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AUTHOR	Wheeler, Arthur E.
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ABSTRACT

Guidelines for maintaining indoor air quality in schools with HVAC air cleaning systems are provided in this document. Information is offered on the importance of air cleaning, sources of air contaminants and indoor pollutants, types of air cleaners and particulate filters used in central HVAC systems, vapor and gas removal, and performance standards for air filters. Tips for upgrading the cost effectiveness of air filters and for maintaining and purchasing them are also provided. Three figures and three tables are included. (LMI)

TECHNICAL BULLETIN

AIR CLEANING DEVICES FOR HVAC SUPPLY SYSTEMS IN SCHOOLS

Prepared by Arthur E. Wheeler, PE
Wheeler Engineering

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Maryland State Dept. of Education
Office of Business Services
Office of School Facilities
200 West Baltimore Street
Baltimore, Maryland 21201
(410) 333-2508

Importance of Air Cleaning

Look inside any air conditioning unit under the classroom window or one serving an entire school and you will find air cleaners - usually filters. Some of those commonly used in schools are shown in Figure 1. They are there for two purposes: to keep the heating and cooling coils, fans and ducts clean, efficient and functional: and to improve the quality of the air breathed by students and staff.

Heating and cooling coils expose large areas of metal surface that transfer thermal energy to or from the air supplied to the building. Dirt deposits upon those coils impair their effectiveness. A major air conditioning equipment manufacturer has found that coils can lose as much as 30% of their efficiency transferring thermal energy in a short period of time due to surface contamination. Once dirty, coils must be cleaned - a difficult, costly procedure.

Cooling coils not only reduce the temperature but remove moisture from the air. In the cooling season these coils are constantly wet. The accumulated moisture is removed through a piped drainage network. Fungi and bacteria that pass through the filters can find the wet components an attractive place to live and multiply. This can also occur in the supply ductwork. if the air inside is at a high humidity, and dirt (nutrient) accumulates on the interior of the surface. Keeping the air conditioning components clean minimizes the microbial buildup, avoiding dispersion through the supply air that can cause disease or allergic reactions. The more effective the filters, the less the health risk and the need for equipment maintenance.

Bacteria and fungi flourish and multiply with a relative humidity above 60%. Some air conditioning systems are unable to keep the humidity within the conditioned space below this level under various weather conditions. More effective filtration can partly offset rampant increases in the number of microorganisms by depriving them of nutrients.

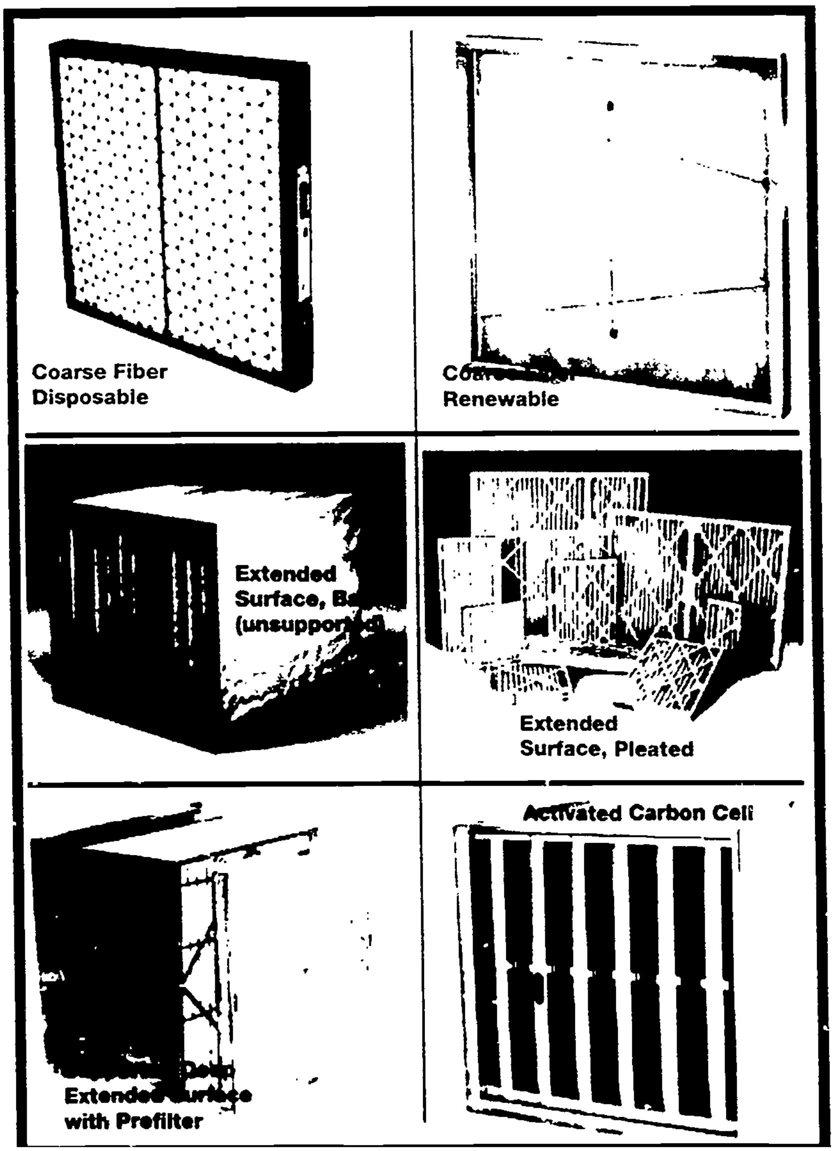
Indoor Air Quality (IAQ)

The quality of the air that surrounds us is measured by its temperature, humidity and the nature and concentration of particulate and gaseous impurities. Air quality has an effect on both occupant comfort and health. The thermal environment affects comfort and also the growth f bacteria and fungi. The adverse effects of irborne contaminants may range from annoynce, upper respiratory irritation, to acute or chronic illness.

With the classroom thermally controlled for comfort and free of excessive contaminant concentrations, the environment for learning is enhanced: conversely, poor air quality can impair performance and contribute to illness and absenteeism.

One contaminant of concern is respirable particulates. Small enough to be invisible to the naked eye, particles between 0.1 and 2 microns (a micron equals 0.00004 inches) can be retained in the lungs. Aerosolized particles are of diverse character: inorganic or organic dust, fungi spores, bacteria, lint, fibers, human skin flakes. Many deposit onto room surfaces; very fine particles may remain suspended indefinitely. Fortunately, human physiology is able to cope with their presence, but high concentrations of certain particulates can cause adverse health effects. People and their activities are the major sources of particulates within the school. Particulates are also introduced into the building from outside through the ventilation air supply and infiltration.

Some gases and vapors also are contaminants of concern. When breathed in sufficient quantity, distress or illness can occur. Many organic compounds used in building materials, housekeeping, maintenance, and educational activities are readily vaporized.



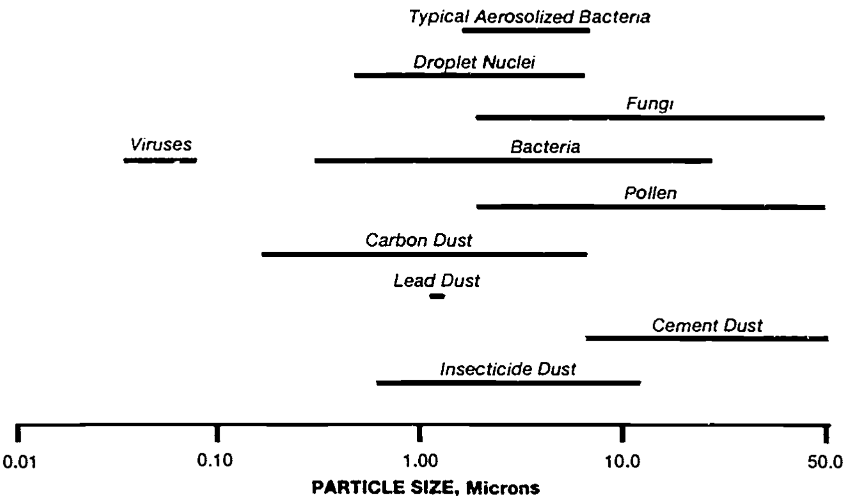


FIGURE 2
PARTICLE SIZE RANGES

Gaseous products of combustion, such as carbon monoxide, while uncommon, may enter from outdoors through intakes. Stack effluent, traffic exhaust or nearby industrial processes are sources of these products. Environmental tobacco smoke is comprised of both particulate and gaseous contaminants.

Control of Indoor Pollutants

Source control or containment is the preferable course to achieving good indoor air quality. Exhausting air from the immediate vicinity where contaminants are generated limits their dispersion. This is an effective strategy for kilns, photography developing, science labs, welding shops and duplicating centers. Smoking restriction is a form of source control. Locating outdoor air intakes remote from contaminated exhaust emissions is another source control measure.

The quality of the outdoor air at a proposed school site also should receive consideration. Providing good air indoors when there is poor air outdoors is a tough assignment.

Other than source control, dilution with relatively contaminant-free ventilation air is the chief means of limiting the concentrations of contaminants in a space. The level of indoor contaminants is determined by the purity of the ventilation air and its rate of circulation through the occupied space. Ventilation air is usually a blend of both outdoor and recirculated air from which contaminants have been removed by air cleaning. When equipment or duct work downstream of the filters becomes excessively dirty it becomes a contaminating source and must be cleaned. Cleanability is largely determined by air conditioning system design and equipment selection. The less accessible, the more difficult the task. Duct cleaning, a major effort to be undertaken only in extreme circumstances, is a job for competent specialists.

Asbestos and radon are health concerns that are not controlled by school HVAC air cleaning systems. Radon control may involve ventilation techniques, but of a specialized nature. These two contaminants are not responsible for symptoms generally associated with poor indoor air quality.

Types of Air Cleaners

Airborne particles are removed from the ventilation air stream by filters commonly located in a filter section of the air conditioning equipment upstream of the coils and downstream of the mixing of outdoor and recirculated air. Figure 2 describes the range of particle sizes for contaminants of interest in school buildings.

Gaseous contaminants, such as odors, are removed by adsorption or chemical modification. The effectiveness and capacity for removal depends upon the chemical character of the gas or vapor, depth of cleaning bed, and the humidity of the air stream. Some gases are effectively removed through chemical reaction with an oxidizer.

Ionizers and Ozone Generators

While ionizers are used to "purify" air they are not generally considered air cleaners. Airborne particulates implanted with an electrical charge will be attracted to surfaces with an opposite charge. The charged or ionized particles frequently are attracted to room surfaces and are thus removed from the air. Accelerated soiling of room surfaces is a consequence.

Ozone, often a byproduct of ion generation, is an oxidant that is produced by some air purification devices to chemically transform odorous compounds. However, ozone is itself a contaminant. Prolonged exposure at elevated levels is believed to cause lung damage. Ionizers and ozone generators are not recommended for classroom use.

Particulate Filters

Types of filters commonly employed in central HVAC systems for schools are shown in Figure 1 and described in Table 1 with comparative descriptions of their characteristics. A wide range of types, sizes, and efficiency ratings are available. High efficiency particulate air filters (HEPA) are used only for an ultra clean environment and rarely found in schools.

Electronic air filters are not included in the Table as their use in schools is uncommon. Their initial cost is comparatively high and maintenance considerations are more exacting than for those described.

Vapor and Gas Removal

Activated charcoal, silica gel and activated alumina impregnated with potassium permanganate are materials frequently employed for removal of offensive vapors and gases which can not be removed by air filters. Their use in schools should be limited to specific situations where the emission of odors or harmful chemical vapors cannot be contained at the source by material selection, isolation or local exhaust. In industrial areas, the outdoor air may be so polluted that removal of gaseous contaminants from the ventilation air supply is necessary.

The nature of the gas to be removed bears upon the effectiveness of sorptive materials. These are not effective for gases of low molecular weight, such as carbon monoxide and carbon dioxide. Selection of method starts with identification of the contaminant - a job for specialists.

Performance monitoring and maintenance procedures are more complex than for filters. In many situations, the noses of the occupants are the best monitors; however, some toxic gases are odorless. Replacement must occur when the sorptive media is saturated or chemically spent. Vapor and gas removal is more costly and demanding a procedure than filtration, but the only solution for some air quality problems. Several new concepts being developed may hold promise.

Since particulate filters are the commonly used air cleaner in schools, the remainder of this bulletin discusses filter selection and maintenance.

Use of Filters in Schools

Recently, the School Facilities Office of the Maryland State Department of Education conducted a survey of filter use. In Maryland, unit ventilators are the most frequently employed means of classroom heating, ventilating and air conditioning. Central variable air volume systems are next most frequently employed.

The use of a wide variety of filters was reported. Most districts report a program of standardization of filter types for both central HVAC systems and unit ventilators. While some cleanable filters are in use, disposable or replaceable media types predominate. In only two isolated instances are sorption equipment in use or under consideration for odor problems.

Filter replacement is based upon visual inspection or time schedule. Several districts have computerized maintenance management plans. Filter replacements are automatically scheduled during the school year. Filters are most often purchased on a school-by-school basis. However, in some districts, they are supplied under bulk purchase agreements covering all or a portion of the schools.

Responsibility for filter changing is divided among the districts almost evenly between school custodians and school system specialists. However, most have adopted standardized filter maintenance procedures.

Air filters are an air conditioning (or ventilating) unit component. Large central station air handling units are found in mechanical equipment rooms or on the roof either enclosed or free standing. In the latter situation, maintenance personnel must choose favorable weather to perform routine maintenance. Frequency of filter changing becomes a strong consideration in selecting a filter type when access is difficult.

Many classrooms are provided with unit ventilators for climate control. The choice of filters is limited to those with a 1" depth. While cleanable filters can be employed, unit ventilators are normally installed with coarse fiber throwaways. The option of extended surface pleated units is discussed on page 5.

Stand alone, portable air cleaners comprised of fan, filters and, possibly, odor adsorbers are sometimes used in problem situations or for temporary service during an exceptional particulate or fume production episode. Effectiveness will likely depend more on the amount of air circulated than the air cleaning efficiency.

FILTER	BED DEPTH, inches	AVERAGE DUST SPOT EFFICIENCY %	MEDIA AREA, ft^2 1000cfm max. capacity	MAINTENANCE	PRESSURE LOSS @ 500fpm, in. w.c. - NORMAL RANGE, Clean to Dirty
Coarse Fiber [1]	1-2	< 20	2	High	0.2 to 0.5 or 1.0
Cleanable Metal [3]	1-2	< 10 (est)	2	High	.3 - 1.0
Extended Surface Pleated	1-4	20 - 30	5 - 15	Moderate	3 - 1.0
Extended Surface Pleated	4-6	40 -45	14 - 24	Moderate	.2 - 1.0
Extended Surface Pleated	12	60 -65	58 [2]	Low	3 - 1.5
Extended Surface Bag	22	80 - 85	55 [2]	Low	.5 - 1.0

1 Disposable cells or replaceable media.
2. Varies among suppliers. Could be as low as half the stated area.
3. No longer used in some districts due to marginal performance and maintenance requirements.

TABLE 1
CHARACTERISTICS OF FILTERS COMMONLY FOUND IN SCHOOLS

Assessing Filter Effectiveness by Performance Standards

Filters are tested according to Standard 52-76 of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and ratings are available from manufacturers on the basis of this standard for *weight arrestance, dust spot efficiency and dust holding capacity*. Higher efficiency filters are also rated according to the DOP (di-octyl phthalate) penetration test - a military standard. Details concerning the test procedures can be found in the ASHRAE Equipment Handbook. In general, *arrestance* evaluates effectiveness for removal of larger particles, above 5 microns; the *Dust Spot Test* for atmospheric dust is a soiling index reflecting fine particle filtering efficiency and is the most useful measure of efficiency available at present. The DOP test is an efficiency based upon smoke with a mean particle diameter of 0.3 micron. *Dust holding* capacity is determined by introducing artificial dust into the filter until the maximum air flow resistance for the filter is reached.

ASHRAE is working on a new and promising standard to determine efficiency of removal according to particle size. Efficiency curves based upon particulate size for many filters are already available as shown in Figure 3. Filter choices can be more clearly evaluated using this efficiency. It is especially useful for evaluating removal effectiveness of specific airborne contaminants such as infectious bacteria and virus bearing droplet nuclei, pollen and fungi spores.

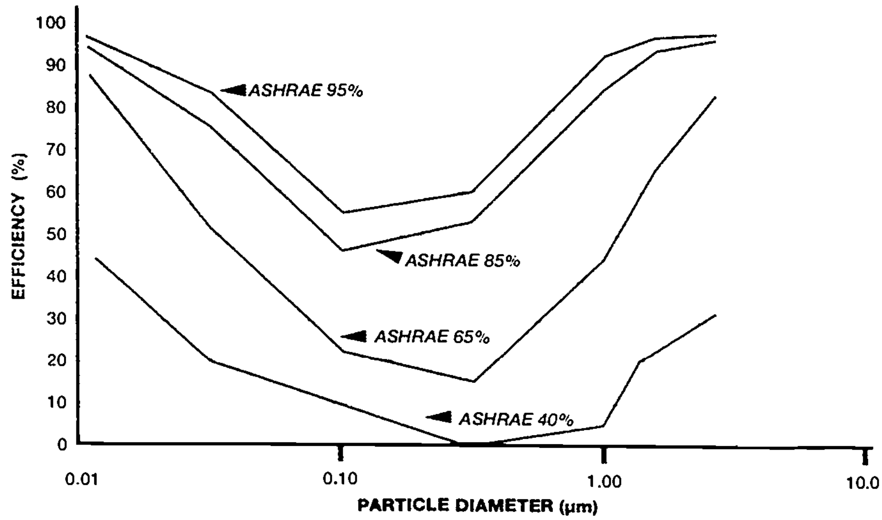


FIGURE 3
PARTICLE SIZE DEPENDENT DRY MEDIA FILTER EFFICIENCIES

Importance of Air Turnover Rate

The concentration of contaminants within a room is not governed alone by the effectiveness of the filters. It is a function of their generation rate and the rate they are diluted by the supply of clean air to occupied space. Thus air turnover is a significant factor in producing good air quality. Although air flow is constant in constant volume systems, the amount supplied in a variable air volume system is regulated by a space thermostat. Thermal loads continually change and the rate at which air flows in and out of a space varies accordingly. The number of occupants and the contaminant generation rate may be relatively constant. If the air supply operates at reduced levels for long periods of time, air quality will deteriorate no matter how efficient the filters. Operating strategies to deal with these conditions need to be well reasoned.

Upgrading Filters in Schools

Upgrading air filtration can improve indoor air quality resulting in a more effective teaching environment, less absenteeism and fewer complaints. Upgrading filters may incur some initial cost. However, it may also reduce related annual filter costs, maintenance requirements, electrical energy charges, coil and duct cleaning, and the need for premature coil replacement.

Cost effectiveness of better filtration can come about in several ways.

Material cost: The first cost of a replacement filter can be misleading. Look at annual cost. Filters manufactured with fine fiber media, configured with pleats or bags to increase the surface area through which the air passes, have an effective life much greater than those made of a coarse fiber mat. Filter life significantly affects total expenditure. Unfortunately, the ASHRAE dust holding capacity is not suitable for comparing different filter types. Pleated media cells can operate at a higher pressure differential than coarse media fiber units. In upgrading, the higher flow resistance could overtax the supply fan capacity, making it necessary to replace the upgrade filters at a final resistance near to that of the supplanted dirty coarse fiber ones. *Comparisons presented in Tables 2 and 3 are based on that limitation.* Unless the fan speed is increased, a higher flow resistance will cause reduced air flow and some power reduction for most fans. Consequently, overloading motors from this cause should not occur.

Labor cost: Reducing the frequency of replacement also reduces maintenance labor. A reduction of two thirds or more is possible.

Coil cleaning: The material not collected on the filter passes through and a portion collects on the coil. The pass-through percentage equals 100% minus arrestance. Dirt buildup decreases coil capacity and increases energy use.

Air quality: ASHRAE's new Ventilation for Acceptable Indoor Air Quality Standard, 62-1989, calls for a significant increase in the outdoor air supply to classrooms for dilution of internally produced contaminants. Most existing systems in schools do not have heating and cooling capacity to accommodate the recommendation. Improving IAQ by upgrading filtration is a step toward ASHRAE's objective.

Upgrading Filters for Unit Ventilators

Classroom unit ventilators are normally supplied with 1" thick coarse fiber disposable or cleanable media filters. These filters have a low efficiency, an ASHRAE arrestance of near 70%, with limited dirt holding capacity, and a face area of about 4 square feet for a typical unit ventilator. With the availability of 1" pleated extended media replaceable filters, unit ventilator filtration can be

	COARSE FIBER	EXTENDED MEDIA
Average Efficiency ASHRAE Dust Spot	< 20 %	20 to 35 %
Arrestance	70 %	90 %
Pressure Loss, Clean[1]	0.05	1 to 2
Pressure Loss, Dirty[1,2]	0.50	6 to .65
Estimated Life Factor	1	2
Filter Replacement Cost per 1000cfm	$ 1.30	$ 3 10 - $ 4.00
Estimated Annual Material Cost per School[3]	$ 120	$ 140 - $ 180

1 Inches Water Column
2 Based on equal loading per unit area of exposed media.
3. Based on 1,500 hours operation and 3 changes of coarse fiber filters per year, thirty 1,000cfm units

TABLE 2
UNIT VENTILATOR FILTERS COMPARED

upgraded. Compare the costs and performance of 1" deep filters as currently marketed in Table 2.

A true cost comparison must consider service life. Annual material replacement costs are in close alignment and the labor of changing filters is cut in half. The improvement in efficiency is quite important in two ways. Even though the capability of the pleated filter is limited as applied to unit ventilators, it can be expected to remove from the circulating air stream some bacteria bearing particles and fungi spores of respirable size. Reducing the amount of dirt passing through the filters on to the cooling and heating coils is a real plus. In light of these benefits, extended media filters are becoming the preferred choice for unit ventilators.

Upgrading Filters for Central Station HVAC Systems

The performance quality of filters in school central systems varies from 2" thick coarse (usually glass) fiber disposable panel filters to extended surface units made from fine glass or synthetic fibers with superior dirt holding capacities and particulate removal effectiveness. A few of the choices, their performance parameters and current replacement costs are presented in Table 3. This analysis relies upon data from several manufacturers and suppliers and employs approximate estimates of some parameters. The intent is a conservative comparison. The labor cost for the filter replacement has been omitted. Salary budgets may not be affected even though the available time of the operating staff for other duties will be.

Replacing coarse fiber with pleated media cells of the same depth involves little or no change to the air handlers. Those with increased depth will require modification of the filter section. For many air handling units upgrading from 2" throwaways to 12" deep cells would involve costly modifications.

The particle size efficiencies are significant to occupant health. Improved filtration can reduce the concentration of respirable infectious or allergenic agents within the room air.

One can develop the comparison further to apply to specific air systems with attendant cost and maintenance benefits. Such comparisons are likely to offer strong reasons for upgrading from cleanable and coarse fiber filters to extended surface types.

Filter Maintenance

Maintenance practices may contribute even more to IAQ than filter efficiency. Improper maintenance and neglect of filters has been shown to be a major contributing cause of IAQ problems. A survey of school districts in another state revealed only 35% had preventive maintenance programs. 45% had no written maintenance instructions and 13% serviced filters only after breakdowns. Accordingly, sound filter selection is only a beginning.

Whether filter maintenance is performed by school custodians, system specialists or as a contract service, on-the-job training with procedures documented in an accessible maintenance manual is essential. The manual

SOME FILTER MAINTENANCE TIPS

- ✔ Poor fit defeats filter performance
- ✔ Replace worn out (dead) or missing gasketing
- ✔ Install filler pieces (end blanks) to seal gaps. Pieces of 1" or 2" polystyrene or compressible urethane foam can be fashioned to close gaps.
- ✔ Seal joints between cells with masking or duct tape at the entering face. For those that slide in, tape the joints as you slide into place.
- ✔ Sections of the air handling unit downstream of the filter, upstream of the fan operate under negative pressure. Seal loose fitting access doors and other inward air leakage points. Use tape as a temporary expedient.
- ✔ Replace missing screws and caulking on sheet metal sections and panels.
- ✔ Replace missing holding clips. Washable metal filters must be sprayed with suitable viscous coatings to retain dirt deposits.
- ✔ Prime traps from condensate pan and floor drains in air handlers.
- ✔ Secure a permanent record keeping card on the filter access door. Record changes and inspections.
- ✔ Keep filters dry. Wet filters become a breeding ground for microorganisms.

FILTER TYPE	COARSE FIBER DISPOSABLE CELLS	EXTENDED SURFACE, PLEATED			
Depth	2"	2"	4"	6"	12"
Average Efficiency, ASHRAE, %	< 20%	25 - 30	25 - 30	40 - 50	60 - 65
Arrestance, %	83	91	91	96	97
Particle Size Efficiencies					
2 microns	15 to 50[3]	55	55	75	80
1 micron	nil	20	20	40	55
0.5 microns	nil	5	5	12	30
Media Area (2ft x 2ft), ft^2	4	18	28	29	58
Cost per 1,000cfm[1]	$ 1.25	$ 3.00	$ 4.80	$ 10	$ 32
Estimated Life Factor	1	3	4.6	4	6.4[6]
Annual Life Replacement Cost[2]	$ 3.80	$ 3.00	$ 3.10	$ 7.50	$ 15.00
Frequency of Coil Cleaning, yrs.	3[4]	5.5	5.5	13	17
Energy Cost of Dirty Cooling Coils	$ 1.50[5]	$ .80	$ .80	$ .35	$ .25

1. Based on 500 feet per minute (fpm) face velocity
2. Based on 1,500 hours operation per year. 100ug/m^3 average concentration in air entering filter. Cost per 1,000cfm
3. Source information wide ranging.
4. Estimated for purpose of comparison
5. Based on 3% denigration each year.
6. 25-30% Pre-Filter may double life.

TABLE 3
CENTRAL HVAC SYSTEM FILTERS COMPARED

should contain a description of all filters, basis for change (time, pressure loss) and methods of replacement, service schedule, and record of work performed.

Responsibility for training is best placed with the district, perhaps with the district IAQ manager. Training must be an ongoing effort; as must be monitoring of its effectiveness.

A fixed time schedule for filter replacement is proving most practical for Maryland school districts. The frequency of change must be geared to the type of filter. Except in locations with unusually high concentrations of airborne particulates, three times a year is fairly typical for most schools and appropriate for coarse fiber filters. Extended media types can last much longer. Pressure loss (air flow resistance), observed on a differential pressure gage, is actually the preferred basis for determining the timing of filter replacement, assuring maximum use (and value) of filter cells. Selective use of filter gauges to monitor performance of a few representative filter banks by pressure loss can provide a more economical basis for establishing replacement times. The cost of gages range between $25 for a manometer to $70 for a more reliable diaphragm actuated dial type with adjustable signal flag. Their use is impractical for unit ventilators and many smaller air handling units.

Filter longevity is strongly influenced by face velocity. For this reason VAV systems filters can be expected to materially outlast those where air flow remains constant - one exception: unsupported, sagging bag filters. All acquired information about time schedules can become input for a district-wide computer preventive maintenance control program to manage timely replacement.

Don't change a filter just because it looks dirty. Coarse fiber filters are probably ready for replacement when they show discoloration on the *leaving* side.

Purchasing

Bulk purchasing for the filter needs of an entire district or school cluster can yield cost savings over individual purchasing by schools. A master inventory on the sizes and types for all district HVAC systems is required. Such compilation is a time consuming but a worthwhile effort. Standardize on types and sizes where practicable. Comprehensive specifications for each type are the foundation for a bid request. Set minimum criteria for average ASHRAE dust spot efficiency; clean, final and maximum pressure loss; and media area. Specify sturdy frame construction. Require submission of independent test reports to support performance claims. Request samples be submitted with the bids. Rounded (vs. pointed) pleats make more effective use of media area. Examine the gasketing.

Blanket purchase orders on a fixed unit price or total price basis to cover the needs for an entire school year are possible with stipulated replacement schedules for each type. Once a replacement schedule for every school is established, the supplier can be contracted to furnish filters as needed. Such a provision virtually eliminates warehousing, storage, handling and transfer of filters by the district. Maryland's Montgomery County is purchasing in this manner. Maintenance training and performance monitoring are part of the contract. Dorchester County, Maryland goes a step further by contracting for complete filter service. This service is monitored regularly by school and district personnel.

Administration

Air filtration is an essential element of a proactive IAQ program. Filter expense is a budget item to be minimized and controlled. Filter selection and the purchasing method affect material, labor and other costs. Selection, standardization. bulk purchasing and shifting of inventory and other responsibilities to suppliers offer potential savings. However, the improvement to the environment is at least an equally motivating reason for upgrading air filtration protocols. Filter purchasing decisions are best not based upon low cost but best *value* for those being served.

The highly regarded approach of "management by walking around" has merit to the subject at hand. The concern school and system administrators demonstrate toward IAQ considerations has marked impact upon the entire program and the attitude of maintenance personnel. teachers. students and parents. ■

CREDITS

Figure 1 a. American Air Filter
b. Air Guard Industries
c. Farr Co.
d. Farr Co.
e. Farr Co.
f. Farr Co.

Figure 2 Owen M.K. Ensor D.S. Sparks L.E. Airborne Particle Sizes and Sources Found in Indoor Air. Indoor Air '90 Proceedings

Kuehn T.E. Matching Filtration to Health Requirements. ASHRAE Transactions [illegible]

Figure 3 [illegible]

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Harold Winger
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