Optimise Air Filtration and Minimise Energy Costs

by Chris Ecob

Cultural facilities are not immune to the economic crisis. Cost trends are upward, and revenues from visitors, endowments and corporate sponsorship are under threat. The news is not all bad, however: an opportunity exists for many cultural facilities to immediately reduce their energy costs and carbon footprint. This opportunity can usually be realised without the need to encroach on precious capital budgets, and the financial benefits start immediately.

Does this sound too good to be true? For the answer, look to the air filters deployed in your ventilation system. Air filters rarely get the attention they deserve: they are often sourced on a "lowest cost to fill a hole" basis. However, not only do air filters have a valuable role to play in air quality and preventative conservation, they can also dramatically influence energy consumption. An inappropriate selection, made perhaps to save a few percent from the maintenance budget, can result in disproportionately higher increments to your facility's energy bill.

Ventilation with "fresh" external air is provided for the wellbeing of workers and visitors. Fresh air brought into the building may be heavily polluted, especially in city-centre locations. Many of the artefacts will be sensitive to these pollutants. Filtration is routinely applied to control particulate (dust) and molecular (chemical) contamination.

A fan is a common component in all ventilation systems. This device is powered by an electric motor, and is required to overcome the ventilation system's resistance to flow, driving the air from outside to inside. Examples of components that create flow resistance include ducting, heating and cooling coils, ceiling grilles and dampers. If the ventilation system is properly maintained, the flow resistance of these components will, at a constant airflow rate, remain unchanged throughout the system's life.

Particulate air filters also create a resistance to airflow; however, unlike the other components, the flow resistance or pressure drop increases as they collect dust. Theoretically, the pressure drop across a filter can increase until it creates a severe restriction to airflow, or until it collapses and fails. In practice, it is usual to specify an upper working limit for pressure loss; at this point, the filter should be replaced with a new clean item. The system designer takes this upper pressure-loss value into account when selecting the fan and the motor. The higher the resistance value, the greater the power consumption of the motor and the operational cost of the ventilation system. (Note that the pressure drop of molecular (carbon) filters should not increase during their operational life).

It is clear that air filters have an influence on the energy demand of a ventilation system. In fact, a simple analysis of the pressure-loss values of all the components in a typical ventilation system shows that filters account for 30% of the total energy demand (see Graph 1). Interestingly, filters are the least expensive component to improve: after all, they are designed to be changed out on a regular basis and, if any system modifications are needed, at most it will be a simple frame or clip change to facilitate the fitting of a different filter.

There is a simple relationship between pressure loss and energy consumption in kWhrs, as seen in Equation 1.

$$E = \frac{Q \times dP \times T}{\eta \times 1000} \text{ kWhr/year}$$

where Q = Airflow (m^3/s)
dP = Pressure drop (Pa)
T = Operating time (8760 hrs per year)
η = Fan efficiency (30–75%)

Equation 1

For example, a small ventilation system may have two-stage filtration (pre-filtration and fine filtration). A single pre-filter and a single fine filter will each handle a flow of

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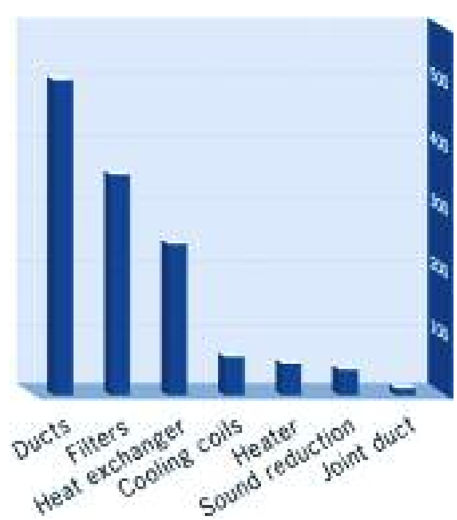

Graph 1: Typical pressure-loss contribution for different components of a ventilation system. (Y-axis in Pa)

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0.94 m^3/s. These two filters may have a combined average pressure loss of 350 Pa throughout their service lives. If the fan efficiency is 60%, the energy consumption (E) is:

$$E = \frac{0.94 \times 350 \times 8760}{0.6 \times 1000} = 4803 \text{ kWhr/year}$$

If, through judicial filter design and construction, the average pressure loss could be reduced to 300 Pa, the corresponding energy consumption is reduced to 4120 kWHr. If the facility is paying £0.1/kWhr, the annual saving (£) is:

$$(4803 - 4120) \times 0.1 = £68.30$$

Now this is only for a single (two-stage) filter. A large facility may have several hundred, and possibly above a thousand, installed filters. If the installed number of filters is 500, then the annual saving is £34,150. As a rule of thumb, each unnecessary Pascal of pressure loss across each filter costs £1.50 per year in energy costs.

The key to understanding the importance of pressure loss and energy consumption comes from the Life Cycle Cost (LCC) analysis for a filter, from manufacturing to disposal. Of the total cost of manufacturing, transport, purchase price, installation (labour), energy and disposal, energy typically accounts for 70% of the total. So buying a cheap air filter may be a completely false economy if it requires an excessive amount of energy to drive air through it.

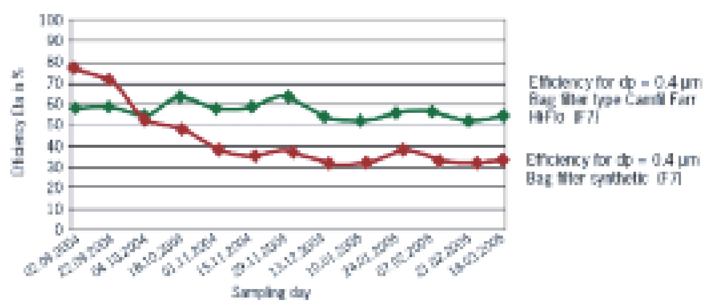
All of the above has been understood for many years. Now, however, increasing energy costs and concerns about carbon footprint and global warming present a new opportunity to scrutinise air-filtration techniques. Many users are now focussing attention on the influence that air filtration can have on artefact preservation, performance of the ventilation system and, most importantly, the cost of operating ventilation systems.

It is worth considering some air-filtration basics. Air filters remove variously sized particulate materials from the air by a combination of mechanisms: inertia, diffusion and straining. The relative importance of these mechanisms depends on the particle size. All filtration media are fibrous, and the diameter of the fibres and the weight of fibres per unit area have a strong influence on filtration properties. To remove very small particles, a filter medium composed of finer-diameter fibres is required. Large particles may be arrested using coarse fibres. Finer fibres are able to pack closer together in the media web, and the interstitial holes between the fibres are smaller. The typical observation in laboratory "flat-sheet" tests—that high-efficiency air filter media have higher pressure-loss values at a given airflow than lower-efficiency air filter media—is not, therefore, unexpected. Very few air filters, except the coarsest low-cost devices, use a flat sheet of medium placed perpendicularly across the airflow. Most filters use techniques such as pleating and the formation of pockets to increase the area of medium incorporated in the filter. Such techniques can have a significant influence on initial pressure loss, final pressure loss, filter lifetime and, most importantly, operational energy cost.

Claims have been made that an electrostatic effect can be used to supplement mechanical filtration mechanisms and enhance filtration efficiency. The potential benefit of such a material would be that coarse fibres could be used to provide the same efficiency as a non-charged media, and the pressure-loss value would be lower. Whilst this may be true for such filters when new, the electrostatic effects have been indisputably shown to be relatively short-term and, over a period of a few weeks, the efficiency value actually falls to well below the claimed value. This behaviour is now recognised and has been reflected in the European and American air filter test standards (EN779:2002 and ASHRAE 52.2-1999), which now require that the filters must be efficiency-tested after any electrostatic charge has been dissipated.

Graph 2 shows the comparative performance of two different types of air filter against 0.4 micron-sized particles over a six-month period. Both claim F7 performance (EN779). The measurements were made in two identical side-by-side fresh-air ventilation units in Berlin. Note, the Hi-Flo filter (glass-fibre media) maintains a constant efficiency of approximately 55–65%. Conversely, the filter made from coarse synthetic fibres, which has a high initial efficiency due to its electrostatic charge, quickly deteriorates to an efficiency value of 30–35%.

It is filter design and filter construction techniques that allow competent manufacturers to produce air filters with minimal energy demands that do not compromise efficiency. Low pressure-drop values can be achieved through good filter engineering. Increasing the amount of filter medium in the filter gives the air more area to pass through, and more capacity to collect dust particles. However, simply increasing the amount of filter medium can itself be problematic if the filter construction actually creates a greater restriction to airflow. It is essential that the additional filter



Graph 2: The efficiency performance of two types of air filter over time.

medium be configured to allow the air an easy passage into, through, and out of the filter.

This point is illustrated in Figures 1 and 2, which show an extended area 12-pocket bag filter and a visualisation of the problems that can occur if the pockets are not properly constructed in a tapered fashion and adjacent pockets are allowed to touch each other.

The benefit of incorporating additional media area in a filter is illustrated by the following LCC software comparison of two Camfil Farr bag filter products. Two filters are compared side by side. Both use identical filter media, and both are F7 grade according to EN779 (MERV 13- ASHRAE 52.2-1999). The only difference between the filters is that the A7 model contains 4.5 m^2 of media; the M7 model 9.2 m^2. In this scenario, the ventilation system contains four filters, each filter is handling 3400 m4/hr (2000 cfm), and the costs are to be calculated over a five-year period. The outdoor air quality has been set to simulate a large town (ODA 3 according to EN13779), and the fan efficiency has been set to 50%. The labour cost to change each filter has been set at £20. Inflation has been set at 0%.

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Figure 1: A 12-pocket bag filter.

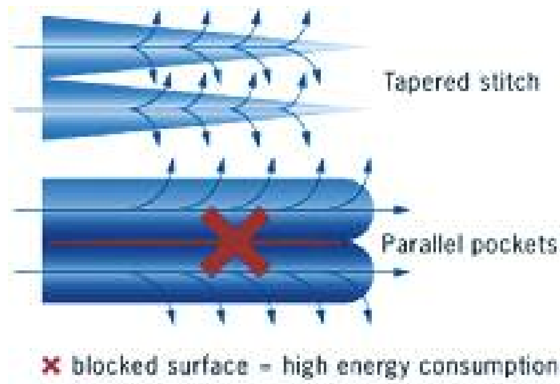

Figure 2: Comparison between the ideal tapered pocket design and a parallel pocket design.

Table 1

FILTERS	Hi-Flo A7
Energy Class	B
Media	CM 285B
Size	592 * 592 * 595 (mm)
Effective media area	4.5 m^2
Filter price	111.2 GBP
Labour cost	20 GBP/Filter
Airflow	3400 m^2/h (0% Return air)
Pressure drop	150 Pa
Final pressure drop	250 Pa
Average dP	190 Pa
Filter life	2200 hours
Number of filter changes	20
LCC cost in GBP based on 5 years lifetime of installation	
FILTERS	**Hi-Flo A7**
Total filter cost	2224
Installation cost	0
Labour cost	1520
Energy	6292
Disposal cost	380
Duct cleaning cost	0
Total LCC	**10416 GBP**

Table 2

FILTERS	Hi-Flo M7
Energy Class	A
Media	CM 285B
Size	592 * 592 * 635 (mm)
Effective media area	9.2 m^2
Filter price	193.2 GBP
Labour cost	20 GBP/Filter
Airflow	3400 m^2/h (0% Return air)
Pressure drop	85 Pa
Final pressure drop	250 Pa
Average dP	142 Pa
Filter life	11200 hours
Number of filter changes	4
LCC cost in GBP based on 5 years lifetime of installation	
FILTERS	**Hi-Flo M7**
Total filter cost	772
Installation cost	0
Labour cost	240
Energy	4716
Disposal cost	60
Duct cleaning cost	0
Total LCC	**5788 GBP**

Tables 1 and 2: Summary of LCC report data for the A7 and M7 filter models over a five-year period.

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The software reports the initial, final and average pressure loss of each filter. Note the average pressure-loss values of 190 Pa (0.76 in. WG) and 142 Pa (0.56 in. WG) for the A7 and M7 filters. From a database of test reports, the software calculates the number of times each pattern of filter would have to be changed over a five-year period, based in both cases on a final pressure-loss value of 250 Pa (1.0 in. WG). The A7 filter would require 20 changes, and the M7 filter a maximum of four changes in the same period.

The lower section of the LCC software report shows the costs of operating the two different filters over a five-year period.

Note that the purchase price of the M7 filter is almost double that of the A7 filter. Yet, when the number of required filter changes is taken into account, the expenditure on filters over five years is considerably less for the M7 filter (£772 vs £2224). Similarly, the labour costs to change the M7 filter are much lower (£3240 vs £1520).

However, the most pronounced difference is in the energy costs. The energy bill to operate the M7 filters will be £1576 less than the A7 filter (£6292 – £4716). Taking all of the benefits into account, the M7 filter will be £4628 (£10416 – £5788) cheaper to operate over a five-year period, for a savings of 44%.

Using effective air filters with durable long-term efficiency values provides other benefits. The need for expensive ductwork cleaning and interior redecoration can be substantially avoided.

Summary

- Air filters play an important role in providing good indoor air quality and in preventative conservation.
- Filters can have a very significant impact on energy costs and carbon footprint.
- Only filters that have a durable high-efficiency value, resulting from the use of fine-fibre media, should be used.
- A Life Cycle Cost analysis is essential to ensure that the total operational costs of an air-filter installation over a period of years are identified and minimised.
- Air filter design and construction can greatly influence lifecycle costs.
- It is a false economy to select air filters simply on the basis of lowest purchase cost.

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