Air filters for HVAC applications

Dr. M. Ram Gopal

Department of Mechanical Engineering

Indian Institute of Technology Kharagpur

Introduction

- Filter selection is often viewed as a relatively minor decision at the time of overall system design
- However, improper selection, installation and maintenance of air filters can have significant effect on:

1. Achieved indoor air quality
2. Overall energy efficiency of the system, and
3. Operating life of the air conditioning equipment

- In addition the recent concern about possible chemical or biological attacks by terrorists puts greater emphasis on air filtration/cleaning systems used in buildings

- Air filters are used in air conditioning systems to:

1. Provide adequate indoor air quality for various applications such as comfort air conditioning, healthcare facilities, clean rooms for precision manufacturing etc.

2. Protect the air conditioning equipment from dust and other impurities

Contaminants

- Atmospheric Impurities are created either by:

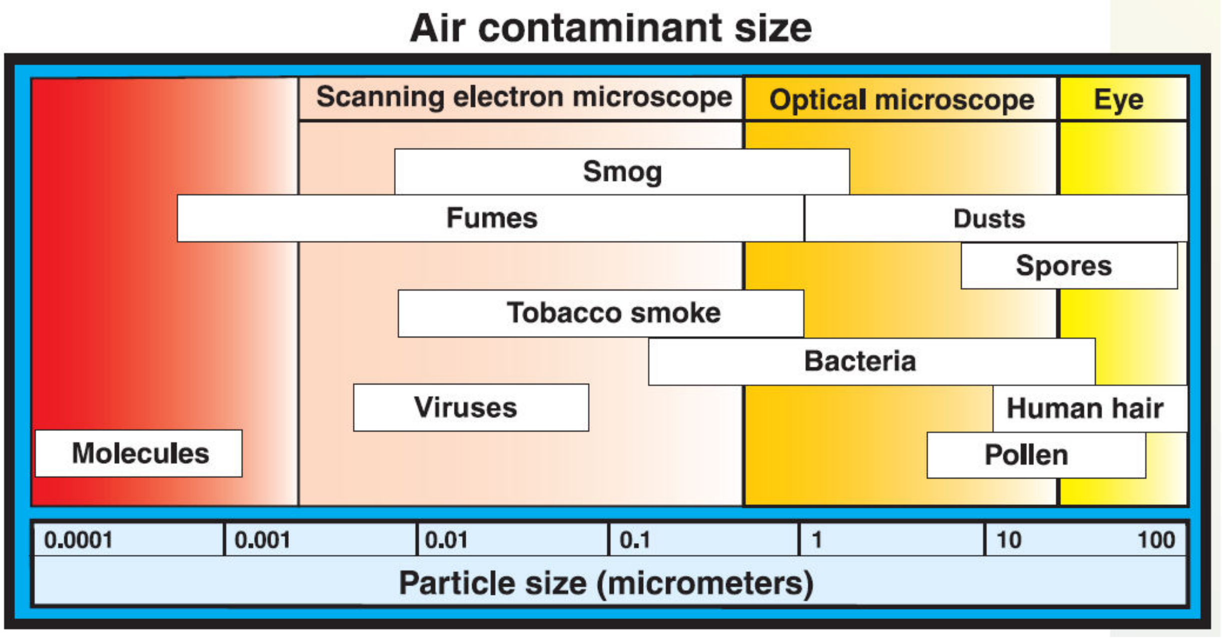
1. Natural processes such as wind erosion, sea spray evaporation etc, or
2. Human activities such as transportation, construction, power generation, agricultural and industrial processes etc.

- Though the concentration of the airborne contaminants in air is generally small (≤ 2 mg/m^3), if not reduced below required levels, they affect the health of the occupants and the performance of the HVAC system adversely

Classification of contaminants

- a) Based on phase/composition of suspended impurities:
- Dusts, fumes and smokes
- Mists, fogs and smokes
- Vapours and gases
- Organic impurities
- Aerosols

- b) based on size of contaminants:
- Ultra-fine mode particles (< 0.1 μm) or $PM_{0.1}$
- Fine mode particles (< 2.5 μm) or $PM_{2.5}$
- Coarse mode particles (2.5 μm to 10 μm) or PM_{10}



Characteristics of contaminants based on size

- Particles of size less than 0.1 μm behave similar to gas molecules ⇒ Brownian motion with no measurable settling velocity
- Particles of sizes between 0.1 μm to 1.0 μm have low settling velocities which is counteracted by normal air currents preventing settling down due to gravity
- Particles of sizes between 1 μm to 10 μm settle in still air, however, normal air currents may keep them suspended in air for longer periods

- Particles of sizes less than 2.5 μm are of concern as they are respirable and are likely to be retained in lungs

- Larger particles are either cleared and swallowed or coughed out

- 99 percent of the total number of particles in atmospheric air is in the size range of 0.1 μm to 1.0 μm

- Contaminants to be removed by air cleaning systems are:

1. Particulates (dusts, pollen, allergen etc.)
2. Gases and vapors (odors, VOCs)
3. Micro-organisms (mold, bacteria, virus)

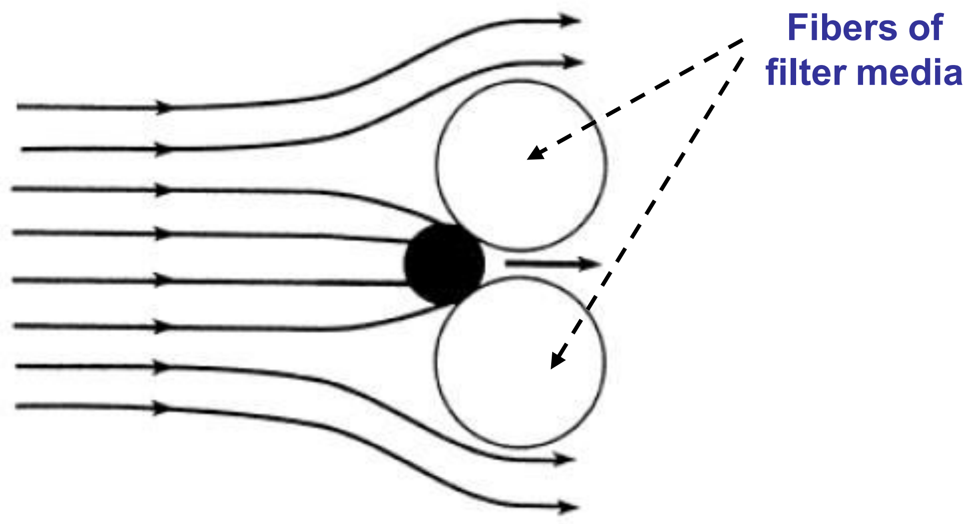
Mechanism of air filtration

- Gravitational separation is not very relevant as the size of air contaminants is small.
- Filtration takes due to one or more of the following mechanisms:

1. Straining
2. Interception
3. Inertial impingement
4. Diffusion
5. Electrostatic effects

Straining

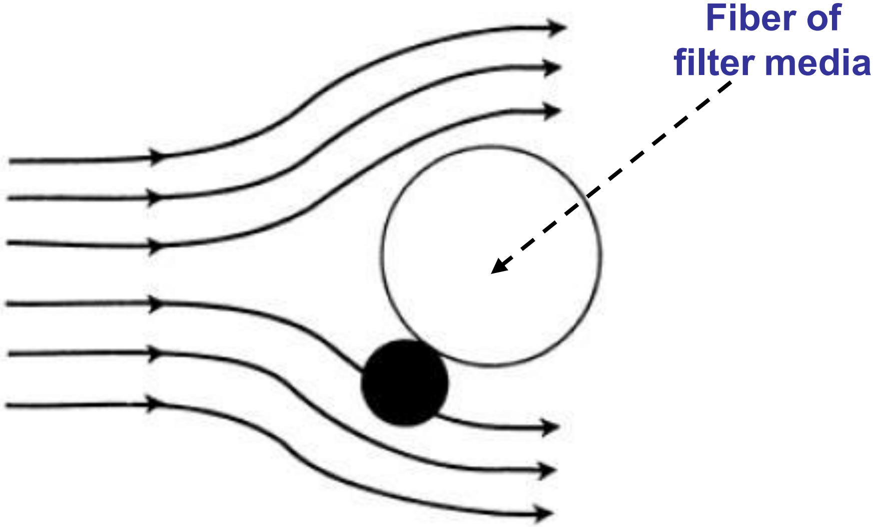
- Contaminant particles are trapped in the space between filter fibers
- Dominant mechanism of filtration for large particles in coarse filters



Filtration by straining

Interception

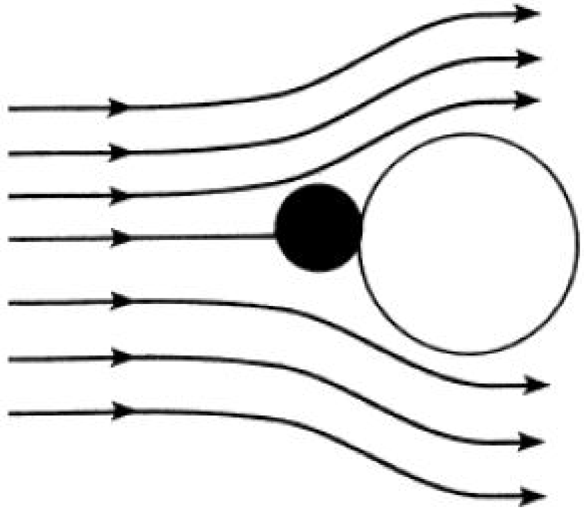
- Smaller contaminant particles follow the airstream, come in contact with the filter fibers and are attached to the filter media due to weak intermolecular forces



Filtration by interception

Inertial impingement

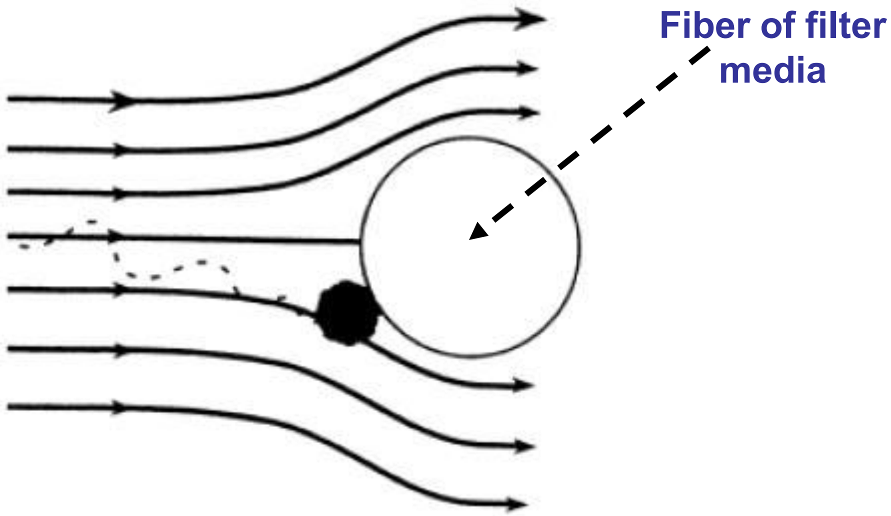
- Denser and/or larger particles cannot follow the air streamlines around the filter fiber, hence they cross the streamlines, come in contact with the filter fiber and remain attached.
- Particles may not adhere to filter at higher air velocities due to drag.
- To overcome this, a viscous coating may be applied to the filter media



Filtration by inertial impingement

Diffusion

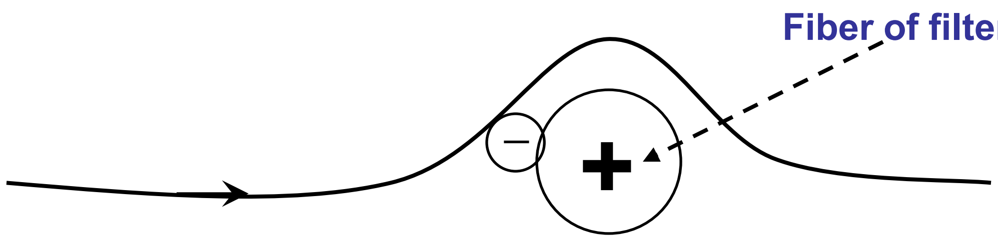
- Very small particles have random Brownian motion across the streamlines, which leads to their coming in contact with the filter fiber and adhesion
- Diffusion effect increases as contaminant particle size decreases



Filtration by diffusion

Electrostatic effects

- Contaminant particles and filter particles are oppositely charged either by natural means or artificially, adhesion takes place due to this



Classification of filters

a) Coarse air filters:

- Normally used to filter large particles (5 to 80 μm)
- Made as **panel** type
- Most commonly used in room air conditioners and small packaged systems
- Normal sizes are: 500 by 500 mm or 600 by 600 mm
- Depth of the filter: 13 to 100 mm
- Face velocity: 1.5 m/s to 3 m/s
- Minimum final pressure drop: 75 Pa

Filter media for coarse air filters

- Viscous and reusable: made of corrugated wire mesh and screen tips coated with oil. Can be reused by washing the dusty filter with detergents

- Dry and reusable: made of synthetic fibres such as nylon and terylene or polyurethane foam etc.

- Dry and disposable: made of synthetic and cellulose fibres and bonded glass fiber mats. Discarded as soon as the final pressure drop is reached

b) Low efficiency filters:

- Normally used to remove particles between 3 to 10 μm (spores, molds, cements, sprays etc)
- Normally made as **pleated filters** or **bag filters** so that the filtration efficiency can be increased and the pressure drop across the filter media can be reduced
- Filter media can be natural and synthetic fibers, viscous corrugated wire mesh, electrostatically discharged fibres or fabrics (Electret)
- Face velocity: Around 2.5 m/s
- Final minimum pressure drop: 150 Pa

c) Medium efficiency filters:

- Used to remove contaminants of sizes 1 to 3 μm (welding fumes, Legionella bacteria, coal dusts etc.)
- Mainly used in demanding commercial buildings and industrial applications
- Normally made as bag and box type with pleated mat and are made of synthetic fibers
- Minimum final pressure drop is 250 Pa

d) High efficiency filters:

- Used to remove particles of sizes 0.3 to 1.0 μm such as bacteria, viruses, tobacco smoke
- Widely used in air systems for hospitals, high-demand commercial buildings and precision manufacturing workshops
- Often made in the form of a bag filter or a pleated mat in a cartridge
- The minimum final pressure drop is 350 Pa
- These are normally preceded by low or medium efficiency filters to extend their service life

e) Ultrahigh efficiency filters:

- High Efficiency Particulate Air (HEPA) filters and Ultra-Low Penetration Air (ULPA) filters, gaseous adsorbers and chemisorbers belong to this category
- HEPA and ULPA filters are used to remove contaminants of sizes less than or equal to 0.3 μm such as unattached viruses, carbon dust, combustion smoke etc
- Widely used in clean rooms, clean spaces for microelectronics industries, operating theatres in hospitals etc.

- HEPA and ULPA filters are generally made in the form of a box with pleated filter media

- Filter media are made of sub-micrometer diameter glass fibers

- To reduce the dust load and increase service life, the high efficiency filters are preceded by a medium efficiency filter or one low and one medium efficiency filter

f) Electronic air filters:

- Filtration is achieved by making use of attraction between oppositely charged particles
- It mainly consists of an ionizer and collecting section
- When air with dust particles is passed through the ionizer (connected to 1200V DC supply), both air and dust particles are charged positively.
- The charged air and dust particles next pass through the collecting section of several plates which are alternatively grounded and insulated
- A strong electric field is produced in the collecting centre by connecting it to a DC supply of 6000 to 7000 V

- The positively charged dust particles are attracted by the grounded plates of opposite charge, and are attached to these plates
- Due to intermolecular forces the attached dust particles agglomerate and grow in size
- The agglomerated dust is blown off by the air stream and is collected by a medium efficiency air filter placed downstream
- Electronic air filters are found to be efficient for particles in the size range of 0.5 to 8 μm
- Pressure drop across the electronic air filter is typically low; 37 to 62 Pa when air velocity is between 1.5 to 2.5 m/s

- Safety measures have to be provided to take care of the high DC potential used
- Electronic air filters typically operate on an AC mains supply of 110 V/230 V, with the high DC voltages required for ionizer and collecting sections being created with solid-state power supplies
- Electrical power consumption ranges from 40 to 85 $W/m^3/s$ of air cleaner capacity
- Panel type pre-filters should be used to distribute the air flow uniformly and to remove large dust particles that may cause shorting or excessive arcing in the high voltage section

g) Activated carbon adsorbers:

- Widely used to remove objectionable odors and irritating vapours (including VOCs) of small gaseous molecules by adsorption

- 1 kg of activated carbon can adsorb 0.2 to 0.5 kg of odorous gases

- Adsorption capacity decreases as air humidity or temperature increase (maximum operating temperature is around 38^oC)

- Filter assembly is made in the form of trays made of granulated activated carbon beds
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- Typical tray measures 580 mm by 580 mm by 15 mm and weighs 5.4 kg
- The pressure drop across the adsorber may vary from 50 to 75 Pa at air velocities in the range of 1.8 to 2.5 m/s
- Normally low or medium efficiency pre-filters are used with adsorbers for optimum use

- Factors to be considered in the selection of air filters:

1. Degree and type of air cleanliness required
2. Amount and type of contaminants to be filtered
3. Disposal of contaminants after they are removed
4. Initial and final pressure drop across filter
5. Space available for filtration equipment
6. Cost of maintaining and replacing filters
7. Initial cost of the filter

Air filter performance parameters

1) Efficiency:

- It is an indication of the ability of the air filter to remove contaminants from an air stream

- As the efficiency of filter varies during its service life, sometimes an average efficiency is used for air filters

- However, since the efficiency of dry type filters increases with dust load, the initial efficiency of the clean filter may be more appropriate for design with low dust concentrations

2) Resistance to air flow:

- It is the static pressure drop across the filter due to its resistance.
- For non-renewable type filters, resistance increases with time as dust accumulates
- The static pressure drop depends on the type of contaminants being filtered and the air flow rate
- To maintain a satisfactory performance of the system, the air filter has to be serviced once the pressure drop across the filter reaches a pre-determined maximum value (service life)

3) Dust-holding capacity:

- It is the amount of a particular type of dust that an air filter can hold when it is operated at a specified airflow rate to some maximum resistance value
- Since actual atmospheric dust is highly variable, the dust-holding capacity is normally measured by using standardized artificial test dust

Air filter tests

- ANSI/ASHRAE standard 52.1 and 52.2 specifies various tests to be conducted on air filters.
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- Some of these relevant to HVAC applications are:
- Arrestance Test (ASHRAE 52.1)
- Atmospheric dust-spot efficiency test (ASHRAE 52.1)
- Dust holding capacity test (ASHRAE 52.1)
- Particle size removal efficiency test (ASHRAE 52.2)

- # Arrestance test:
- A known amount of standard synthetic test dust is fed into the test unit at a known and controlled rate
- The amount of dust in the air leaving the filter is found by passing the entire airflow through a high efficiency after filter by measuring the gain in its mass
- Arrestance is calculated using the masses of the dust passing the filter (W_{AF}) and total dust fed (W_{DF})

$$\text{Arrestance} = 100\left(1 - \frac{W_{AF}}{W_{DF}}\right)$$

- Since the test dust used in the test is considerably coarser than the typical atmospheric dust, this test is more relevant for low efficiency, coarse filters

- Atmospheric dust-spot efficiency test:
- The dust-spot efficiency of a filter indicates the possibility of fine airborne dust particles spoiling interior walls & surfaces
- In this method the atmospheric air with the undefined and uncontrolled dust is passed through the test filter and two white filter papers placed before and after the test filter
- By measuring the change in the light transmitted by the target white filter papers before and after the passage of the air, the efficiency of the filter in reducing the soiling of the interior surfaces is determined

- During the test the downstream sampler (white filter paper) runs continuously for the whole of the test period, but the upstream sampler runs intermittently for a total period of time such that the opacities are as nearly equal at the end of the test.
- Then the dust-spot efficiency EDS is given by:

$$E_{DS} = 100\left(1 - \frac{Q_1 O_2}{Q_2 O_1}\right)$$

- Where Q_1 and Q_2 are the total air volumes sampled through the upstream and downstream samplers
- The opacities O_1 and O_2 are given by:

$$O_{1,2} = \left(\frac{\tau_i - \tau_f}{\tau_i}\right)_{1,2}$$; τ_i and τ_f are initial & final transmittivities

- Dust-holding capacity test:
- The synthetic test dust is fed to the filter
- Pressure drop across the filter rises as more and more dust is fed
- The pressure drop across the filter is measured
- The test is terminated when the pressure drop across the filter reaches a pre-determined maximum
- The dust holding capacity of the filter is the difference between its final and initial weights

- Particle size removal efficiency test:
- This test specified in ASHRAE standard 52.2, addresses the two important aspects of air filters:

1. Ability of the filter to remove particles, and
2. Its resistance to air flow

- Depending upon the manufacturer's choice, the test is conducted at any of the seven face velocities: 0.6 m/s, 1.25 m/s, 1.50 m/s, 1.9 m/s, 2.5 m/s, 3.2 m/s and 3.8 m/s

- This test is conducted by using test aerosol consisting of laboratory generated potassium chloride (KCl) particles dispersed in airstream
- The aerosol particles are distributed into 12 geometric equally distributed particle size ranges covering 0.3 μm to 10.0 μm
- For a given particle size, particle counts upstream and downstream of the filter are taken using an optical particle counter six times starting with the clean filter
- Thus 72 measurement points are obtained for a given filter

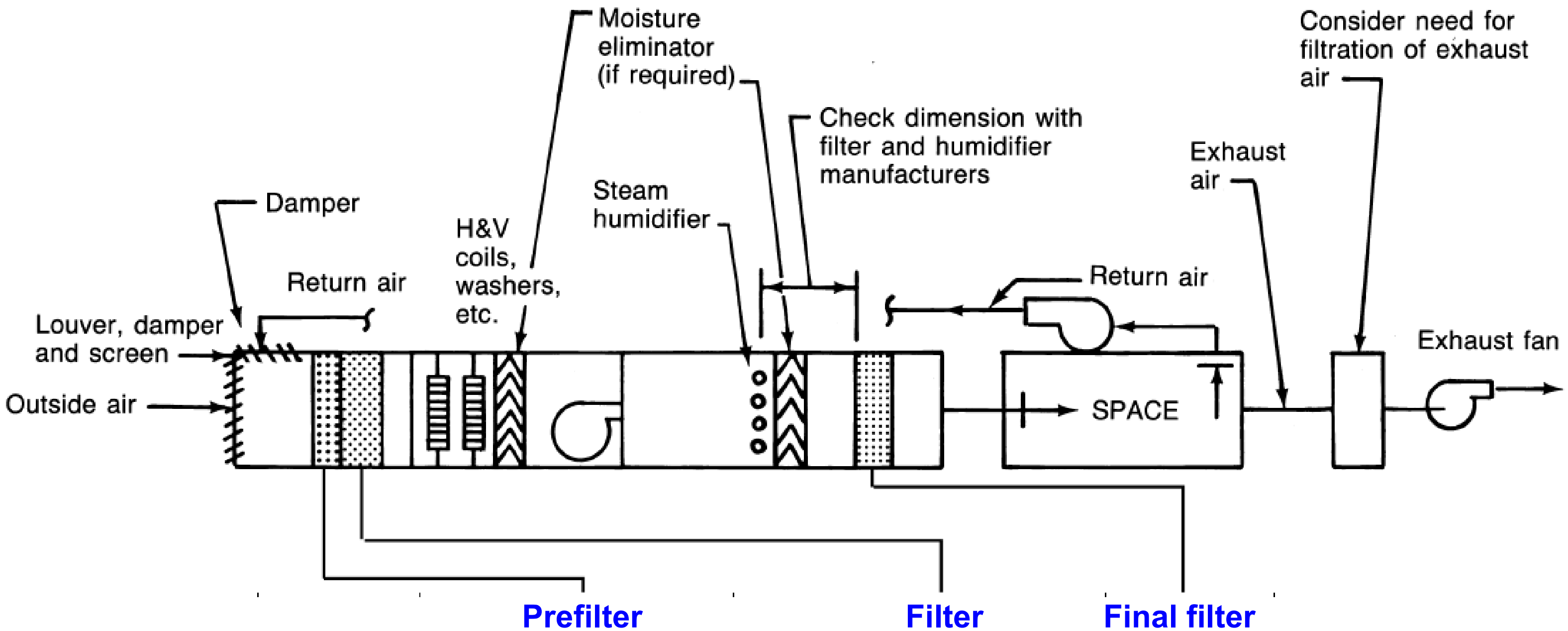
- For each point the particle size efficiency (PSE) is given by:

$$PSE = 100\left(1 - \frac{\text{downstream particle count}}{\text{upstream particle count}}\right)$$

- The lowest value of particle size efficiency out of the 6 test cycles are used to obtain the minimum efficiency rating curve
- The average particle size efficiency (PSE) for each of the size groups E1, E2 and E3 is obtained from the minimum efficiency rating curve

- The average particle size efficiency for each of the size groups E1, E2 and E3 is obtained from the minimum efficiency rating curve
- Then a single performance parameter called Minimum Efficiency Rating Value or MERV is defined based on the average PSE values for the three groups
- For HVAC and clean room applications, a 20-point MERV scale is denoted
- MERV value of a filter is always stated along with the face velocity at which it is tested
- Application guidelines based on MERV

- Installation of air filters:
- Depending upon application, an air conditioning system may have prefilters, filters and final filters



A typical air conditioning system with prefilter, filter and final filter

- Filters may be installed in the outdoor air intake duct, return air duct, recirculation duct etc.
- However, prefilters have to be installed before the cooling and/or heating coils, fans etc. to protect them from dust
- Filters of convenient size (e.g. 510 mm square or 610 mm square) are available for manual installation, cleaning and replacement
- For large systems filter banks are made by fitting filter units in frames of required size using bolted or riveted joints
- Side-loading filter sections are available to facilitate changing of filters from outside the ducts

- Installation and maintenance precautions:
- Studies show that most of the time failure of filtration system is due to faulty installation and/or poor maintenance
- Efficiency of filtration system reduces drastically if bypass is provided because:

1. The filters do not fit properly into the frame
2. Improper sealing of filters in the frame
3. Filters are <u>not installed properly</u> or one or two filter panles are missing!

- When high levels of cleanliness is required the filters should be installed as close to the conditioned space as possible
- Installation should be such that air is distributed uniformly over the filter surface
- Duct connections to and from the filter section should change gradually and uniformly
- For a given filtration system, the air and dust overload should not exceed about 15%

- Sufficient space (0.5 to 1.0 m) with proper lighting should be provided before and/or behind the filter for inspection and servicing
- Access doors should be provided to the filter service areas
- Doors on the downstream (clean air side) of the filter should be properly sealed to prevent infiltration of dirty air
- Indicators should be provided to give a warning when the filter reaches the maximum permissible resistance

- Safety requirements:
- Smoke detectors and fire sprinklers may have to be provided if there is a likelihood of combustion of dust and lint collected on the filter media
- Many filters collect bio-aerosols which can multiply and pose a health hazard to the service personnel
- Regular cleaning and/or changing of filter media can reduce microbial growth
- Used filters should be disposed of in a proper manner so that it does not create environmental problems

- Economics of air filters for HVAC applications:
- Important parameters to be considered are:

1. Initial cost of the air filtration system
2. Energy cost of the filters due to additional fan power consumption
3. Maintenance cost, and
4. Cost due to disposal

- Often the energy cost of filter is much higher than initial and other costs

- Life cycle cost of filters can be minimized by:
- Selecting suitable filters
- Adapting suitable maintenance and replacement schedules
- Optimizing use and replacement of prefilters whenever more efficient and expensive filters are used in the system, for example:
  - Use of a disposable prefilter can increase the service life of a HEPA filter by about 25%
  - Use of a disposable prefilter followed by a 90% extended surface filter can increase the service life of HEPA filter by almost 900%!

However, optimization is always case-specific!

- Recent trends in air filter technology:

1. Use of synthetic nano-fibre materials to reduce:
   1. Airside pressure drop
   2. Increasing the dust holding capacity
2. Use of bi-component spunbond media for improving durability
3. Use of hybrid filters for overall performance improvement
4. Development of software for minimizing life cycle costs of filtration systems

Conclusions

- Proper selection and maintenance of air filters can provide a healthy and clean environment, and at the same time it can prolong the life of HVAC equipment
- A large number of filters have been developed to cater to various applications
- Standards have been evolved for proper testing and rating of air filters
- The field is still evolving and growing due to the growing concerns about air quality, energy consumption and ecological problems

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Thank you!