CHAPTER 12

Air Filters

Outdoor and recirculated air used in air conditioning and mechanical ventilation systems contain impurities and contaminants that need to be removed for the following reasons:

- To maintain an acceptable level of air purity for occupants, processes, and building equipment;
- To protect the air conditioning plant;
- To prevent staining on interior decorations and furniture.

In addition, airborne contaminant arising from any process occurring within the treated space may have to be removed from the exhaust air. Examples of this include grease in kitchen extract systems and wood dust in saw mills.

Atmospheric contaminants are classified as solid, liquid, gaseous, or organic, and usually, within these categories, they are ordered roughly according to particle size and type. The particle size is relatively small, and the unit of measurement commonly used is the micrometre ($\mu m = 10^{-4}$ m). Most of the staining in buildings is caused by particles with a size range of between 0.5 and 5 μm. Although invisible to the human eye, these particles have little mass but are very numerous. For comfort air conditioning applications, it is usually considered necessary to include a filter with efficiency high enough to remove most of the particles in that range.

FILTER PERFORMANCE

Efficiency

The most important characteristic of filter performance is its efficiency. Efficiency is a measure of the ability of the filter to remove dust from the air, expressed in terms of the dust concentration upstream and downstream of the filter; it is given by the equation:

$$\eta = \frac{C_1 - C_2}{C_1} \times 100 \tag{12.1}$$

where C_1 = upstream dust concentration and C_2 = downstream dust concentration.

Air Conditioning System Design
http://dx.doi.org/10.1016/B978-0-08-101123-2.00012-1

Dust concentration can be expressed in terms of either mass, number of particles, or staining power per unit of surface area. Where the concentrations are expressed as a mass, the efficiency is known as the *arrestance* A.

There are a number of ways of determining filter efficiency using standard tests based on the way concentration is expressed, and as these give different values, it is important to state the test method used. For example, most filters whose efficiency is based on the mass of particles removed will have efficiencies of more than 90%, as the heavier, larger particles are more easily trapped by the filter medium; whereas based on a staining power test, the efficiency may be as low as, say, 20%.

There is no one test method suitable for all types of filters, and results from different methods cannot be directly compared. To compare the performance of various filters, the same test method must be used together with the same test dust or aerosol; e.g., the test dust should have the same particle-size distribution.

Tests of Filters for General Purposes

Tests for arrestance and dust spot efficiency are covered by BS 6540: part 1, [1] ASHRAE Standard 52–76 [2] and Eurovent 4/9—1997 [3].

The gravimetric tests use a standardized, synthetic dust with the specification given in Table 12.1. The test is carry out by feeding a measured, controlled quantity of test dust into the airstream, giving the value S of C_1 in Table 12.1. The mass of dust leaving the filter under test is determined

Table 12.1 Synthetic dust for testing filters (using standards ASHRAE 52-76 and Eurovent 4/9—1997)

Proportion by mass	Composition
72%	Natural earth dust, graded to give the following particle size by mass (tolerance ±3%) 0–5 μm 39% 5–10 μm 18% 10–20 μm 16% 10–40 μm 18% 10–80 μm 9% Typical bulk density—1057 kg/m^3
23%	Molocoo (carbon) black—a submicro Particle material forming fluffy aggregates Typical bulk density—272 kg/m^3
5%	No. 7 cotton linters, ground and sieved Through a 4 mm screen

by passing all the air through a high-efficiency filter. The gain in mass of this second filter determines the value of C_2.

FILTER PERFORMANCE

Dust Spot Efficiency

Dust spot efficiency or blackness test uses the airborne contaminants already present in the atmosphere. Air is sampled on either side of the filter via target filter papers using equal flow rates. The sample drawn through the downstream target is continuous, whilst that through the upstream is intermittent with a measured time interval such that the opacity of both target papers is comparable. The efficiency is then a function of the total quantity of air passing through each target combined with its light transmission.

Dust Holding Capacity

The dust holding capacity of a filter is the amount of dust that it can hold whilst maintaining its specified efficiency or within its rated pressure drop, from clean to dirty; its value is obtained at the same time as the efficiency tests. For most filters, efficiency and dust loading are interrelated, and therefore, the efficiency is obtained a number of times during the course of a test; the dust holding capacity is the integrated amount of dust measured at each part of the test. A different technique is used for self-renewable filters such as the automatic roll filter.

High-Efficiency Filters

High-efficiency particulate absolute (HEPA) filters are tested using the sodium chloride test that is covered by ISO 29463-1:2011 [4,5]. The test is a discoloration test using small salt crystals that are carried by the airstream. Samples of air upstream and downstream of the filter are passed through a flame of burning hydrogen gas, which becomes bright yellow when exposed to sodium chloride. The intensity of the colour relates directly to the concentration of sodium chloride particles, the brightness of flame being measured with a photosensitive cell.

In the United States, the DOP penetration test is used. In this test, a vapour of dioctyl phthalate is generated with a particle size of approximately 0.3 μm with a cloud concentration of 80 mg/m. Light-scattering techniques are used to obtain the upstream and downstream concentrations.

The performance of high-efficiency filters is often expressed as the *penetration*, P, that is given by:

$$P = 100 - \eta \tag{12.2}$$

A DOP standard test is also available for on-site testing.

Face Velocity

The face velocity v_f is the mean velocity of the air entering the effective face area of the filter:

$$v_\mathrm{f} = \dot{V} / A_\mathrm{d} \tag{12.3}$$

where $\dot{V}$ = volumetric flow rate (m^3/s) and A_d = cross-sectional area of duct connection of filter (m^2)

Usually, the maximum velocity is recommended by the manufacturer, although this is not necessarily consistent with the face velocity of a filter sized for economic operation.

Pressure Drop

The pressure drop Δp across a filter is related to the face velocity by the following equation:

$$\Delta p = b\,(v_\mathrm{f})^n \tag{12.4}$$

where $1 < n < 2$

For most filters, the value of the constant b will rise depending on the amount of dust it is holding. In much of the literature on filters, the pressure drop is termed, erroneously, the resistance (refer to Chapter 13 for the definition of resistance).

FILTER TYPES

Brief descriptions of the various filters used in air conditioning systems are given below; typical design and operating characteristics are set out in Table 12.2.

Dry Fabric

Dry fabric filters use materials such as cotton wool, glass fibre, cotton fabric, pleated papers, and metal mesh, as the filter medium. The efficiency of the filter depends largely on the area of the medium offered to the airstream. The different types of dry fabric filter include the following:

Table 12.2 Typical design and operating characteristics of air filters

Filter type	Face velocity (m/s)	Pressure drop Initial (Pa)	 Final (Pa)	Efficiency Arrestance *A* (%)	 Dust spot or sodium flame (%)
Panel					
Dry fabric metal mesh	2.0	70	100	70–95	–
Bag					
Low efficiency	2.5	70	300	90–95	45
Medium efficiency	2.0	140	600	98	80–85
High efficiency	1.8	200	600	98	90–95
Automatic roll	2.5	80	160	80–90	–
Absolute					
Low efficiency	2.5	250	500	–	95
Medium efficiency	1.2	250	500	–	99.5
High efficiency	1.2	250	500	–	99.997
Electrostatic	2.5	100	–	90	–

Panel or cell. The filter material is mounted in panels up to 600 mm square. Panels are fitted into a common frame and are placed either at 90 degrees to the air flow or as a series of oblique cells as in Fig. 12.1. The framework is part of either an air handling packaged unit or a separate plant item in the ductwork system. For maintenance, small units are usually side withdrawal, larger units, and front withdrawal; the dirty cells are discarded and replaced with new.

Bag. A set of bags, made of the filter material, is mounted in a frame, with the open ends of the bags facing the airstream as in Fig. 12.2. This provides a large area of material that makes the filter suitable for large volume flow rates at relatively low pressure drops. Filter material is used to provide low, medium, and high efficiencies; the last is often referred to as a semi-absolute filter. The framework and maintenance is similar to that described for panel filters.

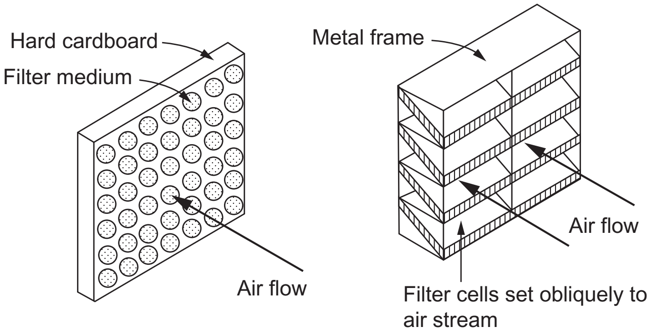

Fig. 12.1 Panel filters.

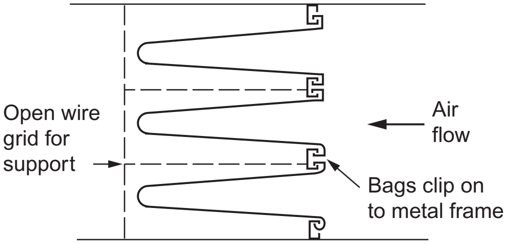

Fig. 12.2 Bag filter (diagrammatic arrangement).

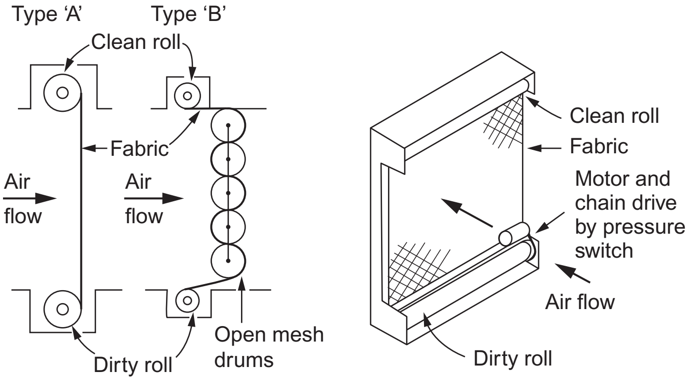

Fig. 12.3 Automatic roll filter.

Automatic roll. In this filter, the medium is stretched between two rollers, one of which is driven by a motor, as in Fig. 12.3. As the filter becomes dirtier, the pressure drop across it increases, and the differential pressure switch starts the motor that rolls on a clean area of filter until the pressure has

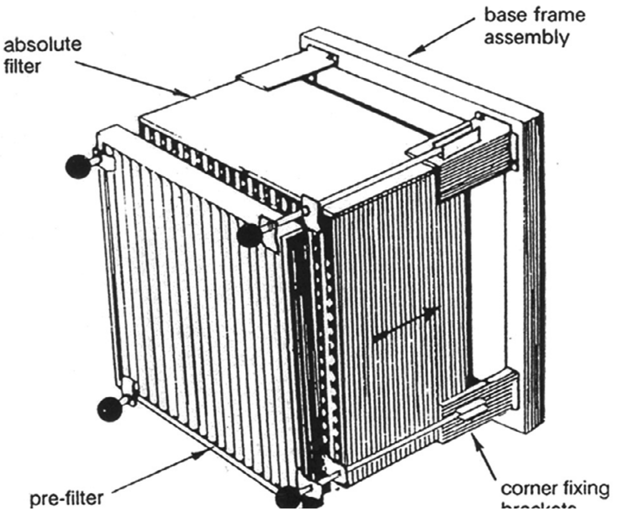

Fig. 12.4 Absolute filter fixing arrangements. *(Reproduced with permission from Mann + Hummel Vokes Air Ltd.)*

dropped to the low limit of the switch. Some media are cleanable, but most are discarded once the whole roll is dirty.

Absolute. HEPA filters use densely packed pleated filter material as shown in Fig. 12.4. Filters are graded under low, medium, and high efficiencies. Some HEPA filters are available to cope with adverse environmental conditions.

The dense filter material results in a high-pressure drop for the rated air flow, and for economic operation, it is often necessary to select a larger filter to give a lower pressure drop, rather than install a unit at the upper limit of at its maximum capacity. A prefilter should be used to remove the relatively large particles from the incoming air and prolong the life of the filter cells; they bolt together to form a multiple unit, and when ‘dirty’, they are discarded.

Electrostatic Filter

An electrostatic filter has two main sections as shown in Fig. 12.5. The first section is the *ionizing section*; it consists of a series of fine wires charged to a voltage of up to 13 kV, placed alternately with earthed rods. This sets up a corona discharge, and as the airborne particles pass through the ionizing field, they receive a positive electrostatic charge. The second part is the

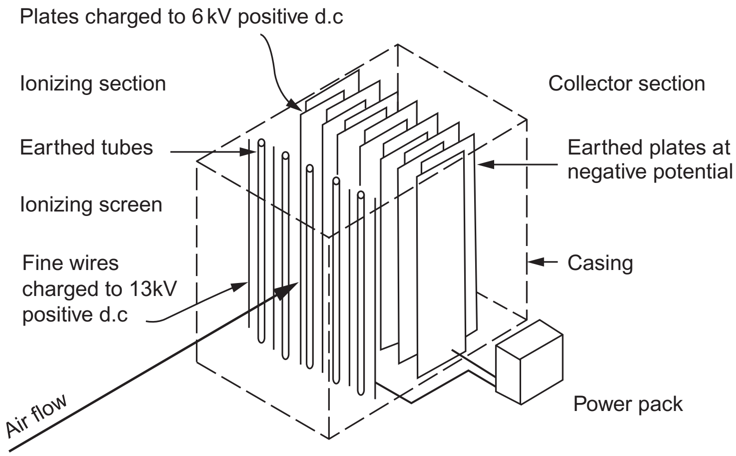

Fig. 12.5 Electrostatic filter.

collector section; this consists of a series of parallel, vertical metal plates with a potential difference of 6–7 kV between adjacent plates. The ionized dust particles are attracted towards these plates to which they adhere. The plates are sometimes coated with oil to help dust retention. The filters are cleaned automatically by washing with high-pressure water.

Adsorption Filter

Adsorption filters are used for the removal of odours, tobacco smoke, and some poisonous gases such as SO_2. The air is passed across a large surface area of activated carbon. The contaminating gas is attracted to the carbon that eventually becomes saturated with the gas. It can be reactivated by removing and heating the carbon to an appropriate temperature.

FILTER SELECTION

The primary requirement is for the filters to remove airborne contaminants at the required efficiency for the application whilst retaining the dust removed from the airstream. Other considerations are as follows:

Environmental conditions. Some conditions, e.g., high humidity and temperature, can adversely affect the filter, and hence, appropriate media should be chosen.

Maintenance. Servicing methods include:

- replacing complete filter;
- renewing filter media;

- reconditioning or cleaning;
- automatic self-cleaning, e.g., electrostatic filters.

Clogged filters can cause failure of systems to supply sufficient air. Suitable indicators and alarms should be provided to ensure filters are maintained; adequate access must be allowed for replacement and cleaning.

Pressure drop. Manufacturers aim to design the filter fabric in such a way as to minimize pressure drop for a given velocity. Nevertheless, the filter should be chosen with as low a pressure drop as possible, consistent with required efficiency and initial costs. This is particularly useful with high-efficiency absolute filters that have high-pressure drops at the maximum recommended face velocities. A derated filter will usually give increased capital costs for builders work and/or ductwork, which is offset by the fan energy savings.

Prefilters. The life of high-efficiency filters can be extended considerably by providing prefilters to remove the larger particles; care should be taken in striking the right economic balance. Prefilters are provided as an integral part of an electrostatic filter system.

Costs. One type of filter may have low initial costs but high operating costs, whereas another type may have high capital cost with low running costs. The initial cost will depend on the filter type, associated ductwork, and any ancillary equipment. The operating cost of the filter is made up of the replacement cost of the media at the end of its useful life, the cost of replacing and/or cleaning the filter media, the energy and cleaning material costs, and the fan power required for the filter pressure drop (the mean value between clean and dirty operation).

A solution to this problem is to calculate the *owner cost-benefit index* (CBI). This index is the ratio of the filter efficiency to the total owning and operating costs. Thus, for a given total cost, the CBI increases with the efficiency and the higher the CBI the more benefit to the client/building owner in terms of

- reduced maintenance, decorating, and housekeeping;
- protection of contents and products;
- protection of high-efficiency (absolute) filters.

SYSTEM DESIGN

Position of the filter in the system. As it is essential to prevent the buildup of contaminants on air conditioning plant items, the filter will normally be the first plant item in the system.

For special areas where high standards of air cleanliness are required, an additional filter may need to be provided as the last plant item. This should be fitted after the fan to cope with any ingress of air, which may occur in the plant. Alternatively, each room outlet may be fitted with a terminal filter.

Recirculated air. A case can be made for cleaning contaminated exhaust air to allow it to be recirculated. The use of potentially contaminated air can be an emotive subject, e.g., recirculation in hospital operating rooms. Even so, techniques for air cleaning are available and may prove to be the most appropriate plant arrangement. The choice will usually depend on the quality of the installation and maintenance to ensure acceptable standards of air cleanliness. An alternative to recirculated air is to use a heat recovery unit.

Changes in air flow rate. The change in air flow rates resulting from increased pressure drop across a dirty filter can be examined by referring to the system and fan characteristics. If the reduction in air flow rate is unacceptable, then near-constant flow rate can be achieved by using one of the following methods:

- Hand reset damper;
- Automatic damper;
- Inlet guide vanes operated with a static pressure controller;
- Variable speed fan.

Protection against fog and frost. Where the filter is to be used in a system employing 100% outdoor air or where a filter is placed in the fresh (outdoor) air duct, fog can sometimes saturate and degrade the filter media; freezing fog can block it completely. Where these conditions are likely, it will be advisable to provide a protective heater upstream of the filter under the control of a low-limit thermostat.

Fresh air intake. The preferred position of the intake is at roof level and sited away from local sources of contamination. Where it is at low level, it should be at least 2 m off the ground; this precaution will reduce the load on the filter. The intake should include a bird and/or insect screen. For buildings that are located in areas liable to sand storms, grilles are fitted to trap any heavy airborne particles.

Installation. Care should be taken to provide adequate seals between the filter units and the holding frames; this is especially important with absolute filters.

REFERENCES

[1] BS EN 779: 2012 Particulate air filters for general ventilation. Determination of the filtration performance, British Standards Institution.

[2] ASHRAE 52-76, Methods of testing air-cleaning devices used in general ventilation for removing particulate matter, 2012.

[3] EUROVENT 4/9–1997, Method of testing air fillers used in general ventilation for determination of fractional efficiency. (Note: There have been various updates to this standard, the latest being EN779–2012.).

[4] BS 3928: 1969, Method for sodium flame test for air filters, British Standards Institution (confirmed 2014).

[5] ISO 29463–1:2011 High-efficiency filters and filter media for removing particles in the air—Part 1: Classification, performance testing and marking.