air filters and IAQ

Camfil Farr	Technical information

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Camfil Farr - clean air solutions

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The need for removing impurities from air or other gases has increased with regard to the degree of separation and the necessity to separate finer particles. Correct specification of filters is a prerequisite for the correct functioning of ventilation systems so they can help safeguard sensitive production processes, protect humans and the environment or improve indoor air quality (IAQ). A filter is a key component of a ventilation system which, in conjunction with other system parts, can contribute towards a better indoor environment.

Every day we breathe about 20-30 kg of air and consume around 1 kg of solid food and 3 kg of liquid food. We should therefore expect our air to have the same quality standards as our food and drink. We spend 90% of our time indoors and the vision should be that nobody gets sick because of the indoor air environment.

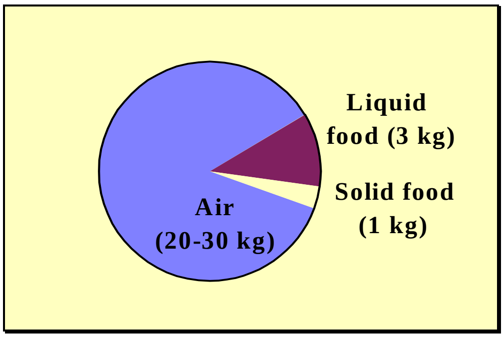

Figure 1. *Human consumption of air and food over a 24-hour period.*

IAQ IN FOCUS

IAQ is in focus for the moment. In the US, ASHRAE (1998) has developed strategies for improved environmental health and defined different areas to tackle. VDI (1998) in Germany has prepared a hygienic standard for the planning, design, operation and maintenance of air conditioning systems. In the Nordic countries, 1999 is dedicated to IAQ and involve a number of activities and presentations of research programs and results on the subject. Eurovent (1998), the association for HVAC manufacturers in Europe, is introducing several documents about IAQ.

VENTILATION SYSTEM

According to current IAQ studies, many problems are still being caused by ventilation systems that are badly designed or operating poorly. Many of these problems can be solved easily. In the US there are two large surveys, NIOSH 1994 and Minnesota 1997, summarising IAQ problems from different studies (Ellringer and Whitcomb, 1997). In most cases, a combination of factors has caused IAQ problems. Table 1 shows the percentage of major problems behind the IAQ syndrome in each case.

Ventilation accounted for 50 to 30% of the main problems. The temperature probably plays a major role in this. Regarding micro-organisms, the two surveys differed considerably. In the Minnesota study, more than 50% of the installations experienced problems with micro-organisms. In 29% of the installations, micro-organisms were the main IAQ problem and 94% of these were in the ventilation system. The NIOSH study indicated only 5% problems related to micro-organisms in the system.

Table 1. *Summary of IAQ problems from two surveys, NIOSH 1994 and Minnesota 1997 (Ellringer and Whitecomb, 1997)*

Type of problem	NIOSH Main problem 450 studies	Minnesota Main problem 263 studies	Minnesota all problem
Ventilation	52%	13%	25%
Temperature	-	19%	46%
Contaminants			
Indoor	17%	14%	22%
Outdoor	11%	7%	16%
Building materials	3%	4%	6%
Micro-organisms	5%	29%*)	54%
Unknown	12%	14%	14%

*) 94% in the ventilation system

Bayer et al (1999) made a study for the U.S. Department of Energy about IAQ research that has been conducted in school facilities. They found that most of the IAQ problems could be avoided or resolved by adequate amount of outdoor air, controlled humidity and efficient air filters to prohibit most mold spores and fungi from entering the HVAC system.

What can air filters do? A filter is one component in a ventilation system and cannot contribute to better IAQ by itself. But filters are normally a must for the system to work properly during many years. If the right air filters are installed and frequently replaced, they can contribute to better IAQ by:

– keeping the system clean, which means that the designed air flow is maintained and temperature and humidity are kept within specifications. A clean system operating with the designed air flow reduces the amount of indoor contaminants generated by humans, building materials and equipment.
– maintaining the efficiency of equipment, allowing fans, heating and cooling equipment to work properly.
– preventing micro-organisms from entering the system.
– removing outdoor contaminants. All outdoor contaminants can be removed easily before they enter the system.

To maintain function for a good number of years, the ventilation system must be effectively protected, both on the inlet and exhaust sides. *Impurities must be stopped at the inlet and not be allowed to enter the system.* An F7 filter is the most appropriate filter in terms of operating costs, cleaning, and installation maintenance.

HYGIENE REQUIREMENTS

Every day we breathe about 20-30 kg of air and consume around 1 kg of solid food and 3 kg of liquid food. We should therefore expect our air to have the same quality standards as our food and drink. We spend 90% of our time indoors and the vision should be that nobody gets sick because of the indoor air environment. We demand a lot of what we eat and drink, but what are the requirements for air? What should we accept? What could we accept?

Atmospheric air and dust

Air is made up of a mixture of gases and materials generated by natural processes and human activities.

Size of particles

The size of particles is often indicated in µm (micrometer). $1\mu m = 10^{-6}$ m. Particles in the atmosphere vary in size from less than 0.01µm up to objects the size of leaves and insects.

Studies of atmospheric particles show that their distribution is often bimodal, i.e. the particles are made up of two separate fractions, one fine and one coarse. Coarse particles, about 2.5µm and larger, consist of natural dust from the effect of wind, erosion, plants, volcanoes, etc. The finer fraction, made up of particles smaller than 2.5µm, consists primarily of particles from human activity in the form of combustion products, vehicle emissions and other processes.

Hygiene requirements for particle concentrations in the air have been based on concentrations of particles smaller than 10µm (particulate mass, PM_{10}). Studies have shown a direct connection between the death rate and finer particles. Official requirements are under review in both Europe and the US, and are to be based on the concentration of particles smaller than 2.5µm ($PM_{2.5}$). It has also been shown recently that smaller particles play a major role in affecting our respiratory system.

Finer filters are needed to effectively eliminate these small particles and meet official requirements, and demands for filtering outdoor air, recycled air or exhausted air are increasing. With an F7 filter, good separation of small particles is achieved.

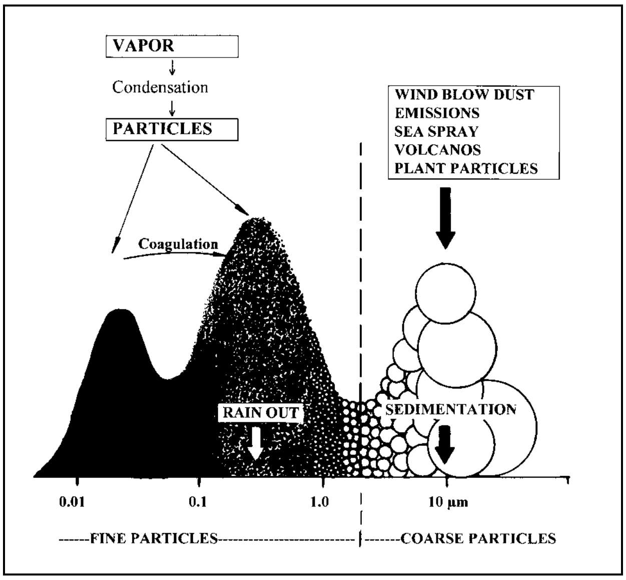

Figure 2. *Size distribution of atmospheric dust. The coarse particles, whose size ranges from about 2.5µm or larger, are made up of natural dust. The finer fraction consists primarily of particles generated by human activities.*

Number of particles
The number of particles varies considerably with time and place. In Table 2 we can see that the concentration of particles in air is 10^9 particles per m^3. In a city the concentration is at least 100 times higher, and to reduce the number of particles in an urban environment to the same number present in the countryside, a filter with 99% separation is required. An urban or polluted environment thus requires a filter of increasingly high quality.

Table 2. *Number of particles at different locations.*

Place (examples)	Particles/m^3
Clean room	10^3
Arctic region	10^7
Countryside	10^9
City	10^{11}
Tobacco smoke	10^{14}

Carcinogenic potential of pollutants
The size and number of particles tell us nothing about how dangerous the particles are, and the filter quality that is required. We know that a large number of studies have been conducted, and that there is a relationship between carcinogenicity, allergens and traffic pollution.

To determine if filters could reduce the carcinogenic effect of airborne contaminants, a study was carried out together with the University of Stockholm. Different filters were tested according to the AMES test, a short-term mutagenicity test to evaluate carcinogenic risks.

In the AMES test, bacteria (*salmonella typhimurium*) are exposed to air pollution. Normally, these specially prepared bacteria cannot grow sufficiently to form visible colonies. However, if the pollution affects the bacteria's DNA, colonies will start to grow and form (the bacteria revert). Many substances in air pollution are not carcinogenic but will transform into active mutagenic substances when exposed to certain enzymes in the liver. The bacteria in the AMES test are therefore exposed directly to air pollution and indirectly via liver enzymes.

The AMES test indicates the mutagenicity of the pollution expressed in bacterium colonies or revertants. The test shows if the pollution is attacking the DNA in bacteria. Furthermore, it is well established that a mutagenic compound acting on the DNA in one organism (bacteria) is likely to act in the same way in another organism (human). Studies have shown a correlation between mutagenicity and carcinogenicity. Compounds that are not shown to be mutagenic would be assumed to be non-carcinogenic, and those shown to be mutagenic would be subjected to further testing.

Air samples were taken after different filters, in downtown Stockholm, and tested according to the AMES test. The results included two separate studies. In each case the test was made with, and without, liver enzymes.

The mutagenicity vs. 0.4 µm efficiency is plotted in Figure 3 for the different filter qualities. To reduce mutagenicity 80% (from 100% to 20%), the filter's efficiency for 0.4 µm particles has to be at least 80%. With good filters, the carcinogenic risk from traffic pollution can be reduced.

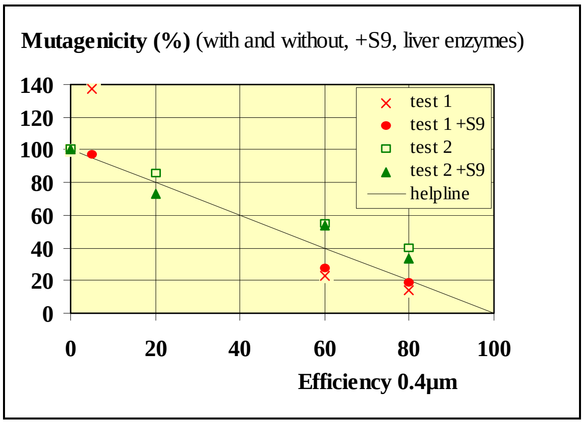

Figure 3. *The reduction of mutagenicity vs. 0.4µm particle efficiency for different filter qualities.*

Allergens
The term allergy means an abnormal reaction of the body to a previously encountered allergen introduced by inhalation, ingestion, or skin contact. An allergic reaction is often manifested by itchy eyes, runny nose, wheezing, skin rash, etc.

Allergy and asthma problems have increased in Western countries. Asthma, for example, has increased dramatically over the last 10 years and affects nearly 15 million Americans today. Thirty-five percent of all children in Sweden suffer from some kind of allergy.

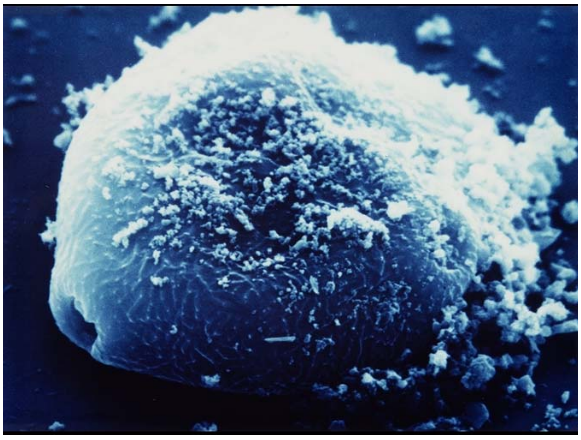

Figure 4. *Pollen with small particles that can dislodge and introduce allergens.*

The tendency to develop allergies and asthma is probably inherited, but exposure to a number of pollutants can trigger the reaction. Besides allergic reactions to food, allergies can in many cases be related to airborne problems, such as:

- Allergens from animals, cats, dogs, etc.
- Pollen, spores, bacteria
- Mites
- Coarse dust
- Diesel fumes, exhaust air, cigarette smoke and small particles from combustion and processes.

Most allergens are related to proteins in compounds (animals, pollen, mites, etc.). All proteins are different but they are about the same in size and react with the same type of mechanisms. There are theories that pollution on pollens could increase the allergic reaction. The allergens are normally connected to larger particles and could be collected in air filters.

There are very few methods for detecting and quantifying allergens. Each protein has its own characteristics. People who are allergy-prone and working with rats are very allergic to protein from rat urine (RUP). In this case, an ELISA technique has been developed to trace RUP and measure the concentrations.

Together with the University of Stockholm, RUP allergen tests were made with different filter qualities. Air was exhausted from a room with rats. The air was then filtered through pieces of filter material cut from different filters. All materials were tested in parallel and the velocity was individually checked. As a reference, one sample was without filter material. The concentration of RUP was about 100 ng/m^3 before the samples were taken.

Figure 5 shows the percentage concentration after the different filter qualities. A standard F6 filter material reduced the concentration 90%, while F7 filters and better filters reduced the concentration below the detection limit (0.01%).

The test also included F7 filters based on electrostatically charged material. Samples were taken from used filters. In this case, the synthetic material reduced the concentration to 8 and 3 ng/m^3. The material was made of coarse electrostatically charged fibres, which lose their efficiency in real life.

A conventional F7 filter is effective in this application, while an F7 filter based on an electrostatic charge is not acceptable, due to the loss of the charge when collecting dust.

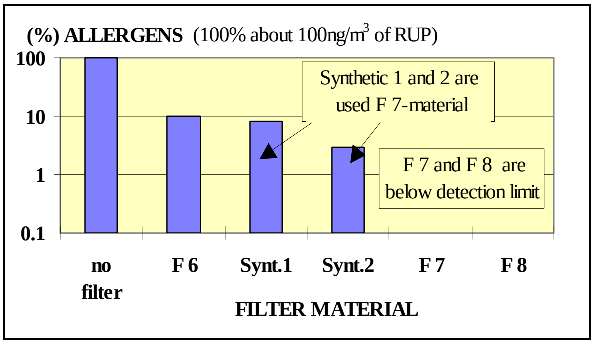

Figure 5. *Reduction of RUP (rat urine protein) allergens for different filter qualities.*

FILTERS IN OPERATION

Minimum efficiency

It is important to be aware of a filter's performance properties in different environments. Figure 6 shows, in the case of *new* filters, how separation varies with particle size and filter class. The filter class is based on the average efficiency and a new filter normally has a much lower initial efficiency. In the case of electrostatically charged filters, separation may be significantly higher for new filters. The figure should be seen as an *indication of minimum separation during actual operation.* Eurovent 4/10 (1996) could be used for verifying the efficiency of filters in an installation.

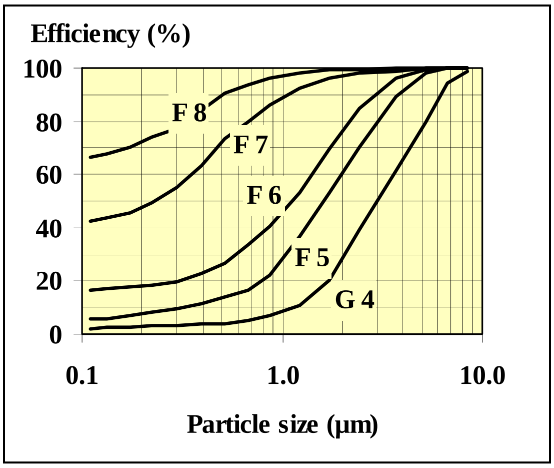

Figure 6. *Efficiency of air filters vs. particle size. The figures should be minimum efficiencies in an installation.*

Dust loading

As a filter accumulates dust, the pressure loss increases and the collected dust improves the normal separation efficiency. Another effect can be seen with electrostatically charged filter material. During operation, the impurities neutralise the material and the filter's capacity to separate is reduced.

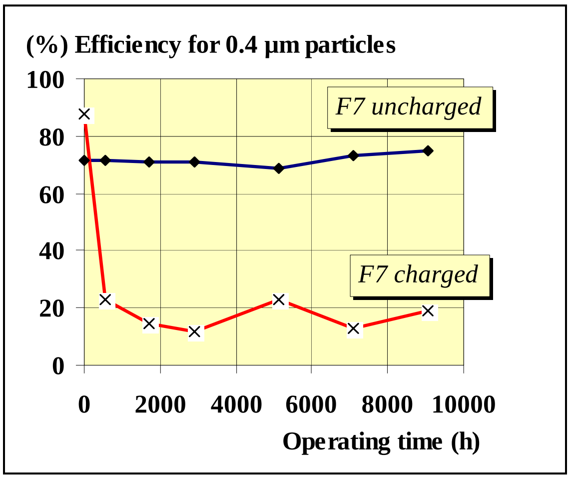

Figure 7. *Example of efficiency changes in an installation with two F7 air filters. One filter maintains almost the same efficiency during the year, while the filter with electrostatically charged material drops quickly after a few weeks Sintef (1995).*

The figure 7 shows examples of filters that laboratory tests have indicated to be in accordance with Class F7 (Sintef 1995). The efficiency drops dramatically from more than 80 % to less than 20 % after a few weeks' operation in the case of the filter based on an electrostatic effect.

The same results have been confirmed by other laboratories (Lehtimäki 1997) and a Nordtest method VVS 117 (1998) has been designed to test this effect be discharging of filter material.

Average pressure loss

The average pressure loss during operation, which depends on the characteristics of the fan and the installation, is often calculated to be the average value of the initial pressure loss and final pressure loss of the filter. Due to requirements for greater energy efficiency, more and more systems are being designed for constant flow, and the average pressure loss is the integrated value. Significant savings can thus be made using filters with a low pressure loss and small increase in pressure during the period of operation.

Energy consumption

A filter's energy consumption, E, based on average pressure loss and constant air flow, can be calculated as

$$E = \frac{Q\,\overline{P}\,T}{\eta\;1000} \qquad \text{(kWh)}$$

where Q *is* Air flow (m^3/s)
$\overline{P}$ Average pressure loss (Pa)
T Operation time (hours)
η Efficiency of fan

Over a period of one year (8 760 hours), a 1 m^3/s filter with an average pressure loss of 100 Pa requires 1250 kWh of energy if the fan's efficiency is set at 70%. The energy cost is generally greater than the filter cost and the reduction in pressure loss becomes increasingly significant for lowering energy consumption. In the above example, a 10 Pa reduction in pressure loss will save 125 kWh of energy.

Lifetime/ Filter Replacement

The lifetime of a filter depends on the concentration and type of dust, air flow and the selected final pressure loss. The filter material and filter construction are often a compromise, or a combination of filter effects and installation space. Low speed or a large filter surface promotes efficiency, low pressure loss, but above all a longer lifetime.

Air flow changes in the plant have been the main criteria for changing filters, i.e. when pressure loss increases to the extent that the fan cannot maintain a minimum air flow. Reduction of ***effect levels, energy consumption*** or ***economic*** evaluation, i.e. when the energy cost and filter cost reach a minimum, are becoming increasingly significant.

Hygiene considerations are being applied more and more to filter replacement. Möritz (1996, 1997) have shown that when the average RH is higher than 80% for three days, there is a risk of microbial growth in the filter and ventilation system. As it is difficult in many cases to avoid a high relative humidity in the air intake, filtration should take place in two steps. The first filter can often be exposed to high humidity or to rain and snow. Organic impurities also become caught in the filters and could be released later. Particles and endotoxins from micro-organisms can loosen in low quality filters.

The first filtration step should thus be carried out using a filter of at least F7 quality, which should be changed after a maximum period of one year's continuous operation or earlier, if the final pressure drop is reached. The second filtration step, using a filter of at least F7 quality, is not exposed to high RH and effectively stops micro-organisms and particles. This filter can remain in place for about two years, as long as the final pressure loss is not reached within this period.

Environment – Life cycle assessment (LCA)
Global environmental questions have increased in significance during the last few years. A life cycle assessment analyses the filter's environmental impact with reference to ecological and health effects and the consumption of resources.

LCA's of filters show that operation often corresponds to 70-80% of the filter's total environmental load and is absolutely decisive with regard to the filter's environmental impact. Raw material, refining, manufacturing and transportation correspond to approximately 20-30%, while the used filter contributes at most 1%. Filters of plastic or other inflammable material can render 10-30 kWh energy when burned, which correspondingly reduces the total environmental load by 0.5 to 1 %. On the other hand, if the pressure loss in the filter is reduced by 10 Pa, the environmental load is reduced by 125 kWh per year to decrease the total environmental load by approximately 5 %.

Life cycle cost (LCC)
An LCA does not take into account economic aspects. An LCA should therefore be considered together with a life cycle cost (LCC) analysis, which takes into account the investment, energy and maintenance costs of the filter, as well as the cost of dumping the final waste product, throughout the lifetime of the ventilation plant.

Eurovent (1999) "Recommendation concerning calculating of Life Cycle Cost for Air Filters" describes the way of calculating. Future costs for replacing filters, and for energy, are calculated according to the current value method.

The final result for a 1 m^3/s filter with an average pressure loss of 200 Pa is shown in the following table. The calculation is for a ten-year period.

Type of cost	*Relative cost (%)*
Investment	4.5
$\mathbf{LCC}_{\text{Energy}}$	80.8
$\mathbf{LCC}_{\text{Maintenance}}$	14.2
$\mathbf{LCC}_{\text{Disposal}}$	0.5
$\mathbf{LCC}_{\mathit{Total}}$	100

The table shows that energy costs account for 80% of the total cost during the plant's period of operation. The actual costs of the filter, investment and maintenance correspond to around 20%, while the cost of disposal amounts to only 0.5 %. The operation and low pressure loss are absolutely decisive for the cost of the filter function.

ASHRAE AND IAQ
ASHRAE has decided to tackle the environmental issues affected by IAQ. The Environmental Health Committee has developed a plan for improved environmental health. The top nine strategies identified are:

1. Increasing Incidence of Asthma and Allergies
Asthma has increased dramatically over the last ten years and affects nearly 15 million Americans today. Asthma is the leading cause of school absenteeism. The tendency to allergy and asthma is probably inherited, but exposure to a number of pollutants can trigger the reaction. It is said that ASHRAE should take an active role in identifying strategies for controlling or eliminating sources causing asthma and allergies.

2. Microbial Contaminants
Microbial agents have been identified as a health risk in indoor air. Many microbial problems indoors are related to indoor moisture problems and could be controlled by designing better ventilation systems. ASHRAE should take an active role in developing strategies to control moisture and microbial problems.

3. Health Dangers from Fungi – Mycotoxins

The emergence of indoor air quality issues has aroused increased concern about fungi – especially stachyboytrys chartarum – and the mycotoxins they can produce. ASHRAE should make its membership aware of this issue and report on research findings that may clarify if this actually represents a truly unique health hazard.

In these three cases a good filter can do an excellent job to prevent allergens from entering a ventilation system, and to keep it clean and avoid microbial growth in the system. Filters could keep the ventilation system in good shape and maintain the air flow, temperature and RH as designed. To avoid microbial growth, the RH should be less than 80% and the filters must be changed regularly.

4. Impact of Operation and Maintenance on IAQ

Building operation and maintenance have both been identified as critical for achieving good indoor air quality. ASHRAE should continue its activities for making improvements in areas such as commissioning, training, O&M manuals, preventive maintenance and system diagnostics.

Here a good filter is a must. The filter can prevent contaminants from entering the system, keep the ventilation system in good shape, maintain the air flow, temperature and RH as designed, and keep the efficiency of equipment at a high level. Both the inlet system and exhaust system should be considered.

5. Global Climate Change

The contribution of buildings to global climate change is estimated to be roughly 40% of the total environmental anthropogenic burden (“greenhouse gases”). Carbon dioxide is also generated during the production of electricity and when energy is consumed in the manufacture of building components. ASHRAE should support efforts to understand the impacts of buildings on global climate change and reduce these impacts where feasible.

A life cycle assessment for air filters is a good tool and analyses its environmental impact with reference to ecological effects, health effects and the consumption of resources. An air filter’s best contribution to reduce global climate change is to use filters with a low pressure drop, low pressure drop increase and low final pressure drop. However, a high efficiency filter should still be used from a hygienic point of view.

6. Ventilation for Controlling Sensor Stimuli

Standards for ventilation rates are often established to control sensory stimuli (odours, eye irritation). It has been recently recognised that contributions from building materials, furnishings and equipment are also important. ASHRAE should undertake studies to better understand the effect of combinations of stimuli and sensor adaptivity to determine ventilation rates.

A good filter is a must to keep the specified ventilation rates. The filter can stop contaminants from entering the system, keep the ventilation system in good shape, maintain the air flow, temperature and RH as designed, and keep the efficiency of equipment at a high level. Both the inlet system and exhaust system should be considered

7. Ozone Generators

Today, ozone generators are being widely promoted as a way to reduce indoor pollutant concentrations and kill mould. These devices have no substantiated benefits and there is no evidence that they can act as a biocide. In fact, ozone can react with airborne chemicals and produce more irritating or hazardous substances. In addition, a malfunctioning ozone generator can lead to even higher ozone levels than anticipated. ASHRAE needs to make its members aware of this issue and avoid contributing in any way to these misconceptions.

There are many air filter alternatives that do not use ozone for air cleaning, or equipment producing ozone as a secondary effect (electrostatic precipitators).

8. Human-generated Pathogens in Indoor Air

Exposure to airborne human-generated pathogens (viruses and bacteria) is recognised as a significant cause of illness, particularly for occupants in high-density indoor environments. Ventilation of indoor spaces with outside air, and filtered recirculated air, are established control techniques.

ASHRAE needs to recognise the health risks involved with these contaminants and to identify control strategies to minimise them. Special attention should be given to the role of ventilation in controlling exposure to airborne human pathogens.

The filter will play a major role in a ventilation system to prevent the spread of airborne human pathogens in recirculated air, keep the system in good shape, maintain the air flow, temperature and RH as designed and keep the efficiency of equipment at a high level.

9. Impact of Thermal Parameters on Perceived Indoor Air Quality

Recent studies have shown that temperature and humidity have a strong impact on perceived indoor air quality. ASHRAE should undertake studies to better understand the interrelationship between perceived indoor air quality and thermal parameters.

SUMMARY

It is clear that air filters will/could play an important role for achieving better IAQ. A filter can do an excellent job to prevent contaminants from entering the system, keep the ventilation system in good shape, maintain the air flow, temperature and RH as designed, and keep the efficiency of equipment at a high level. Both the inlet system and exhaust system should be considered.

The following should be kept in mind when planning filter installations:

- Great care is required regarding the positioning and design of the **air intake** to avoid drawing in local impurities, rain or snow.

- The risk of microbial growth is low, but to minimise the risk, the plant should be designed so that **RH** is always below 90 %, and that the average RH for three days is less than 80 % in all parts of the system.

- For hygienic reasons, **inlet air** should be filtered in two steps /11/. The first filter in the air intake must be at least F5 quality but preferably F7. The second filter step should be effected by a filter of at least F7 quality but preferably F9 quality. If there is only one filtration step, the minimum requirement is F7 quality.

- As regards **recycled air,** at least F5 quality must be used to prevent the contamination of components in the system, but the minimum requirement is F7, if the environment in the room is to be improved.

- **The exhaust air system** must be protected from contamination by a filter of at least F5 quality.

- A large number of **odours** are borne by particles, but for effective separation, **chemical filters** are very often required, something which can be justified in an urban environment.

- Filters must not be **installed** directly after the fan outlet, or across places where there is a large change in area or flow direction.

- **The final pressure drop** is calculated and selected with regard to permitted variations in air flow, the filter's life cycle costs and life cycle assessment.

- Due to the coarse artificial dust used in laboratory tests, a filter's performance in real operating conditions will differ with regard to **dust holding capacity** and other **test** results from lab trials.

- **Efficiency** must not deteriorate or fall below specific minimum values.

- The **tightness** and c**ondition** of the filter must be checked regularly by visual inspections of the plant. No visual leakage or traces of leakage should be accepted.

- **Filters** and filter **housings** must be clearly **marked** with the filter type and designation.

- In the case of more stringent requirements, **in situ** checks of the filter should be carried out according to Eurovent 4/10.

- **Filters must be replaced** when the pressure loss reaches the specified final pressure loss, or when the following hygiene interval is reached, if this occurs earlier:

– The filter in the first filtration step should be replaced after a maximum operating period of 8 700 hours.

– The filter in the second filtration step, as well as filters in exhaust or recycled air systems, should be changed after a maximum of two years' continuous operation.

- **Filter Replacement**. For hygienic reasons, the filter should be replaced after the pollen and spore season in the autumn. If requirements are stringent, filters can also be changed in the spring after the heating season to eliminate odorous combustion products.

- **Filters should be replaced** carefully, using protective equipment, to prevent the escape of trapped impurities.

- **Dumping/Disposal**. It is a good idea to incinerate filters in well-filtered furnaces in order to burn trapped impurities, reduce waste and recover energy. Filters from normal ventilation systems could also be dumped at a landfill.

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