Power factors of small motors can be as low as 50%. The power factor in large fully loaded high speed motors can be as favorable as 90% for large high speed motors.⁸

Order of Calculation

The following sequence of steps are used in the TCO tool from 3M.

1. Estimate primary filter pressure drop at the standard 1970 CFM airflow.
2. Estimate average pressure drop at the standard 1970 CFM (Equation 5).
3. Adjust dp_{Avg} for actual average airflow from the standard 1970 CFM (Equation 4).
4. Add both pre-filter and primary filter pressure drop.
5. Calculate energy use based on total average pressure drop and average airflow.



Scaling TCO AHU to Building

Once an estimate of a representative AHU has been made, these costs are normalized to cost per filter. Based on the square footage of the building, an estimate is made to how many filter slots the building contains. This estimate is one 24" x 24" size filter for 2000 square feet. The basis of this calculation is to assume an average fresh air requirement of 0.1 CFM per square foot and assume 10% outside air for a total of 1 CFM of air per square foot. Utilizing the typical capacity of a 24" x 24" filter, 2000 CFM, results in the conversion factor of 2000 square feet per filter. If more detailed data on the number of actual filter slots is known, the actual number of slots may be used. The cost per filter is then multiplied by this estimated or known number of filter slots for the building.

Summary:

There are five components of the ownership and operating cost of HVAC filters: the cost to purchase the filters, the cost of the associated energy use, the cost of labor for installation and replacement, the cost of disposal, and the cost of shipping. Using Filtrete™ Commercial HVAC Filters may have a positive impact on the ownership and operating cost as a result of their low pressure drop and their design for long filter life. The Total Cost of Ownership tool from 3M, for HVAC Commercial air filtration systems, can be utilized to compare Filtrete Commercial HVAC Filters with alternative filter options and to predict the TCO savings when using Filtrete Commercial HVAC Filters.

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