Filtration 101 for Schools

The HVAC industry (heating, ventilation, and air conditioning) is a multibillion-dollar global industry employing hundreds of thousands and has a presence in virtually every building. Each letter in HVAC represents a separate industry requiring a wide range of engineering disciplines to develop and manufacture the products demanded today.

Within an HVAC system, the V stands for ventilation which in this context, can be defined as the process of supplying or removing air by use of a fan, from a space for the purpose of conditioning the air to control temperature, humidity, or pressure for example. Filtration in this context can be thought of as the process of removing particles from that air and the air filter is the specific device that removes those particles.

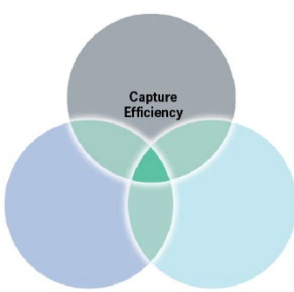
The Air Filter

The air filter is a single component in a much larger and more complex HVAC system. However, since all the ventilated air is intended to flow through the air filter, it can affect the entire system and thus the occupants within the building. Because of this, the air filter is a critical component and must be selected to optimize the HVAC system's design criteria. In order to do so, it is helpful to understand the three main performance attributes of an air filter and how they work together

An air filter should remove the percentage of specific particles sizes according to its rated value (particle capture efficiency) while not restricting airflow through the filter and into the space (resistance to airflow) and should perform those two functions while holding the dirt collected within the body of the filter for a reasonable service life to reduce maintenance expenses (dirt holding capacity).

Each of the three performance attributes works in conjunction with the others. When constructed properly, the best air filter performs in the intersection of all three and delivers optimum performance: high particle capture efficiency with a low average resistance to airflow with a reasonably long service life.

Particle Capture Efficiency (MERV value)



Particle capture efficiency is the effectiveness of the air filter in removing particles. There are two major rating systems commonly used today. MERV (Minimum Efficiency Reporting Value) is contained within ASHRAE Standard 52.2 and ISO16890 is a filter test standard created by the International Organizations for Standardization.

ASHRAE Standard 52.2- 2017, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size, is currently the dominant test standard in North America and provides guidance on how to test a specific air filter and award it a Minimum Efficiency Reporting Value (MERV). This value is then used to apply a specific MERV level to a filter based on the level of protection the application or facility requires as recommended by cognizant authorities. Particles are grouped into three size ranges, 0.3 microns to 1, 1 to 3.0 microns, and 3.0 to 10 microns. A MERV value is assigned based on the filter's ability to capture a certain percentage of particles in each size range.

ISO 16890 Air Filters for General Ventilation is an international test standard that replaced EN779 in July 2018. This test standard classifies air filters based on the removal efficiency of particulate matter (PM) for three size ranges; PM1, PM2.5 and PM10. ISO16890 assigns a value to a filter based on particle capture within one PM range. Unlike ASHRAE 52.2, the ISO standard incorporates a conditioning step procedure to account for the benefit of a temporary electrostatic charge which can inflate a filter's particle capture efficiency performance.

During the COVID-19 pandemic, the ASHRAE Epidemic Task Force provided the HVAC industry with core recommendations for schools and universities. Many state and local officials adopted or refer to these for basic guidelines regarding air filtration. These recommendations call for a **minimum** filtration efficiency of MERV 13. The ISO16890 equivalent of MERV 13 is ePM_1 -50%. See the comparison chart below.

HVAC systems can be configured with a single air filter stage while others can have multiple stages of air filtration. If the HVAC unit is a single-stage type, that air filter should be a minimum of MERV 13. If the unit has multiple stages, the final stage should be a minimum MERV 13 while the prefiltration in those units can be less than MERV 13.

Note: Particle capture efficiencies, (MERV values), are not additive. A MERV 5 filter followed by a MERV 8 filter does not equal the same performance as a single MERV 13 filter.

ASHRAE Standard 52.2-2017					ISO 16890				EN779 (Obsolete)			
Minimum Efficiency Reporting Value	Composite Average Particles Size Efficiency E value (%) in Size Range			Avg. Arrest.	Average of Initial and Discharged Efficiency $E_m = (E_i+E_d)/2$		Initial Efficiency (E_i)	Initial Efficiency (A_i)	Filter Class	Avg. Arrest. (A_m) of Synthetic Dust	Avg. Eff. (E_{min}) at 0.4µm	Min. Eff. (E_{min}) at 0.4µm
MERV	Range 1 (µm) 0.3 - 1.0	Range 2 (µm) 1.0 - 3.0	Range 3 (µm) 3.0 - 10.0	%	ePM1 (%) 0.3-1.0	ePM2.5 (%) 1.0-3.0	ePM10 (%) 3.0-10.0	ISO Coarse (%) ISO Fine Dust				
1			$E_3<20$	$A_m<65$				$A_i<50$ Final dP 200 Pa	G1	$50\le A_m<65$		
2			$E_3<20$	$65\le A_m$					G2	$65\le A_m<80$		
3			$E_3<20$	$70\le A_m$								
4			$E_3<20$	$75\le A_m$								
5			$E_3\ge20$	N/A				$A_i\ge50$ Final dP 300 Pa	G3	$80\le A_m<90$		
6			$E_3\ge35$	N/A								
7			$E_3\ge50$	N/A					G4	$90\le A_m$		
8		$E_2\ge20$	$E_3\ge70$	N/A								
9		$E_2\ge35$	$E_3\ge75$	N/A			$E_i\ge50$		M5		$40\le E_m<60$	
10		$E_2\ge50$	$E_3\ge80$	N/A								
11	$E_1\ge20$	$E_2\ge65$	$E_3\ge85$	N/A		$E_m\ge50$	$E_i\ge70$		M6		$60\le E_m<80$	
12	$E_1\ge35$	$E_2\ge80$	$E_3\ge90$	N/A								
13	$E_1\ge50$	$E_2\ge85$	$E_3\ge90$	N/A	$E_m\ge50$	$E_m\ge65$	$E_i\ge80$		F7		$80\le E_m<90$	$E_{min}\ge35$
14	$E_1\ge75$	$E_2\ge90$	$E_3\ge95$	N/A	$E_m\ge70$	$E_m\ge75$	$E_i\ge85$		F8		$90\le E_m<95$	$E_{min}\ge55$
15	$E_1\ge85$	$E_2\ge90$	$E_3\ge95$	N/A	$E_m\ge80$				F9		$95\le E_m$	$E_{min}\ge70$
16	$E_1\ge95$	$E_2\ge95$	$E_3\ge95$	N/A								

A_i= Initial Arrestance
A_m= Average Arrestance
E_i= Initial Efficiency
E_d= Discharged Efficiency
E_m= Average Efficiency
E_{min}= Minimum Efficiency

- The filter class is the highest class where the filter meets all requirements.
- Comparisons are approximations given for reference only. Filters should be tested to the most recent standards.
- For ISO ePM1 and ePM2.5 both initial and discharged efficiency need to be over 50% to qualify for a class.
- Comparisons between ISO 16890 and ASHRAE 52.2 are more accurate when the MERVA value is used.

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MERV versus MERV-A

A filter's MERV value is important because the user can refer to the MERV chart and see the percentage of particles within each size range the filter is rated to remove. Since a higher MERV generally comes with a higher pressure drop, filter manufacturers have developed techniques to achieve higher MERV, but with lower pressure drops. To do this, electrostatically charged filter media is used. There are positive and negative attributes with this type of air filter.

It's helpful to understand how a typical N95-style face mask works and how this relates to electrostatically charged air filters. The 95 in N95 stands for 95% particle capture efficiency and in this case, on 0.3-micron particles. That's a very high particle capture efficiency; slightly higher than a MERV 16 air filter. However, while you can breathe relatively easily through an N95 mask, the same mask made from MERV 16 filter media would be very difficult to breathe through because the airflow resistance (pressure drop) would be very high.

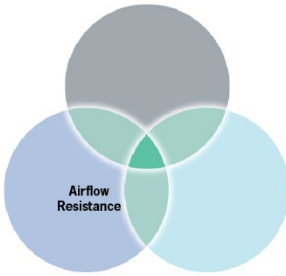
An N95 mask accomplishes high particle capture efficiency with low airflow resistance by relying on a thin layer of fabric with a very low resistance to airflow. This fabric layer also carries an electrostatic charge, creating what's known as an electret. This charge attracts particles out of the airstream onto the fibers (much like how a magnet attracts metal) and the charge holds them in place. The high particle capture efficiency with low resistance is an ideal solution for respiratory face masks, but the technology faces challenges when used on air filters.

An N95 respiratory mask is designed for limited use and the volume of air we breathe is much smaller than the amount of air an HVAC system moves during a typical day. As large volumes of air move through the electrostatically charged filter, the ultra-fine accumulating dirt particles begin to insulate the charge from attracting dirt particles. As this process builds, more and more dirt particles slip past until eventually, the charge is adding no value to the particle capture efficiency performance. The MERV value of this filter falls.

The ASHRAE 52.2 committee is aware of this loss in efficiency phenomenon and created a supplementary test procedure to MERV known as Appendix J. This test procedure removes the benefit of any charge on a filter and delivers a MERV value without it. This gives a more realistic view of how the air filter will perform in a real-world setting after a period of time has passed and its charge is no longer effective.

This is known as the MERV-A value.

Airflow Resistance (Pressure Drop)



All air filters present a measurable amount of resistance to airflow. As air weaves through the fibers of the filter media, the buildup of air increases the pressure upstream of the filter compared to the downstream side. This is commonly referred to as pressure drop and is measured in inches of water gauge, abbreviated as " w.g.

Specifications provided by air filter manufacturers should list the initial pressure drop when the filter is brand new at a standardized volume of airflow. All filters tested according to ASHRAE 52.2 and labeled with a MERV value are tested at 2000 cfm (cubic feet per minute) or 500 fpm (feet per minute) on a 24" high by 24" wide air filter.

As dirt loads on the filter, pressure drop increases, less conditioned air is flowing into the space, and the desired comfort level of the room is not maintained. The length of time for this to occur varies based on the performance attributes of the air filter, the volume of airflow, and the cleanliness of the source air.

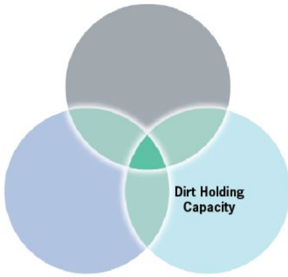
When airflow is restricted, there are two possible responses based on the controls within the HVAC system.

If the unit is equipped with a variable frequency drive fan (VFD) and set to adjust fan speed based on pressure drop, the fan will speed up to restore the proper airflow. At each interval when the fan speed increases, energy cost likewise increases. At some point, the pressure drop has increased to the point where the fan can no longer maintain proper airflow and the filter should be changed.

On systems with a constant-speed fan and no way to increase the fan speed, the airflow into the room will gradually decrease as resistance increases. At some point, this filter will need to be replaced to restore the proper airflow.

A widely used rule of thumb for both systems is to change the filter when the initial pressure drop doubles. This is not an absolute rule but is helpful to use as a starting point to determine when to change the air filters in each system. The rationale behind this is the cost and performance drop-off associated with a pressure drop that has doubled is more expensive than the cost to change the filter.

Dirt Holding Capacity (DHC)

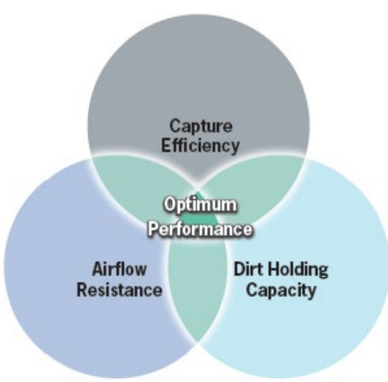


The third performance attribute relates to service-life. Air filters capture dirt from the air as it passes through, but the filter must also hold that dirt and prevent it from working loose and continuing downstream. The amount of dirt the filter can hold directly affects how long the filter can be left in service. Changing air filters can be an expensive and time-consuming task for any maintenance department. Not only does it incur a direct expense, but it also prevents or delays workers from doing other important projects which may have significant cost-saving benefits to the facility. If the facility hires outside vendors for filter changeouts, that can often be a major expense depending on the size of the facility or campus.

Dirt holding capacity is a product of particle capture efficiency. A filter that is more efficient at capturing dirt is going to add more dirt to the filter over the same amount of time. But the limit for how much dirt a filter can hold is based in part on airflow resistance. As dirt accumulates in the filter, airflow is restricted and eventually reaches a point at which it must be changed.

Generally speaking, air filters with greater filter media area can hold a larger amount of dirt which increases their service life. A 24” x 24” x 2” high-capacity, high-quality two-inch MERV 8 pleated panel filter with 17 sq feet of filter media area can hold 175 grams of dirt when tested under ASHRAE 52.2 test procedures. However, a 24” x 24” x 12” high-capacity MERV 14 V-bank style filter with almost 200 sq ft of filter media can hold over 475 grams.

The optimum air filter for each application is one that captures an acceptable amount of unwanted particle sizes, (particle capture efficiency) holds that dirt within the body of the filter for a reasonable length of time (dirt holding capacity), and performs those two functions while still flowing the required volume of clean air into the occupied space (resistance to airflow).



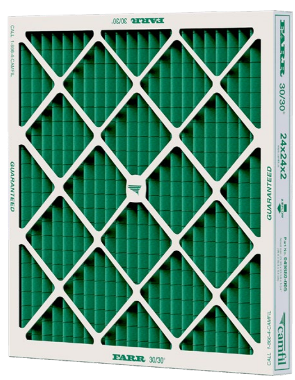
The ideal filter; high capture efficiency, high dirt holding capacity with low resistance to airflow.

How to identify the optimum air filter for each application.

It's first helpful to recognize the four basic styles of air filters; panel filters; box style, pocket (bag) filters, and V-bank style.

1) Panel filter

Carboard-framed, pleated media panel filters are the most common air filter. They come in a wide variety of heights and widths and are typically available in depths of one, two, or four inches. MERV values are in the low to medium range; from MERV 7 to MERV 13. These can be used as the only filter in single-stage HVAC systems or as prefilters in multi-stage systems. Pressure drops can range from a low of 0.20" w.g., up to 0.70" for MERV 13 models. Service life varies tremendously based on the quality of the filter. Economy versions can range from monthly changeouts in high dirt load conditions but are often set up on quarterly changeouts for more typical applications. There are versions of pleated panel filters available with extended service lives from nine to twelve months. There are metal panel filters that are designed to be washed and reused, but these are best suited for industrial applications. Pleated panel filters can also use a filter media containing activated carbon to help control odor, gases, and certain VOCs (volatile organic compounds) in addition to dirt particles.

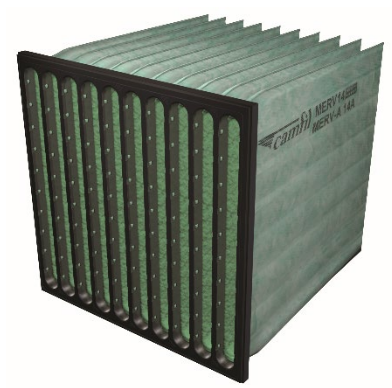


2) Rigid Box Style

Rigid box-style filters are generally MERV 11 and higher and are typically used as the second stage in a multi-stage system. The filters are good in applications with high and/or turbulent airflow. They are available in metal frames with various depths of between four and twelve inches. The metal frame helps to withstand the harsh conditions they are best suited for. There should be a specific condition the HVAC is faced with that leads to the selection of rigid box style filters as other style filters will operate much more efficiently.

3) Pocket (bag) filters

Pocket (bag) style filters are very versatile and can withstand a wide range of operating conditions. They can be used as prefilters in multi-stage units, as the second-stage filter with a prefilter before them, and can even be used as a stand-alone single filter. MERV values can range from MERV 9 up to MERV 16 and are available in depths of 12” up to 36”. The deeper filters have a significantly higher dust-holding capacity and longer lifetimes than most other filters. Pocket filters can also use a filter media containing activated carbon to help control odor, gases, and certain VOCs in addition to dirt particles. They are also made with material to withstand very wet conditions which makes them a good choice where the HVAC systems do not have adequate protection against the weather.



4) V-bank style air filters

V-bank-style air filters are the highest-performing of all filter styles. They maximize the filter media area to be used for filtration while the space between the filter banks helps minimize resistance to airflow. They are designed as the final filter in multi-stage HVAC units because they can hold a high volume of the smaller dirt particles. Using prefilters upstream to remove larger dirt particles means the service life of a high-quality V-bank style filter can be measured in years, not months. It’s not uncommon for these filters in a properly designed and maintained system to last two to three years. Versions that used activated carbon filter media are available to control dirt, odor, gases and VOCs. Generally, these are 12” deep filters but 6” deep versions exist for HVAC units with limited space.

Selecting the Optimum Air Filter

The first step to selecting the optimum air filter is to determine if there is a minimum particle capture efficiency (MERV value) required. Many schools and universities have followed recommendations from cognizant authorities that state MERV 13 is the **minimum** filter efficiency, but higher efficiency is better.

Generally speaking, air filters with a higher MERV value have a higher resistance to airflow (pressure drop) which the air handling unit’s fan must be powerful enough to overcome. When upgrading filters in the air handling unit to those with higher MERV values, it’s important to keep this in mind. Check the operating specifications of the unit to ensure the fan is rated to overcome at least twice the pressure drop of the higher-rated air filter to ensure the system operates correctly and is not damaged.

Air Handling Unit Configuration

Once the minimum filter efficiency has been determined, the next step is to review the air handling unit the filter will be installed in. Assuming the unit is in good operating condition and capable of running at rated capacity, the first detail to notice is if the unit is designed to hold a single stage of air filtration or is a multi-stage air filtration unit.

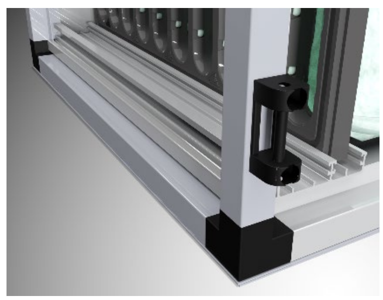
Single-stage: First determine the maximum air filter depth that will fit into the filter holding frame or sliding track. This is important because there are more air filtration options available with deeper filters and deeper filters generally have a lower pressure drop. Single-stage units generally hold one, two, or four-inch filters, but there are some that can hold six-inch or deeper filters. With a single-stage unit, there is only one opportunity to remove all the harmful contaminants from the air so selecting the best filter is important.

Multi-stage: While air handling units can contain three or even four stages of air filtration, two stages are the most common. In multi-stage units, the first stage is known as the prefilter and the last stage is known as the final. The function of the prefilter is to capture larger particles while allowing finer particles to pass through. The final air filter is specifically designed to capture smaller particles. Using a prefilter protects the final filter from quickly being overwhelmed with large particles and extends its service life. The prefilter should be a lower MERV value, typically MERV 8 or 9, and the final filter in schools and universities should be a MERV 13 or higher.

Installing air filters

There are three basic methods to hold filters within an air handling unit; a single holding frame for built-up banks, tracks that multiple filters (with or without headers) sit in a vertical position and are slid into position, and V-bank track configuration tracks set at an angle.

Single holding frame



Track for sliding filters across

Tracks in a V-bank configuration

Single-holding frames may have fasteners that hold the filter in place or may use compression clips that hold the filter without fasteners. If fasteners are required, ensure the correct fastener is used on each corner to eliminate bypass. Filter-holding frames can handle virtually any depth of filter as long as the correct fasteners are used.

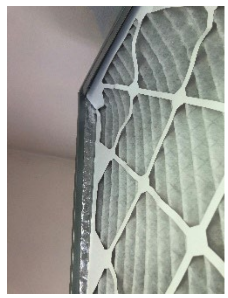
Tracks for sliding filters across. In units that have tracks, the filter itself (or the header) sits in and then slides across and fills the space. It's important to use the correct number and size of filters so there are no gaps. If necessary, blocking panels can be installed to take up any remaining space. The unit should have gaskets on the wall at the end of the track and on the entry door to help seal the filter to the sides of the unit. Filters with headers can be virtually any depth as long as the header is the correct size to fit snugly in the track.

V-bank configurations have the same requirements as other tracks as far as ensuring the correct number and size of filters used so there are no gaps. The advantage of V-bank configurations is greater filtering area, but the disadvantage is they generally can only hold one or two-inch deep filters which limit filter choices.

Monitoring air filters

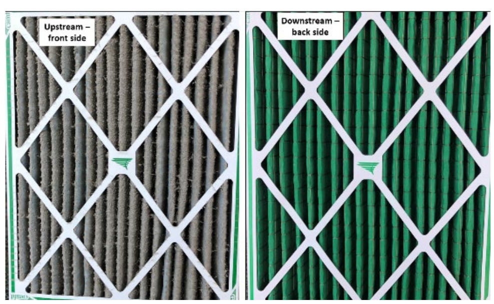
Air filters can be exposed to harsh weather conditions like rain, snow, and ice. They can experience turbulent airflow and depending on the situation, high dirt loads. As they are often out of sight, it's important to establish procedures to monitor the condition of the air filter on a regular basis otherwise, a damaged filter can go unnoticed for a long period of time while dirty air is bypassing into the building.

Filters should be visually inspected for damage as often as the maintenance program allows. Many programs call for monthly inspections. One of the most common types of damage is a filter bowing inward under the airflow because a weak frame could not withstand exposure to the airflow after being exposed to high moisture or water.



Filter frame weaken by high moisture

Filters should also be inspected for a build-up of dirt, but just seeing dirt up on the air intake side of a filter is not always an indication the filter should be replaced. Filters are designed to capture dirt so should appear dirty. One method which can be used is to compare the front of the filter to the back. If the downstream side of the filter appears dirty, it's an indication dirt is penetrating through the filter. Ideally, the downstream side of an air filter should look similar to what it did when new.



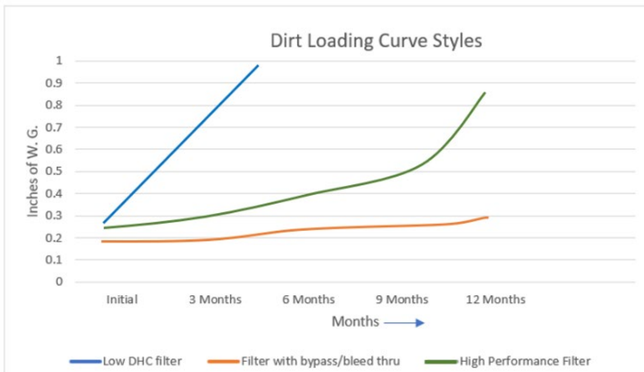
Upstream and downstream of the same filter

Pressure drop

The preferred method is to monitor the condition of an air filter using pressure drop. All air filters exhibit resistance to airflow as air works its way through the body of the filter. This is known as pressure drop and is typically measured using a Magnehelic gauge and displayed in inches of water gauge. As dirt is captured, resistance increases as the air has fewer pathways through the filter. Regularly monitoring and recording pressure drops creates historical trends that can be used to base maintenance around.

Recording pressure drop helps to develop dirt loading curves which can be an indication of the performance of an air filter. In the example below, the blue line was produced from a filter with low DHC so the pressure drop increased rapidly. If this filter had not been changed, the pressure would have dropped to near zero when the filter buckled and collapsed under the pressure. The filter represented by the orange line never showed an increase in pressure drop which on paper would be an indication of a good air filter. However, visual inspection revealed unfiltered air was bypassing the sides of the collapsed filter which was why the pressure was not increasing.

The green line revealed the optimum air filter in this example. The curve displayed a gradual increase in pressure drop until near the end of its service life when it increased much more rapidly. This indicates an air filter that loaded evenly across the entire surface area and utilized all the available filtering area.



When to change air filters

If historical trends or reliable dirt-loading curves have not been developed, a rule of thumb to follow when first installing filters is to base filter changeouts by scheduling changes when the initial pressure drop has doubled. The theory behind this is at that point, the cost of energy to push air through the filters is higher than the cost of the filter, labor, and disposal expense. This is a particularly good rule for single-stage units and prefilters in multi-stage units.

However, this is not an absolute rule and many situations occur when filters should be changed long before the pressure drop doubles. Final filters with high-performance prefilters can maintain a low-pressure drop for a year or more. But caution is warranted; since filters capture all sorts of unknown particles out of the air, a firm service life is often established to ensure the safety of building occupants.

How to dispose of air filters

While some metal filters are designed to be cleaned and reinstalled, any fabric media-based air filter should be disposed of when the service life is over. Air filters should not be vacuumed or compressed air blown through in an attempt to extend service life as this will damage the filter media and create a path of bypass once reinstalled. State and local municipalities may have requirements for filter disposal which should be followed.

During COVID, there were cautions issued by organizations about the potential risk from active viruses caught within the body of an air filter. While perhaps this response was overly cautious, common sense dictates general protective wear is recommended. However, in areas where exhaust filters are used specifically to remove air from an area like a science research lab, work with the department to understand the potential contaminants and take additional precautions as necessary.