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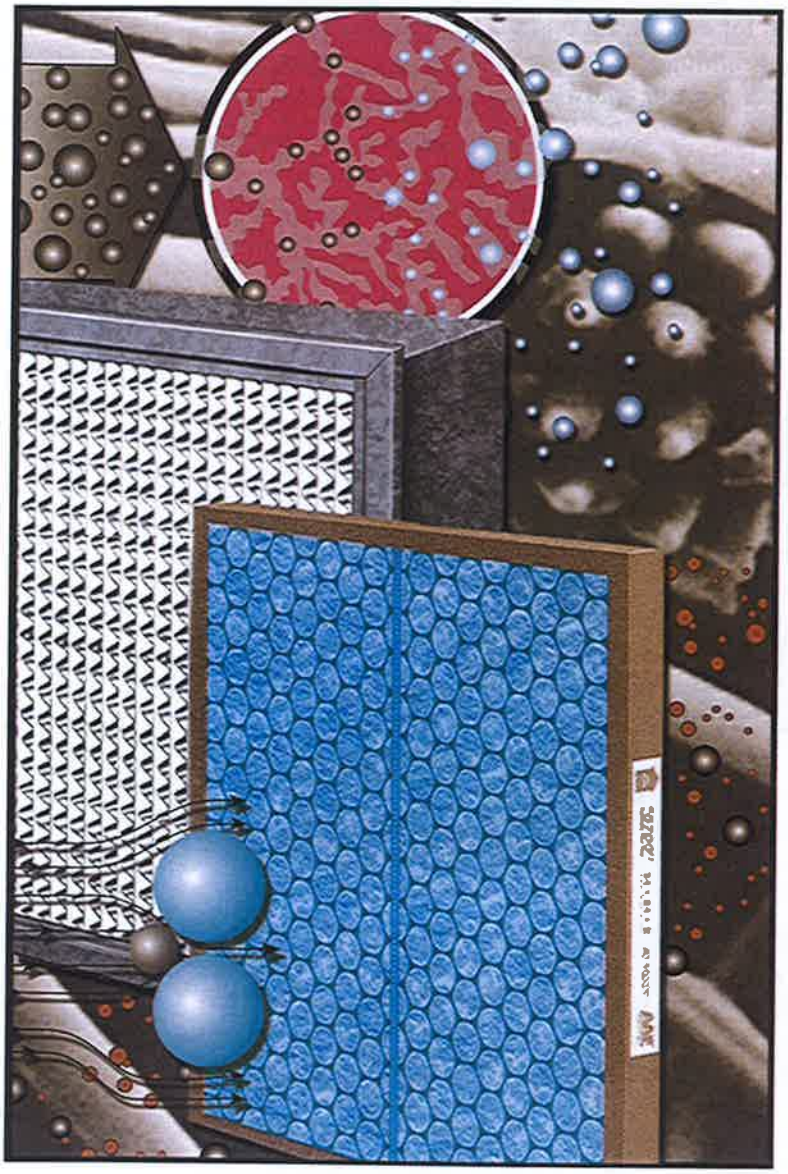


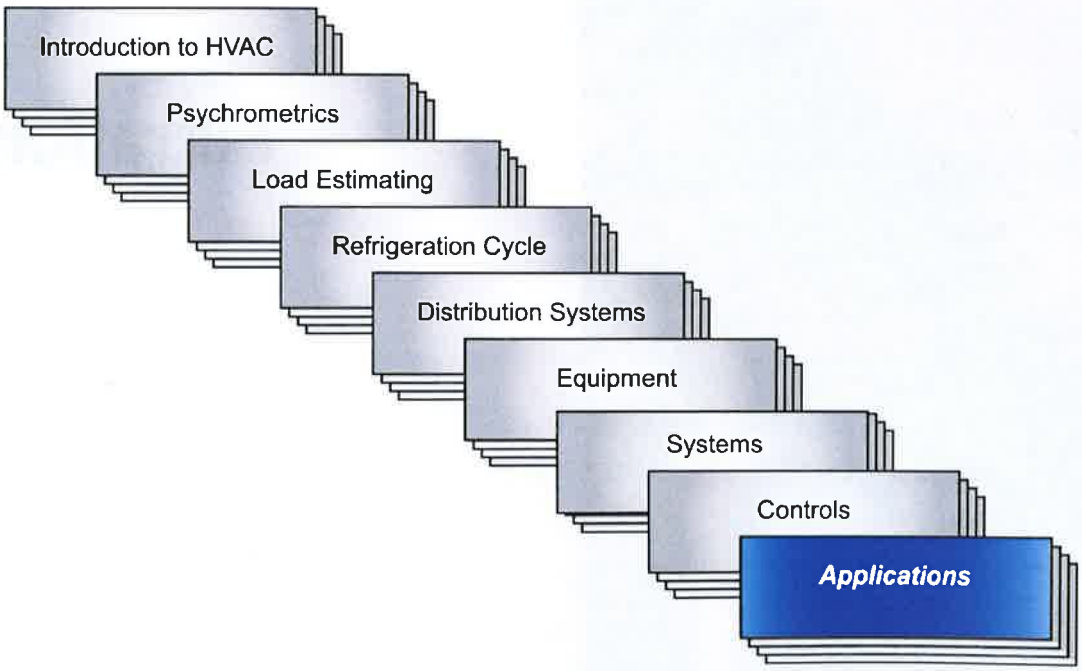
APPLICATIONS

Filtration

Technical Development Program

Technical Development Programs (TDP) are modules of technical training on HVAC theory, system design, equipment selection and application topics. They are targeted at engineers and designers who wish to develop their knowledge in this field to effectively design, specify, sell or apply HVAC equipment in commercial applications.

Although TDP topics have been developed as stand-alone modules, there are logical groupings of topics. The modules within each group begin at an introductory level and progress to advanced levels. The breadth of this offering allows for customization into a complete HVAC curriculum – from a complete HVAC design course at an introductory-level or to an advanced-level design course. Advanced-level modules assume prerequisite knowledge and do not review basic concepts.



The methods and products available for removing contaminants from the air is the focus of this TDP module. Filtration is one part of a good IAQ strategy and is used to manage the indoor environment. Specifically, the types of mechanical and gas-phase filters used in comfort air-conditioning applications along with electronic air cleaners are covered. Upon completion of this module, the reader should have an understanding of the types of filters available, their capabilities and applications.

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NOTE: Words shown in ***bold italics*** are defined in the Glossary on page 55.

Introduction

Most Americans spend up to 90 percent of their time indoors and many spend most of their working hours in an office environment.

To make the indoor environment an acceptable place, indoor air quality has to be addressed. Indoor air quality incorporates three strategies to manage the indoor environment: source control, filtration, and dilution as shown in Figure 1. An effective indoor air quality system must include proper filtration. Through proper filtration, we can control indoor air quality by removing pollutants. Filtration also directly or indirectly influences the level of air contaminants, air movement, temperature, relative humidity, and ventilation.



Figure 1

Indoor Air Quality Control Strategy

The importance of air filtration extends beyond indoor air quality. It is necessary to filter the air for many reasons. Protection of the HVAC system is necessary to maintain system efficiency. Build-up of dirt and lint in ducts can be avoided. Cleaner furnishings also result. Internal machinery and equipment can be kept clean and operative. Perishable product life can be extended by the air being kept free of bacteria during the manufacturing process. Interior maintenance overall is minimized by properly filtering the air, as shown in Figure 2. Filtration provides cleaner air for breathing in all types of buildings including our homes and hospitals.

To educate the reader on filtration and air cleaning, this TDP module will first discuss the various contaminants in our environment. We will examine all types of commercial HVAC ***filters*** and how they work. This includes mechanical filters, electronic air cleaners, and chemical filtration methods, also known as gas phase filtration. In addition, we will also examine ultraviolet technology and how it functions to control the growth of organisms in an HVAC system.

New filter testing procedures and the new MERV efficiency rating system will also be covered. The TDP will conclude with a discussion on the factors that affect filter life and maintenance procedures.



Figure 2

HVAC System Protection

Types of Contaminants

The air is made up of elements as shown in Figure 3. In the air, there are particulates and gases, which are generated by several sources. These sources are both man-made, such as industrial processes, and natural, such as dust. Because of this, the air we breathe is dirty and needs to be filtered.

In the interest of saving energy by reducing the amount of outdoor air brought into the building, contaminants can build up within the building. These contaminants can come from furniture, carpeting, and general construction materials used within the space. Consequently, ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) 62 defines the minimum outdoor air requirements necessary for people to be comfortable. Dilution of contaminants with outdoor air, coupled with filtration is a good IAQ (indoor air quality) strategy.

Indoor contaminants come from both inside and outside the building. Introducing untreated outdoor air can negatively affect the indoor air quality.

Figure 4 shows some of the most common contaminants found in the indoor air.

Airborne contaminants can be classified as either an aerosol or a gas.

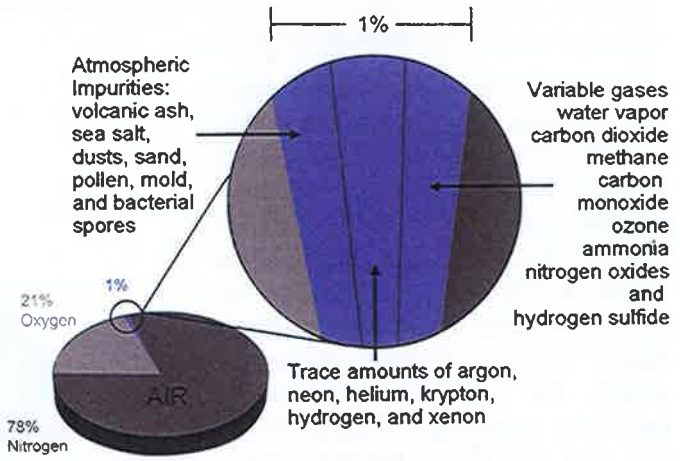


Figure 3

What is in our air?

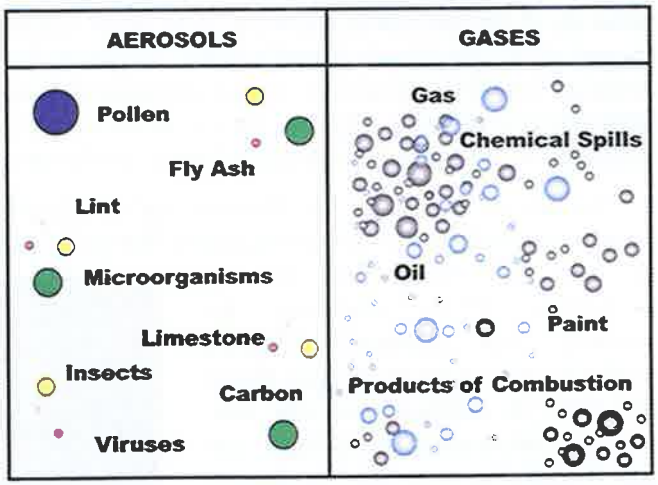


Figure 4

Common Contaminants

Aerosols

An ***aerosol*** is a suspension of fine solid or liquid particles in the air. There are different types of aerosols, depending on their source of generation. Dusts, fumes, fogs, mists, and smokes are all aerosols. The suspended particles range in size and are measured in microns. A ***micron*** is a very small unit of measure. See the What is a Micron? discussion on page 5.

Natural origins include salt particles from sea spray and clay particles as a result of weathering of rocks. Aerosols can also originate as a result of man-made activities and in this case are often considered pollutants. Aerosols should be considered a particulate when determining control options.

One important goal of air filtration is to minimize exposure to biological contaminants, chemical pollutants and other suspended particles. Biological contaminants are excessive concentrations of bacteria, viruses, fungi, dust mites, animal dander and pollen. Sources of chemical pollutants include tobacco smoke, emissions from products used in the building, also known as "outgassing" (e.g., emissions from office equipment, furniture, wall and floor coverings, and cleaning and consumer products), accidental spill of chemicals, and products of combustion such as carbon monoxide and nitrogen dioxide.

Filters may be necessary to both filter out the particulates from an aerosol, and remove a harmful gas in the same airstream. Gaseous contaminants will be discussed on page 6 in this TDP.

Dust and Other Aerosols

Dust is made up primarily of sub-micron size particles, which over time, will cause staining around diffusers and discolor walls and furnishings. Particles such as dust, dirt and other solid or liquid substances light enough to be suspended in the air can be produced by activities that occur in the building like printing, copying, welding or operating equipment. They can also enter a building through doors and windows or through outside ventilation air. In the United States, the average person inhales about two tablespoons of particulates each day, as shown in Figure 5.

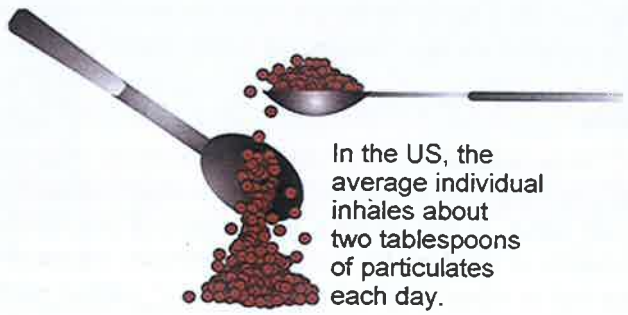


Figure 5

Particulates in Indoor Environments

Other common aerosols which contain particulates of sub-micron size are fumes and smoke.

Airborne Microorganisms

Airborne microorganisms come from a variety of sources and cannot be seen except by microscope. Microorganisms can grow and cluster to form a colony-forming unit. Microbes are one-cell organisms that multiply by single cell division. Viruses multiply by using a host cell's DNA to manufacture clones of themselves. Molds (fungi) produce separate spores that attach to a food source to grow a new colony. The air is the main path that microorganisms use to reproduce.

Measuring the Particles

Methods for the testing of filters for concentration of different size particles are based on three techniques: weight, count, and area.

Weight

Measuring the concentration of dust for a unit volume of air can be done by weight. First, a clean, pre-weighed filter paper is used and a measured amount of air drawn through it. Then the paper is reweighed. The increase in weight is the weight of the dust caught in the filter. Since the quantity of air is known, the weight of dust per unit volume of air is found.

Count

Counting and sizing of dust particles in an air sample can be done by using membrane filters. The membranes are treated with liquids that make the dust collected on their surface visible under a microscope, then the particles are counted and their size noted.

A new procedure using a laser particle counter has simplified the counting of number and size of particles in an air sample. These devices can now count particles smaller than 0.1 micron. A micron is defined in the "What is a Micron?" section on page 5.

This technology is important in certain applications such as process ***clean rooms***. The specification for a clean room may require a certain maximum number of particles of a certain defined size in fractions of a micron, per cubic foot of air volume.

Area

Area measurement is used to measure the staining effect of a dust. As a particle of dust rests on a surface, it occupies or "stains" a certain area. As a defined amount of air is drawn through a filter paper, it will create a stain. Relative concentration of staining can be compared from one location to another, for instance, ***upstream*** versus ***downstream*** of an actual filter. This concept has led to what is called the "dust spot" testing method of filters. Filter testing is discussed on page 32.

What is a Micron?

A micron is one millionth of a meter or approximately 1/25,400 inch. The symbol for a micron is µm. A micron is commonly used as a measure of particle size or fiber size in ***filter media***. The naked eye can see a particle approximately 10 microns or larger. A human hair is approximately 40 to 120 microns. See Figure 6.

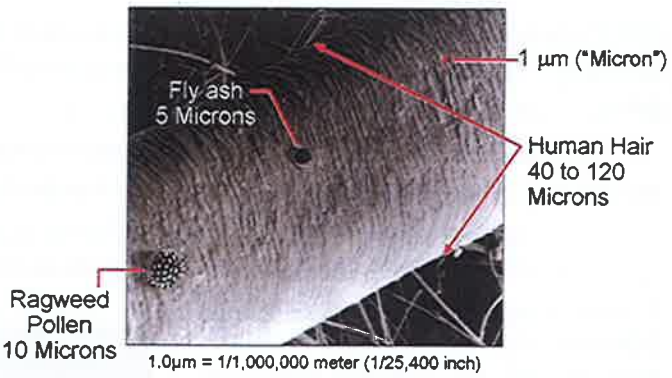


Figure 6

Particle Size Relationship to a Human Hair
(Photo courtesy of AAF)

Particle Size

Almost all particles in the atmosphere measure less than 1 micron. However, while particles smaller than 1 micron comprise 98.5 percent of all atmospheric dust particles, they make up only 3 percent of the weight. Atmospheric dust particles in the 5 to 10 micron size range only make up 0.175 percent of all particles, but they comprise 52 percent of the weight. Therefore, the percentage distribution of particle sizes in the atmosphere depends significantly on the method of measurement (weight or count) as shown in Figure 7. The combination of billions of fine particles and relatively few large heavy particles creates the need for different types of filtration.

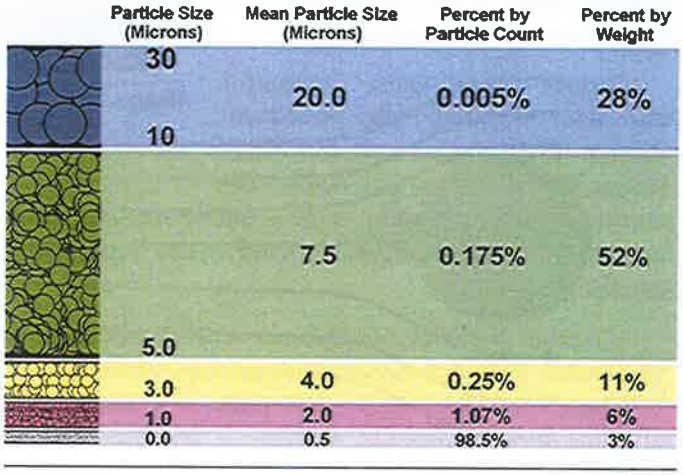


Figure 7

Particle Size Distribution

Gaseous Contaminants

A gas is any material that has neither independent shape nor volume but tends to expand indefinitely. Vapors are gases formed by the evaporation of materials that are normally liquid or solid.

There are a variety of ways by which gaseous contaminants may be characterized. Within the context of IAQ, gaseous contaminants can be classified as corrosive, irritating, or odorous.

Gases may be a by-product of a process or be manufactured for a definite purpose. Either way, when the gas enters the indoor air, it may have to be removed in order to maintain healthy breathable air. This is where chemical filtration (also called gas phase filtration) is used. An example would be the removal of car exhaust from a parking garage adjacent to an office area. Figure 8 shows gaseous contaminants coming from a car exhaust.



Figure 8

Gaseous Contaminants Coming from Car Exhaust

A corrosive gas can cause deterioration or damage to the interior of a building or its contents. For example, the presence of sulfur dioxide can cause damage to paintings and books in museums and libraries.

Irritant gases cause discomfort and can potentially do permanent damage to an exposed person. Many irritant gases produce pain and/or discomfort to the eyes, skin, mucous membranes, or respiratory system. Examples of irritant gases are ammonia, chlorine, and formaldehyde. Formaldehyde is a common building VOC (volatile organic compound).

Odorous gases are compounds considered either unpleasant at normal concentrations or objectionable at higher concentrations (e.g., perfume). Concentration ranges representing an "odor threshold" are often used to determine concentrations in air. The more odorous compounds usually have lower molecular weights of less than 100. A molecular weight above 300 is typically considered odorless.

Odorless Gases

Some harmful gases, such as carbon monoxide, are odorless and are undetectable by humans.

Most of the time, humans can detect the odor of a gas prior to the point where it becomes harmful. However, some gases are odorless, so there is no way of knowing that they have been introduced to an occupied space. One odorless yet deadly gas is carbon monoxide.

Sources of Gaseous Contaminants

There are many different sources for gaseous contaminants. There are chemical and biological processes that can create contaminants.

A chemical process inside a building can produce gases. Sometimes these gases may leak into the air system causing a problem. A chemical process may also produce by-product gases.

The most common source of gases in comfort systems is from building materials such as fabrics used in furniture, decoration, flooring, as well as materials used in walls and ceilings. These materials can release gases for long periods of time after they have been manufactured.

Gaseous contaminants can also be introduced by the outside ventilation air, especially in urban areas with high vehicular traffic.

Mechanical Filtration

Mechanical filtration removes dust and other particulate matter from an aerosol or an aerosol-gas mixture by capturing it on the ***filter medium***. The particle is captured and retained by the fibers in the filter medium. Most comfort applications tend to use only mechanical filters. Special applications may use different types of filtration.

Impingement is a method of filtration that is effective on particles with sufficient inertia to cause them to leave the airstream and collide with a fiber. This is often referred to as "viscous impingement" when the fibers are coated with an adhesive. This method of mechanical filtration shown in Figure 9 is how most low-efficiency filters (such as panel filters) function.

The fiber design and spacing within the filter media has a great impact on the impingement process, as does the speed (velocity) of the air going through the filter. Also, the particle size and mass all affect the impingement.

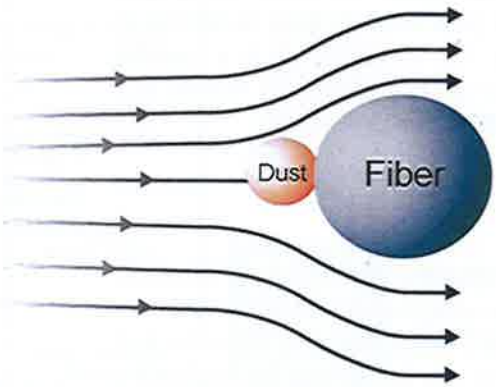


Figure 9

Impingement
(Photo courtesy of AAF)

Adhesives help to hold the particle once it is caught in the fiber. Sometimes just the force of the air passing through the filter dislodges a caught particle in a low efficiency impingement type filter. That is where the adhesive can help. There are a wide variety of adhesives on the market. An adhesive must exhibit the following characteristics:

- Keep its adhesive properties in order to capture particles
- Not dry out in the airstream
- Not have an odor
- Not be toxic in any way
- Have desirable non-flame and non-smoke propagating characteristics.

Interception is a special case of the impingement method of filtration that does not depend on the inertia of particles to bring them in contact with a fiber. Interception occurs when a particle follows the airstream, but touches a fiber as it attempts to flow around it as shown in Figure 10. The particle is held by the inherent adhesive forces (called van der Waals force) between the particle and fiber. ***Van der Waals forces*** are the forces of attraction between molecules. This method of mechanical filtration is how most medium-efficiency filters (such as bag filters) function.

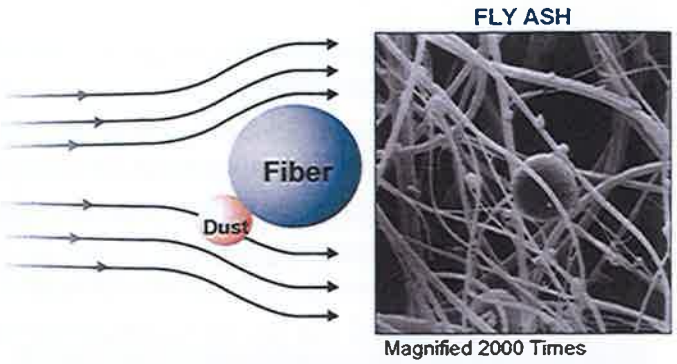


Figure 10

Interception
(Photo courtesy of AAF)

Straining is a method of filtration that removes larger particles. Straining occurs when a particle is larger than the space between fibers and cannot pass through them as shown in Figure 11. This method is a leading method in low-efficiency filters like panel filters and roll filters.

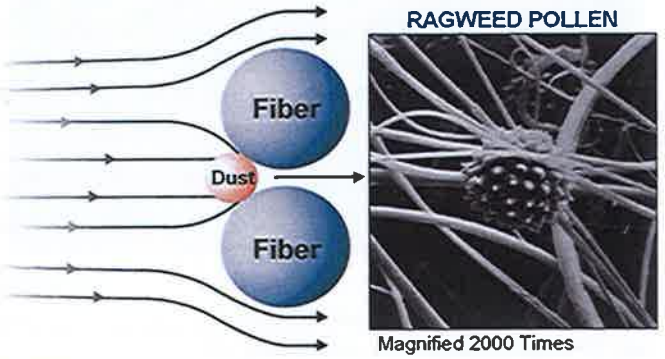


Figure 11

Straining
(Photo courtesy of AAF)

Diffusion is a method of filtration that is effective on particles 0.1 micron and smaller whose direction and velocity are influenced by molecular collisions. Particles of this size do not follow the airstream but behave more like gases than particulate. Their dwell time (or time spent in the media) is longer as they are battered across the direction of flow in a random fashion, increasing the probability that particles will come in contact with fibers and attach as shown in Figure 12. High-efficiency filter methods such as HEPA filters employ this method of filtration, as it is very effective.

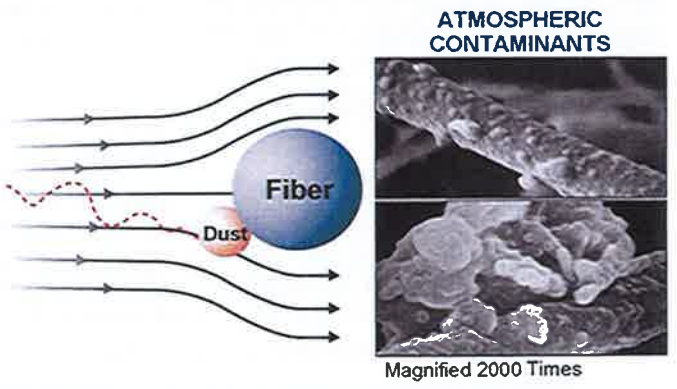


Figure 12

Diffusion
(Photo courtesy of AAF)

Factors in Mechanical Filter Selection

Selecting a mechanical air filter involves consideration of the following factors: efficiency, pressure drop, dust holding capacity, and air capacity.

Efficiency

Filter efficiency refers to the percentage of airborne particles that the filter removes. To understand efficiency, one must take into account the method used to generate the efficiency. There are currently two test procedures to determine filter efficiency: ASHRAE Standards 52.1 and 52.2.

ASHRAE 52.1 does not take into account the size factor in the particles being removed, however ASHRAE 52.2 does factor in particle size. Also, ASHRAE 52.1 classifies filters by using an average efficiency based on the difference in staining (dust spot) and the amount of dust that is captured or arrested (giving us the term arrestance).

The more recent ASHRAE 52.2 method has led to the new MERV rating system for filter efficiency. MERV stands for the minimum efficiency reporting value, and it is a measure of a filter's average worse case efficiency performance (dirty filter). The higher the MERV rating, the more efficient the filter. The process to generate a MERV rating involves counting the particles, noting their sizes, then generating a curve of the results. MERV ratings are shown in Figure 13.

MERV	Particle Size	Typical Pollutants	Applications	Filter Types
1	>10 µm	Pollen, Dust mites, Sanding dust	Residential, Light commercial	Construction, Throwaway
2				
3				
4				
5	3-10 µm	Dust, Molds, Spores	Commercial, Manufacturing	Pleated, Panel Filters
6				
7				
8				
9	1-3 µm	Legionella, Auto Fumes, Welding Dust	Commercial, Industrial	Bag, Cartridge, Mini-pleat
10				
11				
12				
13	0.1-0.3 µm	Tobacco smoke, Copier toner, Bacteria	Commercial, Medical, Industrial	Bag, Cartridge
14				
15				
16				
17	<0.3 µm	Sea salt, carbon dust, chem-bio, viruses	Clean rooms, Surgery, Isolation	HEPA
18				
19				
20				ULPA

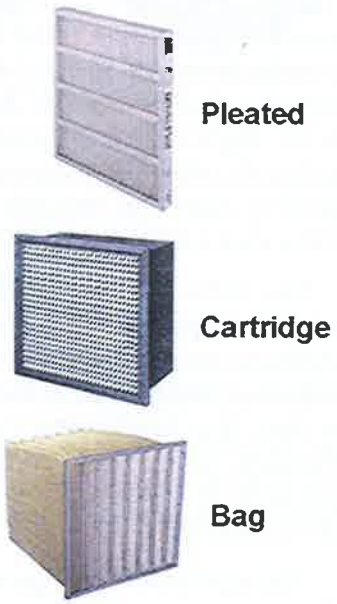


Figure 13

MERV Efficiency Ratings for Filters

Prior to the MERV rating, filters were often categorized by three basic headings:

- Low: filters in this category were in the 25 to 30 percent efficiency range.
- Medium: filters in this category were in the 30 to 65 percent efficiency range.
- High: efficiencies above 65 percent.

Filter Testing

High-efficiency filters, such as HEPA, are tested by a separate procedure called DOP Penetration.

Modern "high" efficiency filters, like HEPA (high efficiency particulate air) and ULPA (ultra low penetration air) types, have efficiencies greater than 99 percent. The highest efficiency mechanical filter types, HEPA and ULPA, are classified by a separate test procedure called ***DOP*** (dioctylaphthalate) ***Penetration***.

In conclusion, filter efficiency is the degree to which a filter will perform in removing solids. Efficiency can be found by several test procedures: ASHRAE 52.1 Average Atmospheric Dust Spot, ASHRAE 52.2 Minimum Efficiency Reporting Value (MERV), and DOP Penetration for the highest efficiency type filters.

Refer to the section on testing for more discussion on these methods.

Pressure Drop

The ***pressure drop*** of a filter is the measure of the resistance of airflow through it. Resistance is measured in either inches water gage (in. wg) or in pascals. Lower pressure drop is preferred because the higher a filter's resistance, the greater the energy needed to overcome that resistance. See Figure 14. Higher filter pressure drops are directly related to increases in fan operating costs. An example of this will be shown later in this TDP.

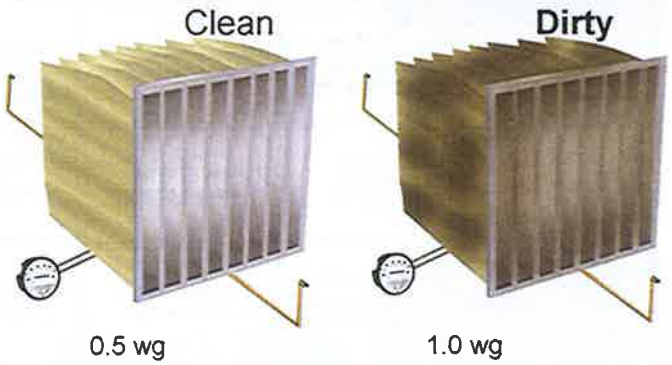


Figure 14

Pressure Drop

The dirtier a filter becomes, the more the pressure drop increases. However, one characteristic of many mechanical filters types is that as they get dirty, they exhibit their maximum efficiency. An extended surface type filter such as a bag is an example of this characteristic.

The right time to change a filter is discussed on page 38 and involves balancing the filter life, efficiency, and the fan energy costs.

Filter manufacturers represent their filters with both clean and required change-out pressure drops. Often the difference is quite large. For instance, there may be well over 1 in. wg difference between a clean bag filter and prefilter versus the same filter assembly when dirty.

If the total system resistance was calculated using the clean filter pressure drop, as the filters become clogged, airflow may be reduced through the system to unacceptable levels due to the increased system resistance.

One solution is to use the average between clean and dirty pressure drops and to use a fan with a steep sloping curve. That way, relatively small changes in airflow will result from the changes in static pressure as the filter gets dirty.

If the system was designed based on the dirty filter pressure drop, the fan selected may be oversized when used with clean filters. For an example of this scenario, see TDP-611, Central Station Air Handlers.

For industrial or health applications where airflow is critical, many designers will use the dirty filter pressure drop in their total resistance calculations so enough airflow is assured. The use of a variable frequency drive (VFD) on the fans in a VAV (variable air volume) system will allow the fan rpm to be adjusted easily. See TDP-613, Fans In VAV Systems for in depth discussion on VFDs.

Measuring a Filter's Pressure Drop

By locating a pressure sensor on both sides of a filter, the pressure drop can be measured on a ***manometer*** or a gauge. See Figure 15. When the pressure drop has reached a certain point, the service person can consider changing the filter.

Typically, there are different approaches taken as to when to change a filter. All are a function of the pressure drop. The filter manufacturer gives a ***final resistance*** value in their literature.

To measure a filter's pressure drop, connect tubing from a pickup in the airstream to a device that measures and displays pressure difference. The measurement device can be a manometer or a dial gauge. The gauge will have two connections, a high side (upstream) and a low side (downstream).

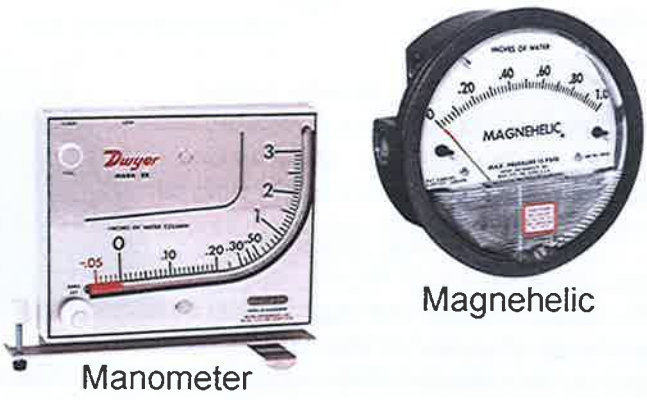


Figure 15

Pressure Drop Measurement Devices
(Photos courtesy of Dwyer Instruments)

A manometer measures the pressure drop by a height difference in two columns of a liquid. Special oil is used as the liquid because of its desirable properties in the measurement process.

A gauge device uses a diaphragm that responds to pressure differences as detected by the sensors on each side of the filter. This movement is represented on the gauge dial as a pressure drop in inches water gauge. Gauges are available in several pressure ranges to accommodate different types of filters.

Dust Holding Capacity

Dust holding capacity is the total weight of ASHRAE test dust that a filter can hold before reaching a given final resistance. The amount will vary depending on the size and design of the filter and airflow rate. This capacity is usually reported in grams or grams per square foot and it provides a relative measure of filter service life.

Capacity

Capacity is the amount of air a filter can handle at a specific pressure drop. The volume of air per unit time is expressed in cubic feet of air per minute (cfm) or cubic meters of air per second (m^3/s). Changing a filter's capacity will affect pressure drop, dust holding capacity, and could also affect efficiency.

The capacity is a very important parameter as it defines the operating envelope of the filter.

Filter Velocity

Filter velocity is directly related to capacity. To determine velocity, divide cfm by the filter ***media area***. See Figure 16.

Many mechanical filters have a maximum allowable velocity through the media of about 500 fpm. The exact value depends on the filter type and the manufacturer. This velocity is about the same as the cooling coil velocity in a typical central station air-handling unit.

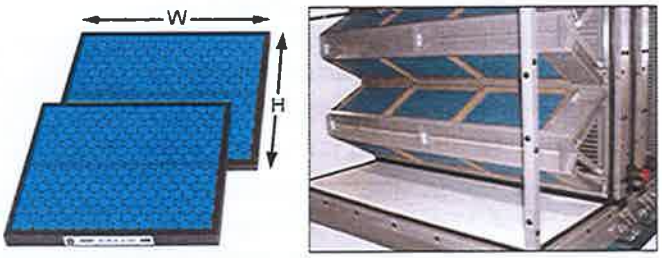


Figure 16

Capacity and Velocity

Packaged units like rooftops that supply a built-in filter compartment may utilize higher filter velocities. Higher velocities will mean higher pressure drops and higher fan energy due to increased resistance. However, the unit chassis may be smaller so a balance has been struck between acceptable filter velocity and the pre-engineered and designed packaged unit.

Special high-efficiency filters like HEPA filters may have less than a 500 fpm maximum velocity, which is required to maintain their high efficiencies. They are typically not incorporated inside packaged units.

Face Velocity and Media Velocity

Face velocity is the speed of air as it approaches the filter. For instance, each panel filter shown in Figure 17 is 20 in. high x 24 in. wide. Each filter is handling 1500 cfm. The filter has a ***face area*** of 480 $in.^2$ (24 * 20 = 480) or 3.33 ft^2. If the filter is standing straight in its pre-filter position (as in an air-handling unit ***filter frame***), then this exposes all of the 3.33 ft^2 of filter area to the 1500 cfm airflow.

Face velocity =
1500 cfm ÷ 3.33 ft^2 = 450 fpm

This particular configuration with a panel filter is often called a high velocity filter configuration. In this case, the face velocity and media velocity are the same.

Filter Specifications

Face velocity is the speed of air as it approaches the filter. Media velocity is the speed of air as it passes through.

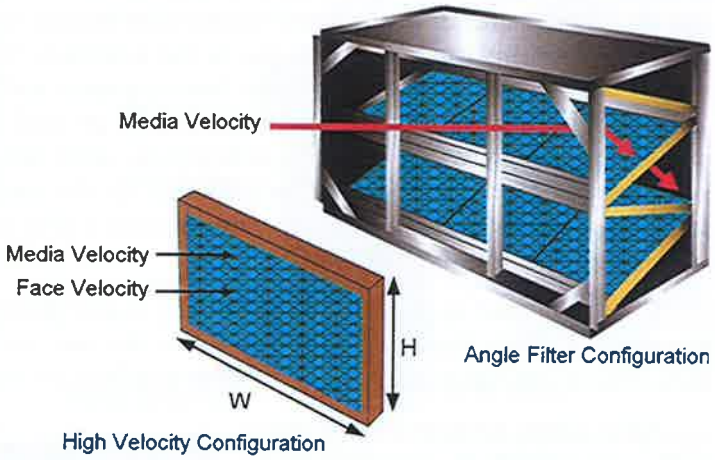


Figure 17

Face Velocity and Media Velocity

If we angle the same filters and increase the filter count as shown, there is more media area so the media velocity is lower but the face velocity is the same.

In the original high velocity configuration, when used in a factory fabricated air handler, the designer must check that the maximum filter face velocity is not exceeded before the maximum cooling coil face velocity. The air handler cabinet size is typically selected based upon a maximum cooling coil face velocity. Once selected, the filter media velocity should be cross checked. If the filter face velocity is exceeded, then the air handler cabinet size would have to be increased, different filters used, or additional filter media area provided by using a different configuration such as an angle filter section.

In the angle arrangement, filter media velocity will not be the driving force in the air handler cabinet selection.

Types of Mechanical Filters

Panel Filters

Panel filters are a wide-ranging group of filters as shown in Figure 18. Panel filters are a type of impingement filter, and are often characterized by equal media velocity and face velocity when configured perpendicular to the airstream. The exception to this is pleated filters which have a greater media area than non-pleated filters. Panel filters should be used as prefilters or roughing filters, where performance needs are at a minimum. Panel filters are further classified by the media material and how they are serviced. Many panel filters are also called "throwaway" filters.

System Protection

Panel filters are an important group, but efficiency is not the main use for these filters. They are often used to protect the life expectancy of the higher efficiency filters.

The media used in panel filters are usually coarse ***fiberglass*** or high loft synthetic. The filter construction varies from paperboard strips or die cuts, to heat sealed, self-sealing ring panels. Bulk rolls or individual pads are also used in combination with a permanent holding frame.

Panel filters achieve what is generally categorized as low efficiency filtration, up to approximately 20 percent, or MERV 4. This typically represents the minimum acceptable quality of filtration for comfort air-conditioning applications.

Extended Surface Filters

Pleated media filters are referred to as pleated panels. The pleats are a way of extending the media surface.

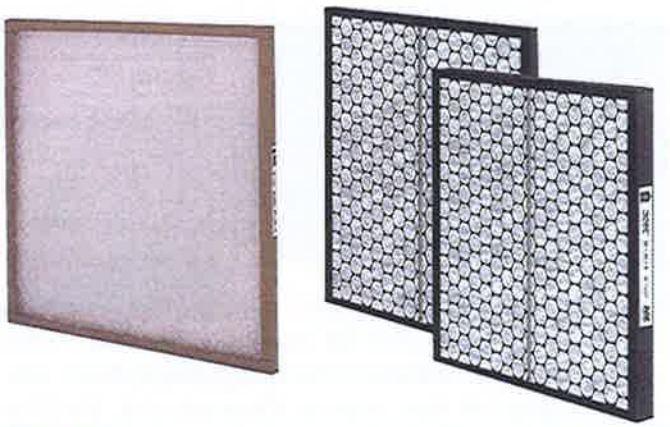


Figure 18

Panel Filters
(Photos courtesy of AAF)

Pleated panel filters are available and considered ***extended surface filters***. Filter efficiency is increased through a series of small pleats over normal fiberglass panel filters. Their MERV value may be rated as high as 8 (about a 35 percent efficiency rating).

An anti-fungal coating can be factory-applied to pleated filters to provide protection against bacterial growth.

Roll Filters

Roll filters are another type of impingement filter. Roll filters are used with a device that automatically feeds the clean media across the face of the unit to expose it to the airstream. See Figure 19. The media is supplied in roll form and is rewound onto a take-up roll as it is used. This allows the pressure drop to remain in the desired operating range. When the entire roll is used, it is discarded and replaced with a new one. Clean media rolls are installed at the top of the filter and the dirty filters are removed at the bottom.

The media is usually advanced across the face of the unit by a motor-driven gear reducer system. These drives may be located out of the airstream. However, when the motor must be placed in the airstream, it is preferable that it is located downstream of the filter (on the clean side).

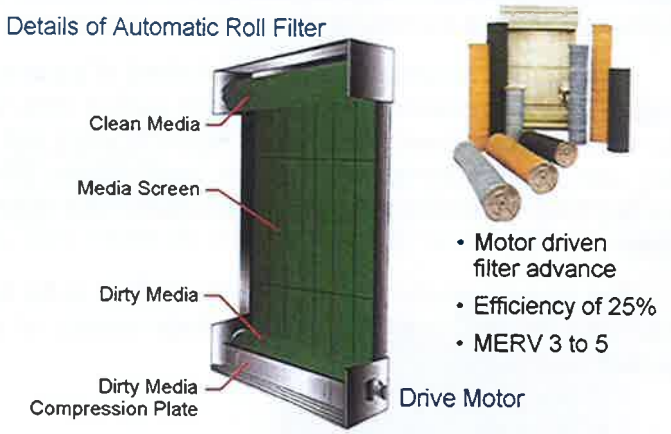


Figure 19

Roll Filters

Roll filters are usually made from a spun-glass media with an adhesive coating on the fibers. They also usually have a backing material to lend strength to the media to keep it from being damaged. There are also dry glass media that are not coated and have lower efficiency. Roll filters can also be made of synthetic fibers in place of glass, typically polyester.

The operating airflow velocity for roll filters is usually 300 fpm, but can go to up to 500 fpm. Initial resistances range from 0.1 to 0.2 in. wg when run at 300 fpm. The filters are not advanced until a final resistance of 0.5 in. wg to 1 in. wg. Roll filters typically have an efficiency classification range of MERV 3 to MERV 5

Typical performance values for impingement type filters like rolls and panels are shown in Appendix A.

Bag Filters

An alternative to panel and roll filters is extended surface filters such as ***bag filters***. These filters include the higher efficiency filter types like bag and cartridge filters. Extended surface filters extend the media surface behind the filter and create extra media surface so that the media velocity is less than the face velocity. See Figure 20.

The lower media velocity characteristic of extended surface filters allows the media to perform more



Figure 20

Bag Filters
(Photo courtesy of AAF)

efficiently. This is especially true of filters that use interception and diffusion methods of filtration, as they require lower velocities to be fully effective.

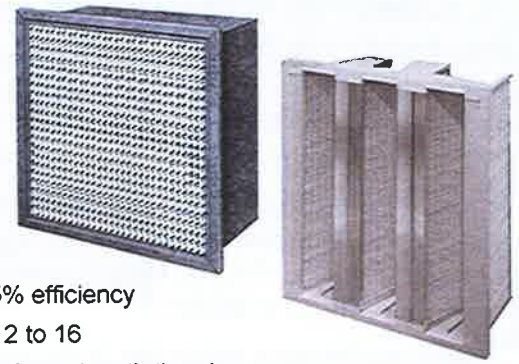
Bag filters have an efficiency level of up to about 75 percent as an average or MERV 12. However, depending on the exact product and manufacturer, the bag filter efficiency may reach MERV 16. These filters are intended to remove fine dust particles. These fine dust particles cause surface soiling and are bad for the respiratory system.

The bags are constructed of a special blend of paper and fiber in the shape of many pockets or bags. This shape creates an extensive filter surface area, which results in low air velocities across the filter. Because these filters have a high efficiency and more complex design than panel filters, they cost considerably more. Therefore, high-velocity pre-filters are usually installed upstream of the bag filter to remove large particulate matter and reduce the replacement frequency of the bag filter.

Bag filters typically depend upon the airflow to be maintained in order for the pocket to extend fully. If used in a variable air volume system, at a certain reduction in airflow, the filter pockets may sag.

Cartridge, Box, and Rigid Cell Filters

While these filters are not identical, we will include them into a single category for purposes of discussion, as they are all extended surface filters. See Figure 21. Where airway length is an issue, ***cartridge***, ***box***, or ***rigid cell filters*** may be used instead of a bag filter. These filters are also an alternative for use in VAV systems because they do not need airflow to stay supported.



- 75 to 95% efficiency
- MERV 12 to 16
- Shorter airway length than bags
- More expensive than bags

Figure 21

Cartridge, Box, and Rigid Cell Filters
(Photos courtesy of AAF)

These filters utilize several different types of paper and high-efficiency media design, such as pleating and mini-pleating, in conjunction with backing. This backing is often bonded to a support system, such as wire, plastic, or cardboard. These filters are inline space savers, so their media velocity is higher than that of bag filters.

Filter Alternatives

Cartridge filters take up less airway length than bag filters. However, bag filters cost less. For VAV application, cartridge filters may be more desirable because they will not collapse during low airflow.

Box and rigid cell filters provide medium-to-high efficiency filtration in the 75 to 95 percent range (MERV 12 to 16). Cartridge filters can have an efficiency and MERV rating comparable to that of bag filters.

These filters usually have a simple rectangular box shape. They mount into a filter frame that is gasketed to minimize air bypass around the filter. The filter is held in place by retaining clips or springs. For access to the retaining clips, the filter rack must be front loading.

Due to the cost of cartridge filters, pre-filters are generally used upstream to trap the larger particulates and extend the life of the cartridge. Cartridge filters may also be used in side-loading racks, similar to a flat filter section. Cartridge filters come with a one-inch header or frame around the filter, which is used to hold it in place in the filter track.

For typical performance values of extended surface filters like these, see Appendix B.

HEPA and ULPA Filters

HEPA "High-Efficiency Particulate Air" Filters

HEPA filters are a type of extended surface filter that has a minimum particle-collection efficiency of 99.97 percent with 0.3 microns. That means the filter will screen out 0.3 micron sized particles with a 99.97 percent efficiency when tested by the DOP test procedure. See Figure 22.

The media area can range from 89 ft^2 to 298 ft^2 in a 24 x 24 in. HEPA filter with initial resistance ranging from 1.0 in. wg to 1.4 in. wg. ***Final pressure drop*** measurements range from 2.0 to 3.0 in. wg. Recommended maximum face velocities (fpm) range from 125 fpm to 500 fpm.



- 99.9% plus efficiency
- MERV 17 to 19 (HEPA)
- MERV 20 (ULPA)
- Used in hospitals, food processing, clean rooms
- Requires special holding frames

Figure 22

HEPA and ULPA Filters
(Photos courtesy of AAF)

The media that was used in HEPA filters years ago was a glass-asbestos paper, but this was replaced with an all-glass paper as concerns regarding even small amounts of asbestos developed. Now, HEPA filter media is a thinner all-glass paper that has increased the efficiency to its current rate.

HEPA/ULPA Filters

HEPA filters are used in hospitals, pharmaceutical manufacturing, food processing and clean room applications. They can also be found on specialized exhaust systems like biological labs.

The media used in HEPA filters differs among manufacturers and the paper fibers are separated by various processes. A binding agent is then added to form the separated fibers into a paper-like substance. An antifungal application may also be used. Before the paper is formed into its permanent configuration, it may even be waterproofed.

ULPA "Ultra Low Penetration Air" Filters

An ***ULPA filter*** is an even more efficient filter than HEPA filters. ULPA filters are extended filters built in a rigid frame. ULPA filters use paper media and have a minimum particle-collection efficiency of 99.999 percent with 0.12 micron particles. See Figure 22. The media area can range from 89 ft^2 to 242 ft^2 with an initial resistance range of 0.31 in. wg to 1.0 in. wg. Final pressure drop measurements range from 0.70 in. wg to 2.0 in. wg.

Bypass Air

Bypass of unfiltered air must be avoided. Properly seal the entire filter assembly.

It is important to retain the high-efficiency characteristic when utilizing HEPA and ULPA filters. Consequently, manufacturers apply sealants to create a leak proof seals between the filter and the holding frame around the media.

Bypass of unfiltered air outside the frame must be avoided. Great care must be taken to properly seal the entire assembly within the jobsite support system. This is discussed in the filter frame section of this TDP.

HEPA/ULPA Applications

HEPA and ULPA filters are selected to operate at lower face velocities (250 fpm) so their use in a conventional air handler is not that common, but can be done. Often, the HEPA filters will be built into a special ceiling or wall grid that is designed to hold them. Typical applications of these special filters are: clean rooms, biological hoods and cabinets, the nuclear industry, computer chip manufacturing, industrial processes, and other special applications where the highest level of filtration is required for health or product.

Application Topics

Bag-In, Bag-Out

If the filter is placed in an airstream where toxic particulates may be present, there is a design filter frame and holding bag assembly called bag-in, bag-out that allows for removal and replacement of the filter without compromising the integrity of the seal around the filter frame. That way, there is minimal chance that during filter changing that toxic particulates could re-enter the airstream.

This is a specialized, step-by-step, controlled procedure. The filter manufacturer's instructions must be followed during the change out process.

Electrostatically Charged Media

There is a subcategory of mechanical filters whose media has been electrically charged to attract particles as a way of increasing filter efficiency. These filters are called "electrostatically" charged filters. Unlike electronic air cleaners, which will be discussed in the next section, electrostatically charged filters do not require a constant source of electricity. Filters that do not use an active source of electricity are described as passive ***electrostatic filters***.

Passive electrostatic media is charged by the manufacturer and then incorporated into a standard mechanical filter.

Filter Framing Systems

Filter frames come in different sizes and designs, and from different sources. They can be supplied as an integral part of an air-handling unit in the form of a modular track that comprises a flat, angular, bag, or cartridge filter section. See Figure 23 for an example of filter frames.

Filter frames or tracks can be part of the design of a packaged unit, such as a rooftop or vertical packaged product. In smaller sizes of packaged units, typically only one type of filter frame will be available. These are used to hold 1 or 2-inch throwaway panel type filters. The frames that hold the actual filters are built right into the unit casing.

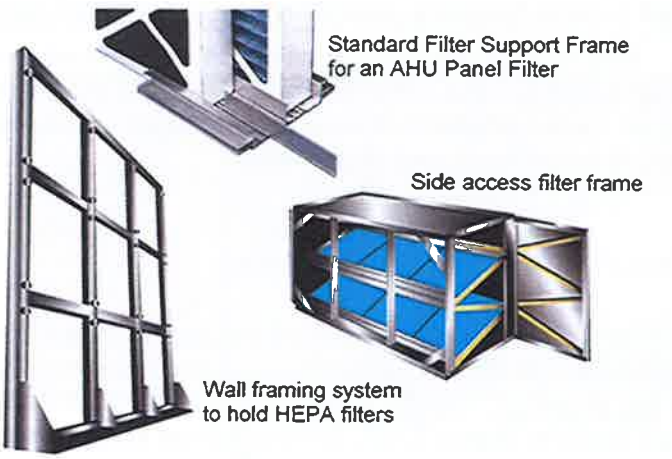


Figure 23

Filter Frames

A typical arrangement for an extended surface filter would be to utilize a prefilter as the first stage of filtration to remove large particulates. The higher efficiency filter would then be used as the second stage of filtration to remove fine particulates. Each filter would be installed in a separate track or frame.

More specialized applications may use field-erected frames. The project may involve individual filters placed in a framework assembled into large ***filter banks***. There are also special framing considerations for HEPA type filters, which are discussed below.

On any type of framing system, the total airflow divided by the number of filters determines the cfm per filter. That cfm can be checked against manufacturer literature to make sure each filter can handle the capacity.

Service Access

On filter systems with prefilters, upstream servicing is more desirable.

Servicing within a filter frame is more common from the upstream side of the filter instead of the downstream side. One reason for upstream servicing is if there are prefilters present. Prefilters are more easily

Special clamping frame for HEPA filter to eliminate air bypass

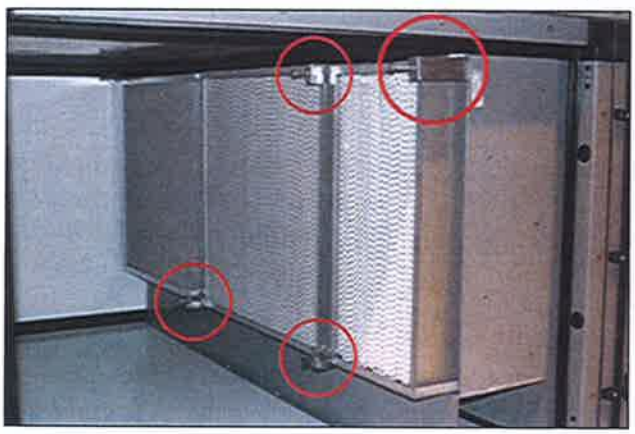


Figure 24

HEPA Filter Frame in AHU

replaced since you do not have to remove the downstream filters for access, so upstream filter service is more desirable. Downstream servicing can save some space when the filters are in a final position because no additional access is required upstream.

With an upstream frame or rack, as the filters load up with dirt, the increased pressure pushes them harder into the support frame. This actually helps maintain a seal between a filter and its frame. On a downstream service design, the air pressure tends to push the filter off the frame, so the filter must be secured to the frame.

Front Loading and Side Loading

On front-loaded filters, space is required in front of the filters to install and remove them. On side-loaded filters, the filters are slid from the side on tracks into the filter section so front access is not necessary. Airway length is saved with side-loaded filters. Side service housings require side access to change filters, however airway access is not required so unit length is saved.

Framing HEPA and ULPA Filters

Wall and ceiling framing modules are both used for HEPA filters. These are often made from extruded aluminum that is field-welded into assemblies and then suspended from ceilings or formed together to create walls. This type of holding frames is often used in clean rooms.

The framing system for HEPA type filters must not allow any bypass of air around the filter. Any bypass of air would defeat the integrity of the high-efficiency filter system. Clamping mechanisms are used to securely hold the filter in the box frame and prevent leakage around the media, as shown in Figure 24. Clamping systems for HEPA filters must exert pressure to create a seal. Some clamping mechanisms even utilize a gel to create a fluid seal when the filter is positioned in the frame.

Any space left over between the filter frame and plenum can be caulked to eliminate air bypass. Caulk can also be applied between each row of frames to eliminate air bypass.

Electronic Air Cleaners

Electronic Air Cleaners (EAC) use ***electrostatic precipitation***, which is a method of filtration that imparts a positive charge to airborne particulate matter and collects the particles on negatively charged collection plates. Unlike electrostatically charged mechanical filters, electronic air cleaners require a constant source of electricity to clean the air.

Operating Principle

Electronic air cleaners are filtration and cleaning systems that are installed permanently in the ductwork of the HVAC system.

An important feature of electronic air cleaners is that they have a very low resistance to airflow. This results in lower fan static pressures than with other methods of air cleaning.

Electronic air cleaners work on the principle that like charges repel and dissimilar charges attract. EACs have the following basic components: a prefilter, a power pack section, and an ionizer/collector section. See Figure 25.

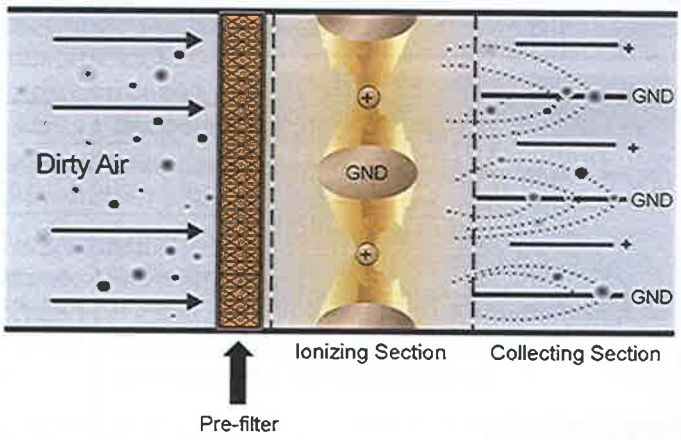


Figure 25

Electronic Air Cleaner Operation

The prefilter is a simple, low efficiency filter that stops large particles from entering the electronic air cleaner. The power pack transforms normal alternating current into high voltage direct current. This high voltage direct current is sent to the ionizer/collector section. It is here that particles in the air encounter the electrostatic field from the direct current and become charged. The plates on the collector are arranged so that every other metal plate in the collector is charged with high voltage. The plates in between the charged plates are grounded. Particles in the airstream are repelled by the charged plates and attracted and held by the grounded plates.

The most common and most efficient EAC is the 2-stage electrostatic precipitator as shown in Figure 26. This type of filter works on the principle of charging the particulate with an electrified wire, and then collecting the particulate on oppositely charged plates.

The negatives of this type of system are the large initial cost and the need for continuous maintenance to maintain the high efficiency. Maintenance involves removing the panels and washing them.

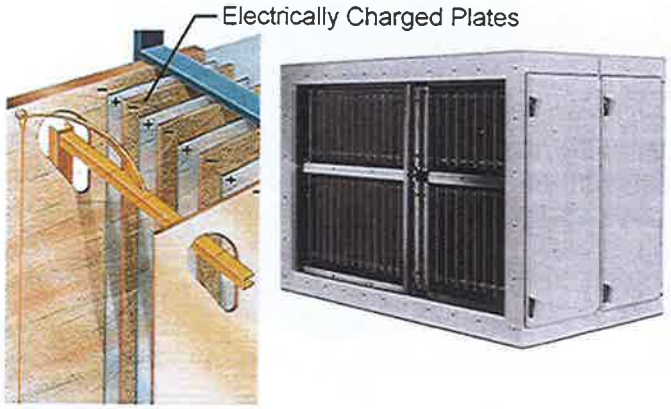


Figure 26

2-Stage Electrostatic Precipitator
(Photos courtesy of AAF)

Efficiency

Typical air velocities through a system are 300 to 500 fpm. At higher air velocities, the efficiency of removing larger particles tends to decrease. Because the EAC is using the electrostatic charge as the collection mechanism, and not fibers, the resistance is very low, 0.1 in. wg at 500 fpm. Resistance does not increase significantly as the collection plates build up. The efficiency will begin dropping as the collection plates become dirty before the resistance is an issue. This is why routine maintenance of the collection plate is so important.

Filter Efficiency

The efficiency of Electronic Air Cleaners (EAC) usually decreases over time, while filters relying on mechanical filtration, increase over time.

There is a wide range of efficiencies available, but the most common 2-stage EAC are in the MERV 11 to MERV 14 range.

Applications

Historically, electronic air cleaners have been used in residential applications to remove particulates in the air that may cause or aggravate allergies.

Location and Service

Remote locations without periodic service are poor choices for electronic air cleaner usage.

In commercial applications, electronic air cleaners are ideal for high concentrations of small particulate, such as in bars or restaurants with heavy smoke. There are applications where electronic air cleaners are not recommended such as any system where gases might be in the airstream that could pose a fire risk mixing with the high voltage plates.

If the installation is in a remote location or where it will receive little or no periodic service, electronic air cleaners may not be the best choice since they require maintenance to stay functional.

Gas-Phase Air Filtration

Gas-phase (also known as ***chemical*) *filtration*** involves either ***adsorption*** or ***chemisorption*** (adsorption with chemical reaction). Adsorption is a physical process by which gaseous contaminants adhere to solid surfaces. Chemisorption removes gases via chemical reactions between the gases and a substance distributed throughout the media.

The major differences between mechanical and gas-phase filtration are displayed in Table 1 below.

Table 1
Gas-Phase and Mechanical Filtration

Gas-Phase	Mechanical
Designed to filter gases	Designed to filter particles
Constant pressure drop over time regardless of loading	Pressure drop increases as filter loads
Efficiency decreases as filter exhausts	Efficiency increases as filter exhausts
Very dynamic contamination input levels (i.e., contaminants in rapidly changing concentrations)	Defined contamination input (e.g., particle size, physical form, particle type, etc.)
Changes in environmental conditions i.e., humidity, etc.) can significantly affect filter performance.	Changes in environmental conditions will not generally affect filter performance.
Interactions between gases can result in physical changes (i.e., from gas-phase to solid or liquid form).	Particles can coalesce to form larger particles or rub together to form smaller particles, but will not change physical form.
Measuring filter performance is difficult.	Particle measurement is comparatively simple and well understood.

Adsorption

By definition, adsorption is the process by which one substance is attracted to and held on the surface of another. Adsorption can occur wherever a material has sufficient attractive force to overcome the kinetic energy of a gas molecule. This is evident by the adsorption of cigarette smoke on the interior of an automobile or of cooking odors on a person's clothing.

Adsorption is a surface phenomenon. The removal capacity of an adsorbent is directly related to its total surface area (which extends well into the interior of the solid). Therefore, it is important to develop as large an accessible surface area per unit volume as possible. Granular activated carbons (GACs) are the most common materials that fulfill this requirement. See Figure 27. Another commonly used adsorbent is activated alumina.

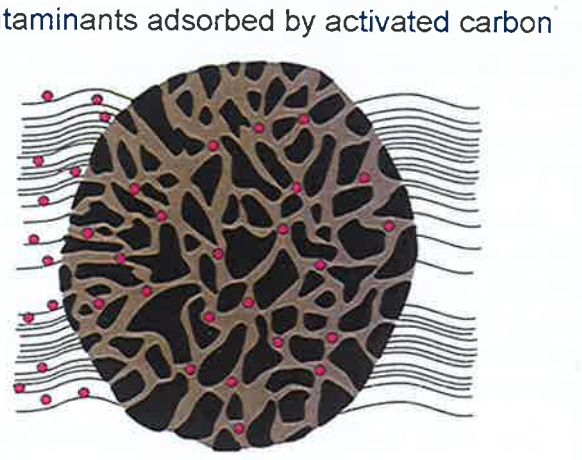


Figure 27

Adsorption
(Art courtesy of Purafil, Inc.)

Because of the relatively weak forces involved, gases that had been initially removed from the air can begin to "desorb" as the medium approaches its adsorptive capacity. Also they may desorb due to the preferential adsorption of higher molecular weight compounds over lower

weight compounds. In either case, the efficiency of the gas-phase medium begins to decrease and breakthrough will occur. As the media becomes saturated no further gases can be adsorbed.

Many other factors can affect removal of gaseous contaminants by physical adsorption. Among these are the type of adsorbent, the resistance to airflow (ΔP), the adsorbent bed depth, the gas velocity, the concentration and characteristics of the contaminant(s), and the temperature and relative humidity of the airstream.

Chemisorption

In contrast to the reversible process of physical adsorption, chemical adsorption, or chemisorption, is the result of chemical reactions on the surface of the adsorbent. See Figure 28.

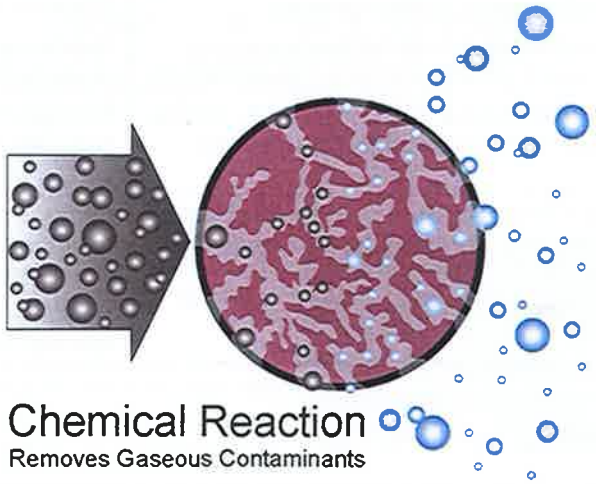


Figure 28

Chemisorption
(Art courtesy of Purafil, Inc.)

Adsorbent materials do not adsorb all contaminant gases equally. One way to improve the effectiveness of sorbents for these materials is by the use of various chemical additives, or "impregnants," that can react with these less-adsorbable gases. These impregnates react spontaneously and irreversibly with these gases forming stable chemical compounds which are bound to the media as organic or inorganic salts or released into the air as, for instance, CO_2 or water vapor. It is quite common to have a gas-phase air filtration system that utilizes a combination of plain (unimpregnated) and chemically impregnated adsorbent medias.

Chemisorption is specific and depends on the chemical nature of both the contaminant gas(es) and the impregnant used. It is actually a two-stage process. First the gas molecules are physically adsorbed onto the medium. Once adsorbed, they react chemically with the impregnate. The chemical added to the adsorbent makes it more or less specific for a contaminant or group of contaminants. Many of the same factors that affect the removal of gases by physical adsorption also affect their removal by chemisorption.

One of the more broad-spectrum chemical impregnants in common use is potassium permanganate ($KMnO_4$), and it is typically used as an impregnant on activated alumina. Potassium permanganate-impregnated alumina is often used in conjunction with granular activated carbon to provide a very broad-spectrum gas-phase air filtration system.

Types of Media

The indoor and outdoor environments differ significantly in both the types and concentrations of gaseous contaminants. Contaminants with sources predominantly from outdoors include sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), and a number of volatile organic compounds (VOCs). Contaminants generated primarily from indoor sources include CO_2, formaldehyde (HCHO), ammonia (NH_3), acrolein, and a variety of organic chemicals.

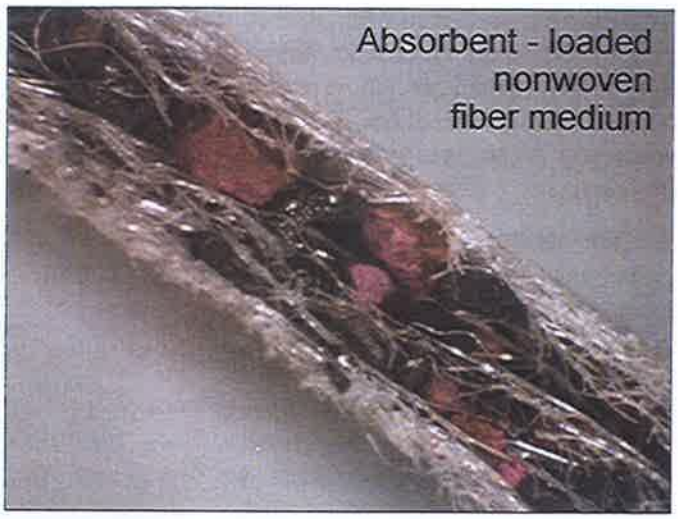


Figure 29

Gas-Phase Filter Medium
(Photo courtesy of Purafil, Inc.)

Practically all commonly available gas-phase filter media are manufactured from adsorbent materials such as activated carbons and activated aluminas. Figure 29 shows an example of gas-phase filter medium. These materials have a very high surface area due to their highly porous nature and provides for broad-spectrum removal of these gaseous contaminants. Specific chemical additives (impregnants) may be introduced during the manufacturing process to impart distinct gas removal characteristics to the media and make them more or less specific for various chemical species. Examples of common media types are shown in Table 2 below.

Table 2
Common Gas-Phase Media Types

Media Composition	Principle Target Gases
Activated carbon	Volatile organic compounds (VOCs), ozone
Activated alumina + potassium permanganate ($KMnO_4$)	Sulfur dioxide (SO_2), nitrogen oxide (NO), hydrogen sulfide (H_2S), formaldehyde, low molecular weight organics
Activated carbon and alumina + potassium hydroxide (KOH)	Hydrogen sulfide (H_2S), chlorine (Cl_2), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), acid gases, mercaptans, automobile exhaust
Activated carbon + phosphoric acid (H_3PO_4)	Ammonia (NH_3), amines

For impregnated media, manufacturing can be optimized using a dry-feed process in which the chemical-impregnant solution is added to a powdered adsorbent mixture assuring a uniform distribution throughout in the finished product. The media, after pellet formation, is cured to a moisture content of 15 to 30 percent by weight. This allows the media to have a sufficient hardness to prevent particle attrition in handling and use, but still maintain a well-developed pore structure to allow gas molecules to be physically adsorbed.

These media are available in number of particle sizes, but are typically supplied as roughly spherical or cylindrical pellets in a size range from 1/16 in. (1.6 mm) to 1/4 in. (6.4 mm). Media size distribution can be well controlled in order to maintain product uniformity and performance.

A few manufacturers are applying gas-phase filter media to various filter substrates (fibers, foams, etc.). In the past, most processes have caused the adsorbent materials to become "blinded" or spent through reaction with various binders and adhesives and the manufacturing techniques employed. Advances in filter manufacturing technology, however, have eliminated these deficiencies.

One manufacturer has developed a gas-phase filter using a patented technology that allows for the application of multiple plain and chemically active sorbents to a non-woven bi-component fiber matrix. The resulting product is a pleatable roll that can be produced with an integral particulate filter to provide a unique and effective combination filter material. This medium can be pleated into any standard filter size for the removal of both gaseous and particulate contaminants. See Figure 30. This allows for flexible filter design for easy application into new or existing HVAC systems.



Figure 30

Combination Chemical-Particulate Filters
(Photo courtesy of Purafil, Inc.)

Equipment Designs

Gas-phase air filters based on adsorption and/or chemisorption are available in a variety of commercial designs. They are usually available as packed bed media filters where the dry, granular gas-phase media is filled in the space between perforated metal or plastic screens. As shown in Figure 31, these include units in which a variety of filter bed types and depths are employed. In HVAC systems, these equipment designs include partial bypass, serpentine, thin-bed trays, intermediate bed depth "V" module, thick bed trays, and thick bed depth "V" module.

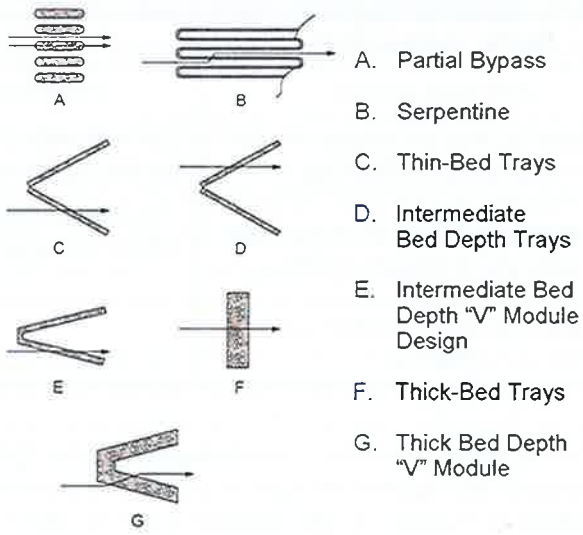


Figure 31

Gas-Phase Filter Configurations
(Art courtesy of Purafil, Inc.)

Partial bypass design (A) is a loosely packed media filter, producing gaps or spaces. These filters generally have low efficiency and are used for odor control.

Serpentine design (B) is a thin bed (0.375 to 0.5 in.) of convoluted filters used in medium-duty recirculation applications.

Thin-bed trays (C) are multiple filter trays (0.5 to 0.625 in.) arranged in a "Z" configuration.

Intermediate bed depth trays (D) are much the same as thin-bed trays except for an increased tray depth (0.875 to 1 in.) used to create a higher efficiency and longer service life.

Intermediate bed depth "V" module design (E) configures filters in a "V" shape and allows for low air velocity with a bed depth between 1 to 1.125 inches.

Thick-bed trays (F) are a single filter design with a bed depth of 2 in. or greater. The filter is set perpendicular in the airstream. The thickness of the bed makes this a high-pressure drop filter.

Thick-bed depth "V" module (G) is a filter bed depth of 3 in. and is comparable to the intermediate-bed depth "V" module.

Many of these systems are used in tandem with particle removal filters for optimal filtration capabilities. See Figure 32. The ***prefilter*** section removes unwanted particulate matter and serves to protect the gas-phase filtration media. The gas-phase filter section removes unwanted gases and odors. The ***final filter*** section removes any remaining particulate matter.

Gas-phase filters can be installed in side-access or front-access housings or other standardized equipment. They can also be installed in self-contained air cleaner units. These filters are available as refillable or ***disposable filters***.

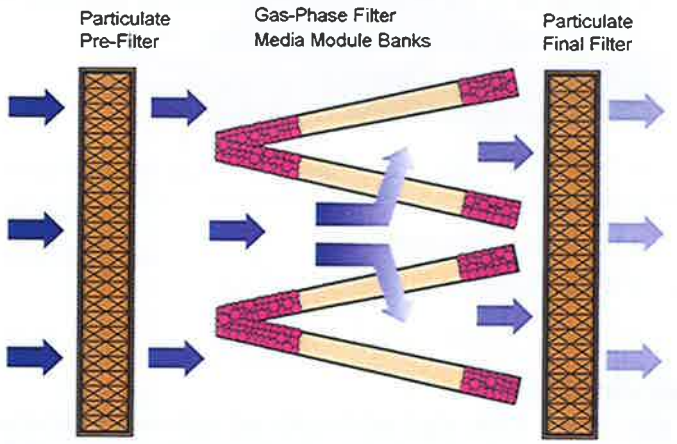


Figure 32

Gas-Phase Filtration System
(Art courtesy of Purafil, Inc.)

Common Applications

Common applications for gas-phase filtration are:

- Outside air filtration for office buildings, hospitals, restaurants, and manufacturing facilities - especially those with street-level air intakes.
- Recirculation air filtration in animal research facilities, hospitals, and schools
- Protection of artifacts and historical documents in museums and archives
- Removal of asphalt and tar fumes from roofing or paving activities
- Removal of chlorine odors from indoor pools in hotels and schools
- Removal of odors from locker rooms
- Removal of jet aircraft exhaust and de-icing odors from airports and heliports
- Smoking lounges and other sources of cigarette (tobacco) smoke odors
- Removal of diesel and automobile exhaust fumes from parking garages
- Control of noxious fumes from cleaning compounds, disinfectants, and insecticides
- Removal of exhaust fumes (from Zamboni machine) from ice skating rinks
- Municipal and commercial facilities
- Waste-water treatment plants
- Cooking odors
- Sewer odors
- Animal odors
- Cleaning compounds
- Paint fumes

Service Life

Once a gas-phase filtration system has been purchased and installed, the most important question is "What is the expected service life of the filter media?"

Service life can be defined many ways, but is most often referred to in terms of removal efficiency. When the efficiency of the system drops below a minimum value, the gas-phase filter (media) is replaced. What the minimum efficiency may be is the subject of much debate. It may an actual value (e.g., 50 percent) or can be based on a subjective criteria such as odor levels.

The most accurate method of determining service life would involve direct gas monitoring upstream and downstream of the gas-phase filters. However, this is an expensive option and cannot be easily applied to most HVAC systems.

Some manufacturers offer media life analysis (MLA) services to assist in determining the appropriate media replacement cycles. This can provide an accurate gauge of actual life remaining. Chemically impregnated media can be readily tested for remaining activity, however, due to the reversible nature of physical adsorption, life analysis cannot be used reliably to test plain activated carbons.

Computer models have been developed that can help provide an estimate of media usage over time. One such model takes the contaminants of concern, their concentrations, and the system airflow and provides recommendations as to the media type(s) required as well as calculates media use over time.

UV-C and Air Purification Systems

UV-C is defined as ultra-violet light at a wavelength that focuses on germicidal disinfection. It is installed in homes and businesses through air-conditioning systems to clean the air of germs, mold, viruses, pollen, and odors. As the air circulates through the UV-C light, it causes damage to the nucleic acid of the microorganism by keeping it from reproducing. This is a beneficial approach to disinfection because there is no use of chemicals. It is inexpensive and requires very low maintenance. The effectiveness of this design is based on the exposure time and intensity of the UV-C light.

Applications for UV-C purification systems include:

- Food processing areas such as breweries, bottling facilities and liquid sugar and sweetener manufacturers
- Medical facilities such as pharmaceutical production, laboratories
- Hospitals and industrial facilities such as cosmetic manufacturers and pond and lake reclamation.

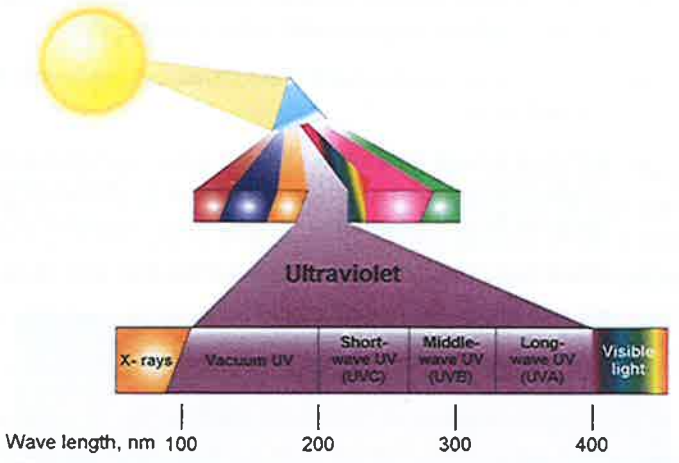


Figure 33

UV-C Spectrum

Introduction to Ultraviolet Light

As shown in Figure 33, the light spectrum shows that the ultraviolet light wave length falls below the visible light and is divided into four areas; UV-A, UV-B, UV-C, and UV Vacuum. All are found in sunlight. However, the negative aspects of sunlight are concentrated in UV-A and UV-B. UV Vacuum contains the wavelength that produces ozone and should be avoided in air that comes in contact with humans. UV-C is the wavelength that affects microbial growth. UV-C is used in the process called UVGI (Ultraviolet Germicidal Irradiation).

UV-C History

Ultraviolet energy was first discovered in the early 1800s. In the 1870s a Scottish physicist theorized that radio waves, microwaves, visible light, ultraviolet light, X-rays, and Gamma rays traveled through space in wave-like patterns.

In the late 1900s a Danish physician found that human bacterial infections that were exposed to the sun healed more rapidly.

Around 1930, Westinghouse discovered that an un-coated quartz-glass, mercury lamp eliminated several kinds of organisms. Knowing of the previous work, Westinghouse introduced it as the "Sterilamp" UV-C tube.

The lamps were primarily used for medicine sterility and food preservation, both of which were needed for World War II. In the mid 1940s, UV-C was used for sterilizing surgical implements, dental instruments, barbering tools, and bowling shoes, as well as, dairy, bakery, pharmaceutical, veterinary, and meat storage facilities.

In the 1950s, when the number of cases of tuberculosis was rising, UV-C was used in upper-air wall applications in hospitals to help limit the spread of the disease.

Much was learned during this period:

- It was determined that the short wavelength, "C" band, was the most effective germicidal light wavelength.
- UV-C was shown to inactivate viruses, mycoplasma, bacteria, and fungi.
- UV-C followed the Inverse Square Law for distance and intensity. In other words, as the distance increases, the intensity is reduced by the squared value of the distance. This means that distance from the lamp is very important for efficiency.
- UV-C lamps produced the highest output in still air at 90° F.
- The dosage needed to eliminate various organisms was established.
- Low pressure lamps were most efficient in terms of watt input to watt output.

UV-C History

Early uses of UV-C light were sterilization and food preservation.

In the mid 1950s more buildings were being air conditioned, so UV-C lamps were put into air handlers. It was found that the velocity and temperature of the air required so many UV-C lamps that it became too costly. The required dose to eliminate an organism was a combination of intensity versus time (D = I x T). About that same time, the HEPA filter was declassified from the Manhattan project and was used in air handlers instead of UV-C.

From 1960 to the mid 1990s the use of UV-C in air systems was primarily upper room and lab hood applications. The use in liquid applications remained strong as the UV-C tube could be sleeved and protected from the cold temperatures.

New Generation of UV-C

About 1995 it became economical to install UV-C fixtures in air handlers due to advances in technology and affordability.

Dirty coils reduce heat transfer and are energy wasters due to air resistance. Coils still get dirty despite good filtration. There is a bio-film on the coils that is the glue to hold both organic and inorganic particulates.

With this bio-film, the cooling coil becomes an incubator as viruses and bacteria double in number approximately every twenty minutes on an average. One particle will become



Figure 34

UV-C Lights Installed in Cooling Coil Section

70 trillion in 24 hours. Mold (fungi) is a little slower. It doubles about every six hours, taking 18 days to get to the 70 trillion particles. This growth is carried into the occupied space with the conditioned air.

Proper application of the UV-C lamps on the coil and drain pan will substantially reduce the contaminants in the air delivered to the occupied space. Additionally, UV-C will return a dirty cooling coil back to its original heat transfer condition. This will result in energy savings that will generally pay for the installation of the UV-C fixtures in the first year. Installing UV-C fixtures on the coils in new equipment will prevent the coils from getting dirty, provided the lamps are changed when required. See Figure 34.

How UV-C Works

The UV-C germicidal lamps are installed in the airstream or pointed at the cooling coil. See Figure 35 for an example of a UV-C lamp. UV-C only affects the organic particles in the air-stream and on surfaces. The dose required to eliminate any species is a combination of intensity and time. UV-C's major target is to destroy the cell. If the dose is not sufficient to destroy the cell, it still can interrupt the DNA strand to prevent replication. The UV-C lamps should be pointed directly at the cooling coil and condensate pan to keep the surfaces free from organic particles. Components and wiring exposed to UV-C light must be resistive to UV-C exposure.

UV-C Exposure

All components within the UV-C lamp exposure area must be resistive to UV-C light or damage may occur.

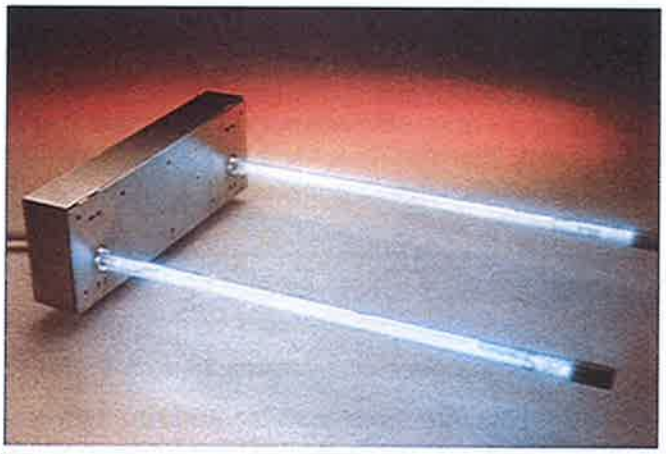


Figure 35

UV-C Lamp

UV-C and Filtration

UV-C technology does not replace mechanical air filters since it only removes organic particles. UV-C intensity works the opposite of mechanical filtration as the smaller the particle, the easier it is to eliminate. Viruses are the easiest to destroy (least intensity required), next is bacteria, then finally mold (fungi) which takes the greatest intensity to eliminate.

Testing and Certification

Currently there are no recognized testing standards or certification methods to document the UV-C fixtures output except for the Illuminating Engineering Society (IES) standard rating method, which is used for any type of light. Proposed standards for testing are presently in development by ASHRAE and International Ultra Violet Association (IUVA). As a result of the lack of standards, the end user of this type of product should have confidence in the integrity of the seller.

UV-C PCO (photo-catalytic oxidation)

The UV-C PCO process is a combination of a UV-C light source and a PCO catalyst that causes a chemical reaction. In order to understand PCO, we must first learn a little about the metal catalyst involved. Titanium has a unique very thin layer of oxidized film present on it called Titanium Oxide (TiO_2). The TiO_2 film has a high refraction ratio and when it is irradiated by UV light. When it is irradiated, molecules such as volatile organic compounds (VOCs) or bioaerosols are attracted to the Titanium catalyst. The contaminants are oxidized by the reaction that takes place during this process.

With PCO technology, after the volatile organic compound or bioaerosol is attracted to the titanium strip it comes into contact with compounds which change the molecular structure of the contaminants. Photo-catalytic oxidation will kill and decompose absorbed bioaerosols, as well as addressing volatile organic compounds.

Mechanical Filter Testing

Before we discuss industry testing let's review some terms associated with filters and testing.

Arrestance is the measure of the weight of synthetic ASHRAE dust a filter can remove from the airstream. Arrestance is the weight of dust caught as a percent of the weight of dust fed. Arrestance is used on low-efficiency filters and provides a measure of air cleaning capability for larger, heavier particles.

ASHRAE Dust is a specially formulated dust is used as a test method for determining arrestance and dust holding capacity. The dust consists (by weight) of 72 percent SAE standard test dust (fine), 23 percent powdered carbon and 5 percent No. 7 milled cotton linters.

Dust Holding Capacity is the amount of ASHRAE dust held by the filter to its rated final resistance.

Filter Efficiency is the degree to which a filter will perform in removing solids. Specifically, it refers to any of three filter tests, ASHRAE 52.1 Atmospheric Dust Spot, ASHRAE 52.2 MERV, or DOP Penetration.

Whereas there are ASHRAE Standards 52.1 and 52.2 that are used to rate the performance of particulate filters, there are currently no standards to rate the performance of gas-phase filters. Work is currently being done to create standards for the rating of gas-phase filters.

ASHRAE 52.1

ASHRAE Standard 52.1 establishes procedures to measure the ability of air-cleaning devices to remove dust as they become loaded with a standard synthetic dust. The dust-removal performance is measured in two ways: first by the percentage of the weight of the synthetic dust captured by the filter (ASHRAE weight arrestance) and second by comparing blackening of targets both upstream and downstream of the air-cleaning device using ambient atmospheric dust (ASHRAE Atmospheric dust-spot efficiency). An example of both tests are shown in Figures 36 and 37.

Determining dust holding capacity is done by introducing a known quantity of dust into the filter inlet and measuring how much dust the filter captures. This standard does acknowledge that the dust holding capability may not match to real-life filter ability. This is because real life conditions and dust types may vary from the test. The initial resistance is measured and compared to the final resistance. A drawback to ASHRAE 52.1 is that it does not determine efficiency ratings for particle size for different filters. The ASHRAE 52.1 test also gives little indication of filter life efficiency.

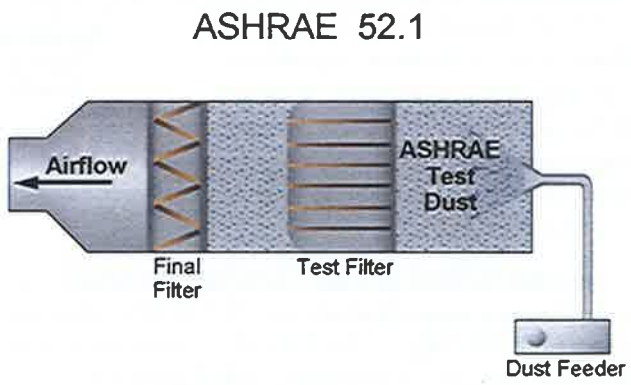


Figure 36

ASHRAE 52.1 Arrestance Weight Test

The dust spot test determines efficiency by sampling an air stain (dust spot) on a target upstream and downstream of the filter being tested. Atmospheric dust is used in the test. Since the amount of staining on the upstream will be greater than that on the downstream, the difference in staining is an indication of filter efficiency. See Figure 37.

The procedures in this standard do not measure the ability of the air cleaner to remove particles of specific diameters. This standard is not intended for testing air cleaners exhibiting ASHRAE dust-spot efficiencies of greater than 98 percent. Depending on the efficiency level of the filter, ASHRAE Standard 52.1 measures up to 5 characteristics of the filter at a specified airflow to a specified final resistance. These characteristics are the initial resistance of the filter, which is the resistance to airflow when the filter is clean; the initial atmospheric dust spot efficiency; the average atmospheric dust spot efficiency; the average synthetic dust weight arrestance; and how much synthetic ASHRAE dust the filter holds (known as dust holding capacity).

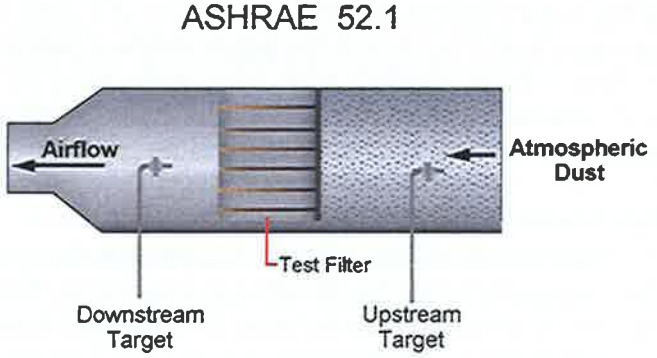


Figure 37

ASHRAE 52.1 Atmospheric Dust Spot Efficiency Test

ASHRAE 52.2

ASHRAE Standard 52.2 is a method of testing general ventilation air cleaning devices for removal efficiency by particle size. ASHRAE Standard 52.2 does not use atmospheric dust. The standard test uses a chemically treated test aerosol. This aerosol (dust) allows for generation of fine particles down to 0.3 microns.

The filter to be tested is loaded with test dust in stages starting with clean and finishing with maximum loading. Each stage is then tested for the filters ability to arrest particles in the 0.3 to 10 micron size. This method produces a more accurate representation of the filters capability to arrest particles instead of the average method used by ASHRAE 52.1 This standard is the new method used to replace portions of 52.1.

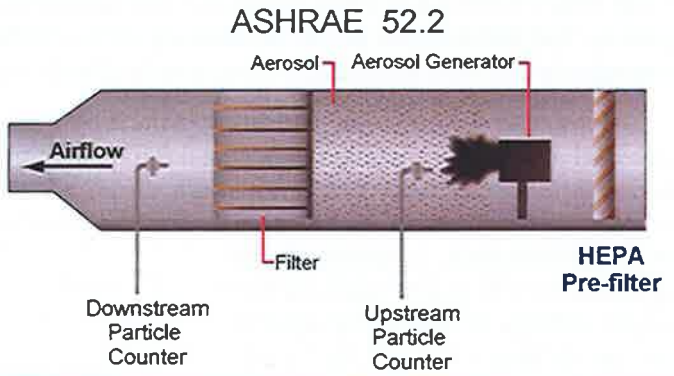


Figure 38

ASHRAE 52.2 Particle Size Efficiency Test

This new method is more accurate because it considers particle size in determining efficiency. This test uses a particle counter to determine the number of particles upstream and downstream of the test filter. The final downstream particle count, taking into account final particle sizes, is the measure of efficiency. See Figure 38.

This standard also establishes performance specifications for the equipment required to conduct the tests, defines methods of calculating and reporting the results obtained from the test data, and establishes a minimum efficiency reporting system that can be applied to air-cleaning devices covered by this standard.

MERV

The test process in ASHRAE 52.2 uses the particle count to assign a minimum efficiency reporting value (MERV). MERV is a measure of a filter's average efficiency performance. Numbers range from 1 to 20 with the higher numbers indicating higher efficiency. The MERV value represents various criteria that the filter meets based on the testing performed. A higher MERV value indicates a greater efficiency across multiple size ranges. As an example, a MERV 13 filter has a higher efficiency of removing smaller particles (0.30 to 1.0 microns) than a MERV 8.

Differences between MERV and Dust Spot

MERV values are often used to describe efficiency for newer filters in the marketplace. This is true especially for the higher efficiency type filters because the MERV process reflects a better indication of efficiency than the older 52.1 dust spot method. As a comparison:

MERV 8 = dust spot efficiencies of 30+ percent

MERV 13 = dust spot efficiencies of 80+ percent

MERV 15 = dust spot efficiencies of 95+ percent

For the high efficiency type HEPA and ULPA filters, the MERV 17 to 20 range is utilized.

Manufacturers will often show the MERV ratings next to the associated dust spot ratings for their product. This is to allow a period of transition from old to new standards.

Refer to Appendix C, Approximate Relationship between a Filter MERV, ASHRAE Dust Spot Efficiency, and Arrestance.

HEPA Testing

HEPA filters are tested with a separate procedure from the standards described above. Because a HEPA filter is so efficient and elimination of bypass air is so critical, the filter media, frame, and even the gasketing must be incorporated into the test procedure.

The test procedure is called the DOP (dioctylphthalate) test. DOP is an oil-like substance, which is used to form the test aerosol used in the ***penetration*** and scan tests of HEPA filters. It is a non-destructive test system and will not damage the HEPA filter.

HEPA filters are manufactured at the factory to remove 99.97 percent of the particles with a mean diameter of 0.3 microns from the airstream. However, upon installation in the field, these filters should be evaluated. This is called "in-place testing" and checks, as a whole, the particulate removal efficiency of the filter, ductwork, gasketing, and filter housing box as installed. The success of an in-place test is a particle removal efficiency of at least 99.97 percent unless local specifications specify a different value. Installed HEPA filters should be tested in-place upon installation, before initial use, and on a regular schedule afterwards.

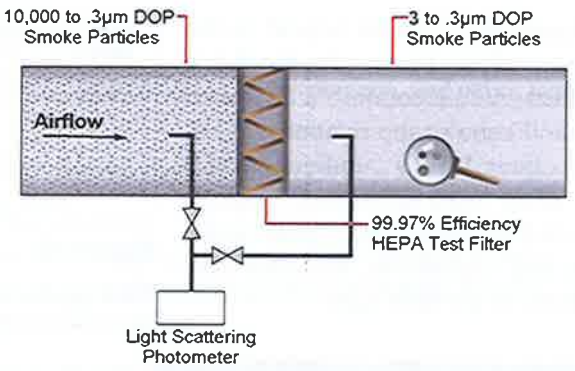


Figure 39

HEPA Filter Test

Because of the critical nature of how these types of filters are used, field testing is extremely important to confirm that the filters are properly installed. Applications like fume hood exhaust and biological safety system filtration require high standards and any leaks due to manufacturing defects or installation workmanship must be found before operation.

The test procedure is performed by introducing an aerosol upstream of the HEPA filter and scanning immediately downstream of the filter and support frames. The aerosol has a controlled distribution of droplet sizes. To obtain a proper mixing of the aerosol and air, the aerosol is injected upstream of the filters with the system fan operating. An aerosol photometer measures representative concentrations upstream (unfiltered air) and downstream (filtered air) of the HEPA filters. The HEPA filter and its installation are acceptable if the percent leakage is equal to or less than 0.03 percent. If the in-place leakage exceeds 0.03 percent and cannot be corrected with sealing clamps, then the filter should be replaced. When possible, the filter system should be checked for filter leaks or seal bypasses. After the defect in the filter is discovered and repaired or replaced, the filter system must be re-tested. See Figure 39.

Selection and Life Cycle Costs

Selection

An acceptable filter must meet or slightly exceed the efficiency requirements of the application. However, there may be several choices that can meet the efficiency requirements. How does one initially decide which filter to use?

The amount and type of particulate and/or chemical contaminants in the air is a major factor in selecting the correct filter type. The selection of the air cleaning method must take into account project location. Contaminant generators like exposed dusty areas, highways, and industrial facilities must be recognized.

The internal operation of the facility itself must be considered next. For example, painting, spraying, hair treatment, smoking, copying, and cooking all create a unique requirement for filtration. Activity within the building that will tend to generate dirt or carry in contaminants from outside should be identified.

Appendix C can be helpful in the decision making process for mechanical filters and electronic air cleaners. Figure 40 shows the relationships between filter MERV, traditional ASHRAE Dust Spot Efficiency, typical controlled contaminant, typical application and limitations, and then recommends an air filter type.

Table C - Approximate Relationship Between a Filter MERV, ASHRAE Dust Spot Efficiency, and Arrestance

Std. 52.2 Minimum Efficiency Reporting Value (MERV)	Approx. Std. 52.1 Results		Application Guidelines		
	Dust Spot Efficiency	Arrestance	Typical Controlled Contaminant	Typical Applications and Limitations	Typical Air Filter/Cleaner Type
20	n/a	n/a	≤ 0.30 µm Particle Size Virus (unattached) Carbon dust Sea salt All combustion smoke Radon progeny	Cleanrooms Radioactive materials Pharmaceutical manufacturing Carcinogenic materials Orthopedic surgery	HEPA/ULPA Filters ≥ 99.999% efficiency on 0.10-0.20 µm particles, IEST Type F ≥ 99.999% efficiency on 0.30 µm particles, IEST Type D ≥ 99.999% efficiency on 0.30 µm particles, IEST Type C
19	n/a	n/a			
18	n/a	n/a			

Figure 40

Filter Application Table
(Reproduced with permission from NAFA Guide to Air Filtration – 3rd edition)

Filter Catalogs

Manufacturers' filter catalogs should be used to determine filter selection from the required cfm and maximum velocity.

For example, for a superior quality commercial office building, the contaminants include bacteria, smoke, copier toner and make-up. The particle sizes in the air can be from 0.3 to 1.0 microns. A good solution would be bag or box filters which are MERV 13 to 15 (80 to 95 percent efficient).

The filter manufacturer's catalogs should then be used to determine the area of filter required based on the cfm and the maximum filter media velocity for the chosen filter type.

Other factors which can affect final selection are: the available space for the filters, design of the filter holding frames (if existing), and operating conditions like temperature and moisture. As an example, an electronic air cleaner should not handle moist air due to electrical arcing concerns.

Operating Costs

The operating cost is a direct function of the filter pressure drop (resistance). A low pressure drop filter costs less in yearly fan motor energy consumption than a high pressure drop filter. The energy to overcome that resistance can be calculated and added to the maintenance costs. Maintenance costs also include the labor to bring replacement filters to the ***filter bank***, the removal of the spent filters, installation of the replacement filters, and disposal.

To calculate the operating cost of the filter we can use the following procedure:

The equation for horsepower for a fan is: $hp = \frac{(cfm * P_s)}{6350}$

P_s is the filter static pressure drop as measured by the methods shown previously. The number 6350 is a constant for air. If we take into account normal losses for belt drives, typical motor efficiencies, and typical fan efficiencies, we can arrive at an equation for the kW (kilowatts) required. This kW will be for the fan to move air across a filter whose static pressure drop and cfm is known. This equation works out to be:

$kW = .0002 * cfm * P_s$

We assume a motor efficiency of 90 percent, fan efficiency of 67 percent, and drive losses of 4 percent.

Knowing the hours of operation of the fan, and the cost of electricity in kWH we can easily convert the filter resistance into fan operating cost.

Unfortunately, the filter resistance is constantly changing as the filter becomes dirtier. It is necessary to use a value of pressure drop that is considered representative during the time duration.

Example: Calculate the cost of operating a 30,000 cfm fan with a bag filter section whose static pressure drop including prefilters is measured at 2.2 in. wg. The fan runs 8 hours a day year round. The cost of electricity is $0.08 kWH.

Annual operating cost = 0.0002 * 30,000 cfm * 2.2 in.wg * 8 hrs/day * 365days/year * $0.08/kW

= $3,083 per year

Maintenance and Replacement Costs

These are the costs involved in making sure the filter system is operable per the manufacturers recommendations. These costs should be added to the first cost, operating costs, and initial installation costs to arrive at a filter cost figure.

Appendix D shows an example of a comparison of two types of filters for a hospital application. The bag and box filters are of equal efficiency. First cost and replacement cost have been factored in. Because of the lower frequency of filter replacement, the box filters look more attractive even though they cost much more. In this example, the filter pressure drop differences are not considered, which could have affected the results.

Replacement Time

There are several factors that determine how long a filter lasts:

If an increased amount of airflow is put through a filter, the pressure drop increases. This shortens the life of the filter. Conversely, when the filter is operated with less cfm than its rated capacity, its life is increased.

Shown in Figure 41 is a chart for an extended surface type filter that depicts the effect of under-rating and over-rating. Under-rating and over-rating means to pass less or more air through it than its rated capacity.

As an example, if the filter in Figure 41 was operated for 3000 hours at 100 percent of rating capacity (cfm), it would have a pressure drop of 0.62 in. wg. If, however, it was installed and operated at only 80 percent of its rating capacity, it would take over 5000 filter operating hours for it to achieve a 0.62 in. wg pressure drop.

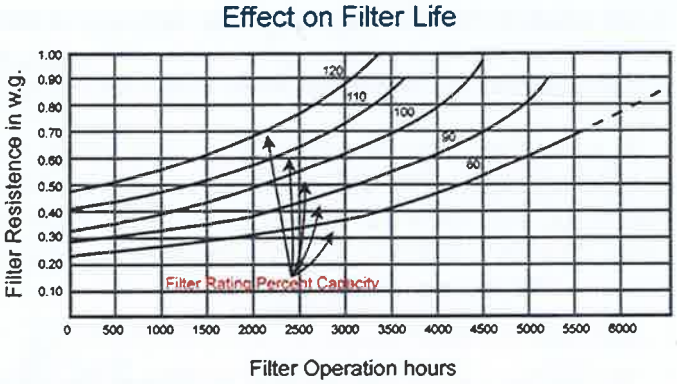


Figure 41

Under-Rating and Over-Rating
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Filter life can be measured as the hours taken to register its final pressure drop.

Filter life is also affected by particle size. Large fibers, for instance, can actually help an extended filter by serving as a screen, but can damage a prefilter by plugging it.

Changing filters is a pivotal decision in filter life cycle analysis. Under-rating the filter increases filter life. However, more filters would have to be purchased in order to handle the required airflow. The longer a filter can be operated, the lower the cost to own it per unit of time. Running the filter to its maximum acceptable pressure drop lengthens its life, but at the expense of fan power.

Filter Changeout

The basis on which filters are changed should be determined through a preventive maintenance program by following a time cycle, through monitoring pressure drop by gauge readings, or by a visual inspection.

The lowest total cost occurs at a point in time where the optimized final filter pressure drop is lowest. If the filter were left in place, pressure drop increases and the resulting power more than offsets the lower cost to own per time. On the chart in Figure 42, T-A represents power cost. T-B represents filter costs. T-C is the total cost. At point C the optimum pressure drop occurs and at that time, not before or after, the filter should be changed.

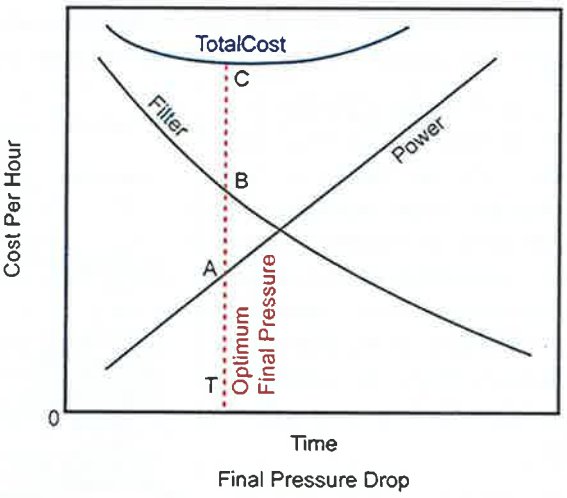

Figure 42

Optimum Final Pressure Drop
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Cost Comparison Worksheet

An owning and operating cost comparison may be necessary to help select between several air cleaning alternatives all of which satisfy the initial criteria. Appendix E is a filter owning and operating cost study sheet that can be used in preparing a final life cycle comparison.

Filter Maintenance

Mechanical Filters

Filtration system maintenance is key to any IAQ program. Filters should always be changed at the right time to utilize the benefits of enhanced filtration. The maximum life of a non-treated filter is one year to minimize microbial growth within the air filter. The allowable system filter resistance should be monitored and the manufacturer's recommended final resistance maintained. Filter resistance should be checked monthly and along with a maintenance log. Plenum doors should be cleaned with every filter change. Defective filters should be replaced when discovered during monthly inspections. Gaskets should be checked to avoid dirty air bypass.

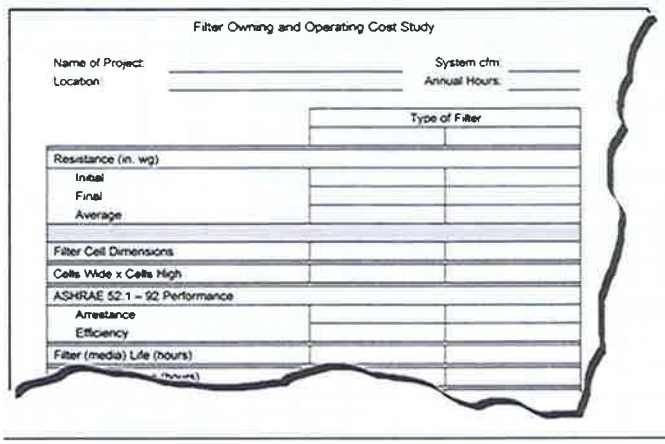
All filters and air cleaning devices must be replaced or maintained as specified by the manufacturer's Operating and Maintenance Manual. Many manufacturers of such devices offer testing and/or monitoring services/equipment to aid in the determination of proper changeout intervals. Filter replacement and/or maintenance activities should be performed as needed. This may not allow for a regular schedule. Although this may present challenges within budget maintenance cycles, timely filter replacement and system maintenance is essential to the optimum performance of the air cleaning system.

An important suggestion for filter maintenance is to keep a filter log. See Figure 43. It may contain the filter manufacturer, type, size, pressure reading and date. The clean pressure drop is very important as a means to determine when to change the filters.

Filters should be periodically inspected for damage by shutting the system down. Routine checks of the pressure drops are most important. If the pressure drop is reporting low (which is an indication of bypassed air) after operation, there may be damage to the filters. If the pressure drop is artificially high, the prefilters may be loaded with leaves or other large debris.

Holding frames should also be inspected with special attention given to gaskets and sealing membranes.

Removal of loaded filters should be done carefully to avoid the release of dust into the system.


Filter Owning and Operating Cost Study

Name of Project: _____ System cfm: _____

Location: _____ Annual Hours: _____

	Type of Filter	
Resistance (in. wg)		
Initial		
Final		
Average		
Filter Cell Dimensions		
Cells Wide x Cells High		
ASHRAE 52.1 – 92 Performance		
Arrestance		
Efficiency		
Filter (media) Life (hours)		

Figure 43

Filter Log

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Electronic Air Cleaners and UV-C

Electronic air cleaners can have washable or removable elements. The manufacturers washing recommendations should be followed, as there are slight differences between various brands. Often common household detergent is used to wash components.

Ionization wires should be checked for breakage (which is common) and be replaced. The prefilter should be cleaned or replaced when loaded. Special attention should be given to making sure the EAC is dry.

UV-C lights must be checked on a regular basis to be sure they are operative. Follow manufacturer's recommendations for hours of usage before replacement. Check that the lamp mounting hardware is directing the light at the coil surface and condensate pan.

Filtration and Energy Conservation

While the Ventilation Rate Procedure (VRP) of Standard 62.1 specifies minimum ventilation rates that should result in acceptable IAQ, these rates represent an indirect solution for the control of outdoor and indoor contaminants. Although it does allow for the use of cleaned and recirculated air, it does not allow the use of this air to reduce the amount of outdoor air specified.

The Indoor Air Quality Procedure (IAQP) provides a direct solution for reducing and controlling both particulate and gaseous contaminant concentrations through air cleaning to specified acceptable levels. It acknowledges that air cleaning, along with recirculation, is an effective means for controlling contaminants via this procedure. The IAQP allows the amount of outside ventilation air to be reduced below levels that would have been required by the VRP, if it can be demonstrated that the resulting air quality is equal to or better than that achieved using the VRP.

Reducing the outdoor air intake rate can result in significant HVAC capital equipment and operating cost savings for some systems in some climates. Additionally, many major utility companies have established aggressive programs to help large energy users develop conservation programs, and, in most cases, will provide substantial funding to implement these system improvements in existing buildings and new designs. Similar funding is available from building control system suppliers.

The tools to conserve energy and reduce HVAC operating costs are in place. ASHRAE Standard 62.1-2004, in particular, the IAQ Procedure, allows for a balance to be struck between IAQ and energy conservation. New gas-phase air filtration technologies now provide an off-the-shelf, retrofit filter that removes a broader spectrum of gaseous contaminants as well as maintaining a specified level of particulate filtration. This allows control of the indoor environment while reducing energy costs.

For many buildings, the IAQ Procedure is an option that will provide improved indoor air quality as well as reduce the amount of energy spent on conditioning the ambient air. It is a powerful tool for building owners and engineers to consider.

Summary

Indoor air quality has become an increasingly important aspect of commercial HVAC system design due to concerns regarding occupant health and the work environment. Filtration is a key aspect in any IAQ strategy because, when properly designed, a filtration system can provide cleaner air to the occupied spaces while conserving energy.

Using air filtration for improved IAQ involves knowing the sources and types of contaminants found in comfort air-conditioning systems, understanding the characteristics of a good IAQ air filter and providing proper selection, installation and maintenance of the air filtration system.

Air is contaminated by natural and man-made sources, including atmospheric dust, airborne microorganisms, and gases. Filters clean air by either capturing contaminants or removing them from the airstream. They are characterized by the method employed to remove the contaminants, the type of media used, the physical construction of the filter, and the efficiency rating.

Several air filtration strategies exist and selecting the optimum program depends on the standard of cleanliness required, the operating environment, the space available for filtration, the cost of maintenance, and the system design.

Particulate filtration choices include panels, automatic self-renewable, extended surface, HEPA, electrostatic, and electronic air cleaners.

Gas-phase air cleaning choices include bulk granular adsorbent and/or chemisorbant media in refillable or disposable trays and modules and pleated adsorbent-loaded non-woven fiber filters.

ASHRAE Standards 52.1 and 52.2 govern the rating and evaluation of filters. Filters are assigned a Minimum Efficiency Reporting Value (MERV) that distinguishes their ability to remove dust and particles from the airstream.

Work Session

1. What are the metric and English values of one micrometer (micron)?

   _____ meter _____ inch

2. Name four mechanical air filtration methods:

   _____

   _____

   _____

   _____

3. Define air filter pressure drop.

   _____

   _____

4. What is atmospheric air composed of? (name 3 basic components)

   _____

   _____

   _____

5. Why are adhesives used on impingement filters?

   _____

   _____

6. True or False? With the ASHRAE 52.1 Test method, the term "arrestance" relates only to the test which measures the weight of an injected synthetic test dust which is removed by the air filtering device. _____

7. When conducting the ASHRAE 52.1 dust spot efficiency determination, what test dust is used to determine the filter efficiency?

   _____

   _____

8. True or False? Most extended surface mechanical filters have their lowest efficiency when the filter media is clean. _____

9. Why is it good air filtration practice to have a prefilter and final filter for a gas phase filtration unit?

_____

_____

10. True or False? To be called HEPA, filters must have a minimum particle collection efficiency of 99.97 percent with 3 micron particles. _____

11. Give two reasons why it is desirable to prefilter electronic air filters.

_____

_____

12. True or False? ULPA filters typically have an efficiency of 99.999 percent with 0.3 micron particles. _____

13. List eight criteria for filter selection:

_____ _____

_____ _____

_____ _____

_____ _____

14. List the factors that could affect filter life:

_____

_____

15. What does "MERV" stand for?

_____

_____

16. Give the reasons for having enhanced air filtration in a commercial building air-conditioning system:

_____

_____

17. List the 3 techniques for testing filters for concentration of particles:

_____

_____

_____

18. True or False? The air is one path that microorganisms use to reproduce.

_____

19. Explain the two types of chemical filtration:

_____

_____

20. True or False? Changing a filter's capacity will affect pressure drop, dust holding capacity and could also affect efficiency. _____

21. What is the advantage of having air filters made with extended media surface?

_____

_____

Work Session Answers

1. 1.0 μ = 1/1,000,000 meter or 1/25,400 inch
2. The four mechanical air filtration methods are:
   - straining
   - impingement
   - interception
   - diffusion
3. The difference between the measurement of static pressure upstream and downstream of the filter.
4. The atmosphere is composed of oxygen (21 percent), nitrogen (78 percent), and a mixture of remaining trace gases (1 percent).
5. To hold the dust particle once it is caught on a fiber.
6. True
7. Suspended Atmospheric Dust
8. True. These filters are rated on their average efficiency, when the filter is clean it has no dust to build on. The filter is at its highest efficiency when it is ready to be changed.
9. Prefilters will be in place to capture any particles that might plug the media. The final filter should be in place to capture any adsorbant dust which may become airborne.
10. False. 0.3 microns
11. It is desirable to use prefilters with electronic air filters for enhanced air distribution and to capture large particles which may short circuit the electronically charged plates.
12. False. 0.1-0.2 μ
13. The eight criteria for filtration selection are:
    - Degree of air cleanliness required
    - Amount and type of dust in the air
    - Operating conditions (temperature and relative humidity)
    - Operating resistance to airflow
    - Space available for filtration
    - Cost of maintaining and replacing filters
    - Design of the filter holding frames
    - Disposal of the filter after it is removed
    - Initial cost of the system.
14. Factors that can affect filter life are: moisture or humidity, use of variable or fixed airflow HVAC system, the type of prefilter, the amount of media (dust holding capacity), the surrounding environment (nearby construction site, heavy pollen drop), and the number of stages of filtration (two stage versus three stage).
15. Minimum Efficiency Reporting Value

16. The reasons for having enhanced air filtration in a commercial building air-conditioning system are to:
    - Protect the general well being of the occupants of the space
    - Remove the staining portion of airborne dust
    - Reduce maintenance of building interiors such as blinds and bulbs
    - Protect the contents of the building, such as furniture and window treatments
    - Eiminate fire hazards by removing lint and other items that accumulate in duct work
    - Protect machines and equipment.
17. Weight, count, and area
18. True
19. The two types of chemical filtration are adsorption and chemisorption. Adsorption is the process by which gases adhere to solid surfaces. Chemisorption removes gases by a chemical reaction of the gas with an impregnant substance on or in the filter.
20. True
21. An extended media surface on filters offers the advantages of lower velocity, higher performance, lower initial resistance, longer life, and extended filter life

Appendix A – Typical Performance Values of Impingement Filters

(Note that these are typical values)
(Filter manufacturers should be contacted for performance data of specific filters)

Media Description	Face Velocity fpm (m/s)	Clean Pressure Drop in. wg (Pa)	AHSRAE 52.1 Arrestance Percent (1)	AHRAE 52.2 MERV	Dust Holding Capacity (1) (2) g/ft^2 (g/m^2)	Final Pressure Drop in. wg (Pa)
2" washable metal, graded density, adhesive coated	350 (1.78)	0.06 (15)	60-70	1-2	110-120 (10.2-11.1)	0.50 (124)
1" washable metal, graded density, adhesive coated	350 (1.78)	0.05 (12)	50-60	1	100-110 (9.29-10.2)	0.50 (124)
2" formed screen permanent washable	300 (1.52)	0.10 (25)	75-80	3-4	100-110 (9.29-10.2)	0.50 (124)
1" thick spunglass	300 (1.52)	0.06 (15)	60-70	1-2	40-50 (3.71-4.65)	0.50 (124)
2" thick spunglass	300 (1.52)	0.08 (20)	70-80	3-4	50-65 (4.65-6.04)	0.50 (124)
1" thick dual-density polyester	300 (1.52)	0.14 (35)	85-90	4	40-50 (3.71-4.65)	0.50 (124)
0.5" thick monodensity polyester	300 (1.52)	0.10 (25)	80-85	4	35-45 (3.25-4.18)	0.50 (124)
1" thick monodensity polyester	350 (1.78)	0.08 (20)	80-85	4	40-50 (3.71-4.65)	0.50 (124)
1" thick passive electrostatic polyethylene media	350 (1.78)	0.12 (30)	60-90	4	40-50 (3.71-4.65)	0.50 (124)

Notes:
(1) Average value to the final pressure drop shown
(2) Note that dust holding capacity is given in terms of grams per square foot

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Appendix B – Typical Performance Values of Extended Surface Filters

Face Dimensions 24 in. x 24 in. (610 mm x 610 mm)
Rated Capacity 2000 cfm (0.945 m^3/s)

Type Filter	Media Type	Depth Inches (mm)	Average Efficiency (1)	ASHRAE 52.2 MERV	Initial Pressure Drop in. wg (Pa)	Media Velocity fpm (m/s)	Media Area ft^2 (m^2)
Non-supported (Bag)	Glass	29 (737)	90-95	14	.50-.60 (124-149)	24 (.122)	84 (7.8)
			80-85	13	.40-.50 (99.5-124)		
			60-65	11	.35-.40 (87.1-99.5)		
			45-50	9-10	.15-.20 (37.3-50.0)	32 (.163)	63 (5.85)
Non-supported	Synthetic	29 (737)	90-95	14	.50-.60 (124-149)	24 (.122)	84 (7.8)
			80-85	13	.40-.50 (99.5-124)		
			60-65	11	.35-.40 (87.1-99.5)		
		25 (635)	45-50	9-10	.30-.35 (74.6-87.1)	45 (.224)	44 (4.18)
		15 (381)	30-35	8	.25-.30 (62.2-74.6)	63 (.102)	32 (2.97)
Box (Corrugated Separators)	Glass	12(305)	90-95	13-14	.65-.75 (162-202)	16 (.081)	125 (11.6)
			80-85	12-13	.50-.60 (124-149)	20 (.102)	100 (9.26)
			60-65	10-11	.40-.50 (99.5-124)		
Box	Glass (high loft)	12 (305)	90-95	13-14	.65-.75 (162-202)	34 (.088)	58 (5.39)
			80-85	12-13	.50-.60 (124-149)		
			60-65	10-11	.60-.65 (99.5-124)		
Pleated Panel	Polyester/Cotton	2 (50.8)	20-30	6-8	.20-.35 (49.8-87.1)	125 (.635)	16 (1.49)
		4 (101.6)	20-30	6-8	.20-.35 (49.8-87.1)	83 (.422)	24 (2.23)
	Glass	2 (50.8)	30-40	7-8	.20-.35 (49.8-87.1)	125 (.635)	16 (1.49)
		4 (101.6)	30-40	7-8	.20-.35 (49.8-87.1)	83 (.422)	24 (2.23)
Box Vee Panel Type	Glass	12 (305)	90-95	14	.35-.40 (87.1-99.5)	10.5 (.053)	190 (17.7)
			80-85	13	.25-.30 (62.2-74.6)		
			60-65	11	.20-.25 (49.8-62.2)		

Note: 1. Efficiency is ASHRAE 52.1 atmospheric dust spot discoloration efficiency (percent)

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Appendix C – Approximate Relationship between a Filter MERV, ASHRAE Dust Spot Efficiency, and Arrestance

Std. 52.2 MERV	Approx. Std. 52.1 Results		Application Guidelines		
	Dust Spot Efficiency	Arrestance	Typical Controlled Contaminant	Typical Applications and Limitations	Typical Air Filter/Cleaner Type
20	n/a	n/a	**≤ 0.30 µm Particle Size** Virus (unattached) Carbon dust Sea salt All combustion smoke Radon progeny	Clean rooms Radioactive materials Pharmaceutical manufacturing Carcinogenic materials Orthopedic surgery	**HEPA/ULPA Filters** ≥99.999% efficiency on 0.10-0.20 µm particles, IEST Type F ≥99.999% efficiency on 0.30 µm particles, IEST Type D ≥99.999% efficiency on 0.30 µm particles, IEST Type C ≥99.999% efficiency on 0.30 µm particles, IEST Type A
19	n/a	n/a			
18	n/a	n/a			
17	n/a	n/a			
16	n/a	n/a	**0.30-1.0 µm Particle Size** All bacteria Most tobacco smoke Droplet nuclei (sneeze) Cooking oil Most smoke Insecticide dust Copier toner Most face powder Most paint pigments	Hospital inpatient care General surgery Smoking lounges Superior commercial buildings	**Bag Filters** Non supported (flexible) microfine fiberglass or synthetic media. 300 to 900 mm (12 to 36 in.) deep, 6 to 13 pockets. **Box Filters** Rigid style cartridge filters 150 to 300 mm (6 to 12 in.) deep may used lofted (air laid) or paper (wet laid) media.
15	>95%	n/a			
14	90 – 95%	>98%			
13	80 – 90%	>98%			
12	70 – 75%	>95%	**1.0-3.0 µm Particle Size** Legionella Humidifier dust Lead dust Milled flour Coal dust Auto emissions Nebulizer drops Welding fumes	Superior residential Better commercial buildings Hospital laboratories	**Bag Filters** Non supported (flexible) microfine fiberglass or synthetic media. 300 to 900 mm (12 to 36 in.) deep, 6 to 13 pockets. **Box Filters** Rigid style cartridge filters 150 to 300 mm (6 to 12 in.) deep may used lofted (air laid) or paper (wet laid) media.
11	60 – 65%	>95%			
10	50 – 55%	>95%			
9	40 – 45%	>90%			
8	30 – 35%	>90%	**3.0-10.0 µm Particle Size** Mold Spores Hair spray Fabric protector Dusting aids Cement dust Pudding mix Snuff Powdered milk	Commercial buildings Better residential Industrial workplaces Paint book inlet air	**Pleated Filters** Disposable, extended surface, 25 to 125 mm (1 to 5 in.) thick with cotton-polyesters blend media, card board frame **Cartridge Filters** Graded density viscous coated cube or packet filters, synthetic media **Throwaway** Disposable synthetic media panel filters
7	25 – 30%	>90%			
6	<20%	85 – 90%			
5	<20%	80 – 85%			
4	<20%	75 – 80%	**>10.0 µm Particle Size** Pollen Spanish moss Dust mites Sanding dust Spray paint dust Textile fibers Carpet fibers	Minimum filtration Residential Window air conditioners	**Throwaway** Disposable synthetic media panel filters **Washable** Aluminum mesh, latex coated animal hair, or foam rubber panel filters **Electrostatic** Self charging (passive) woven polycarbonate panel filter
3	<20%	70 – 75%			
2	<20%	65 – 70%			
1	<20%	<65%			

Note: A MERV for other than HEPA/ULPA filters also includes a test airflow rate, but it is not shown here because it has no significance for the purposes of this table.

Taken from ANSI/ASHRAE Standard 52.2-1999, p. 39

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Appendix D – Hospital Final Filter Cost Comparison

Bag Filter									
Size	**Description**	**Efficiency**	**Media**	**Media Area**	**Dust-Holding Capacity**	**Price**	**Change Costs**	**Frequency**	**Total Cost**
24 x 24 x 21	Bag	95%	Fiberglass	60 ft^2	270 grams	$22.03	$8.00	3	$90.09
Box Filter									
24 x 24 x 12	Box	95%	Ultra-fine micro-glass paper with dual-density construction. Mechanical filtration.	175 ft^2	560 grams	$72.61	$8.00	1	$80.61

Appendix E – Filter Owning and Operating Cost Study

Name of Project: _____ System cfm: _____

Location: _____ Annual Hours: _____

	Type of Filter	
Resistance (in. wg)		
Initial		
Final		
Average		
Filter Cell Dimensions		
Cells Wide x Cells High		
ASHRAE 52.1 – 92 Performance		
Arrestance		
Efficiency		
Filter (media) Life (hours)		
Replacement Time (hours)		
Number of changes per year		
Cost of Initial Installation		
Equipment cost		
Installation		
Electric wiring		
Miscellaneous		
Total Installed Cost		
Annual Operating Cost		
Material		
Labor at $____/hr		
Electric Power		
Miscellaneous		
Annual Operating Cost		
Fixed Charges at _____%		
Total Owning and Operating Cost		

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Glossary

adsorption	a process by which a gas, vapor, or liquid molecule is attracted and held on the internal surfaces of a solid, particularly on a finely divided material.
aerosol	a mixture of fine liquid or solid particles suspended in air, i.e., smoke, fog, and fumes.
arrestance	a filter efficiency rating that measures the percentage of captured dust relative to a known total dust quantity.
ASHRAE dust	a specially formulated dust used as a test method to determine arrestance and dust holding capacity.
bag filter	an extended surface filter constructed of a special blend of paper and fiber in the shape of many pockets or bags that are held open only by the velocity of the airstream.
box filter	a filter that has pleated media installed in a rigid frame constructed of metal or plastic.
cartridge filter	an extended surface filter, normally rectangular, with internal support grids.
chemisorption	removal of gases from an airstream by the chemical reaction of the gas with an impregnant on or in the adsorbent media.
clean room	a specially constructed enclosed area that is environmentally controlled with respect to airborne particulates, temperature, humidity, air pressure, airflow patterns, air motion, and lighting.
diffusion	a method of filtration where a particle strikes a fiber and is retained by the inherent adhesive forces between the particle and fiber (van der Waals forces).
disposable filter	a filter that is discarded when completely loaded and replaced with a new one.
DOP (dioctylphthalate)	an oil-like substance that is readily atomized to form the test aerosol used in overall penetration and scan tests of HEPA filters.
downstream	the portion of the system located after the filter on the leaving air or the clean air side of the filter.
dust holding capacity	the total amount of ASHRAE dust held by the filter at the time it reaches its rated final resistance rating.
electronic air cleaner	a electronic device used to remove particulate or impurities from the air using electrostatic precipitation.
electrostatic filter	a mechanical filter whose ability to collect impurities in the air is enhanced by an electrostatic charge that is applied during manufacture.

electrostatic precipitation	a method of filtration requiring a continuous external power source that imparts a positive charge to airborne particulate matter and collects the particles on negatively charged collection plates.
extended surface filter	a filter that is designed with pleats or pockets to increase the amount of media exposed to the airstream within a given face dimension to increase efficiency.
face area	the area of the filter media within the filter frame through which air passes.
face velocity	the speed of the airflow as it approaches the filter at 90 degrees to the filter frame.
fiberglass	a term used to describe a variety of filter media made with fine glass fibers.
filter	a device used to remove airborne contaminates.
filter bank	two or more filters connected to each other to form a panel of filters.
filter efficiency	that fraction of contaminants which are removed at a given time by physical and/or chemical means; relative comparison of the amount of contaminants removed or reduced at a given time by the filter/air cleaner compared to the amount exposed to it.
filter frame	a structure that houses the filter media and keeps its shape; not all filters have frames.
filter life expectancy	the service life or change out interval of a filter cartridge.
filter media	the material in the filter that performs the task of capturing contaminants.
filter medium	the porous material through which air passes to remove particulates; generally made of fiberglass, polyester, or metal and usually confined within a frame or cell sides.
final filter	the last, most efficient filter in a multi-stage progressive filtration system that is placed downstream of all other components.
final pressure drop	see final resistance.
final resistance	the maximum recommended pressure drop across a filter normally determined by the manufacturer and used to indicate when a filter should be changed.
HEPA filter	"High-Efficiency Particulate Air," type of extended surface filter that has a minimum particle collection efficiency of 99.97 percent.
impingement	a method of filtration that is effective on particles with sufficient inertia to cause them to leave the airstream and collide with a fiber, causing the particle to be held in place by the air and fiber spacing.

interception	a method of filtration that occurs when a particle is held by the inherent adhesive forces of attraction between the particle and fiber.
manometer	a device that measures pressure drop in gases and vapors by a height difference in two columns of a liquid.
media area	the measure of the filter media through which air passes.
micron	a unit of length in the metric system equal to one millionth of a meter (1/25,400 inches) commonly used as a measure of particle size or fiber size in filter media.
panel filter	a low-efficiency filter consisting of a flat sheet of media that is usually contained within a frame.
penetration	the leak rate through the filter expressed as a percentage based upon a specific particle size; the reciprocal of percent efficiency.
prefilter	a filter placed upstream of another filter to remove the larger, heavier particles to extend life of the final filters.
pressure drop	in a filter, the measure of the resistance to airflow in in. wg.
rigid cell filter	multliple box filters arranged within a frame, with low pressure drops and extend life.
roll filter	a filter in which the filter medium is a continuous belt on movable rolls that brings clean filter media into the airstream, either automatically or manually.
straining	a method of filtration that occurs when a particle is larger than the space between fibers and cannot pass through them.
ULPA filter	"Ultra Low Penetration Air," type of extended surface filter that has a minimum particle collection efficiency of 99.99 percent.
upstream	the portion of the system located before the filter on the entering air side of filter.
van der Waals forces	the forces of attraction between molecules.



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