

# The First Principle of Air Filter Technology: “Keep the Filter Dry”

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## ABSTRACT

Air filters can be responsible a number of perils in air handling systems, particularly if they get wet. Air filters get wet when supplied with foggy outdoor air. High efficiency filters are capable of retaining water particles which can saturate the filter. The adverse effects include microbial growth, odour emission, corrosion, penetration of moisture into the air handling system, and in some conditions freezing of the filter. These effects must be taken seriously because of the growing tendency to use 100% outdoor air to supply air handling systems.

According to DIN 1946, humidity in air filters must be kept below 90% RH. This is an excellent principle for safe and fault-tolerant operation. But can we achieve it? The answer is simple: preheat the outdoor air. This paper presents a calculation method for the required preheating capacity and a description of some applied methods, including the control system.

## 1. INTRODUCTION

Air is an essential of life. A man who breathes his last at 85 has inhaled and exhaled approximately 440 tons of air in his lifetime. This is well over nine times the amount of food and more than ten times the amount of water he has consumed.

In Western society, people spend roughly 85% of their time indoors - at home, in a vehicle, at the office or factory etc. The quality of interior air is thus a very important matter.

## 2. INDOOR AIR QUALITY

(Fitzner 1999) has proposed a target value for the quality of indoor air in offices of 4 dP1, made up as follows:

(1) Outdoor air	1 dP
(2) HVAC system	1 dP
(3) Interior	1 dP
(4) People in interior	1 dP

Poor outdoor air quality (1), a dirty HVAC system (2), unhealthy building and furnishing materials, inadequate regular cleaning and ventilation (3) and a high density of occupants and

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1dP = deciPol – Unit of air quality according to Fanger

tobacco smoke (4) can reduce the quality of indoor air to such an extent that the building may be designated as suffering from *Sick Building Syndrome*.

Fitzner's model also makes it clear where the opportunities for improving indoor air quality lie. In buildings which are located in surrounding with clean outdoor air and which are ventilated by natural or hybrid systems, air pollution sources (1) and (2) are absent and an air quality of 2 dP is easily achievable. A hybrid ventilation system with air intake through wall inlets would be the first choice in this situation (Bronsema 2001).

For buildings which have mechanical ventilation, whether or not it forms part of a complete HVAC system, the outdoor air supply has to be filtered as thoroughly as possible. One purpose of this filtering is to supply the interior with the cleanest possible air. It has a secondary advantage of keeping the air handling system itself as clean as possible, enabling it to function hygienically.

### 3. QUALITY OF OUTDOOR AIR

Outdoor air is generally cleaner than indoor air. This is something we may be thankful for, because it makes it possible for us to improve the indoor air quality by ventilation. Still, in industrialized regions, the outside air is never really all that clean. Table 1 shows the major pollutants of outside air. Under certain conditions, some of these substances, termed precursors, can cause secondary pollution problems such as summer or winter smog, ozone and fine dust. Fine dust can penetrate deeply into people's lungs and cause irritation. High concentrations of fine dust reinforce the irritating effect of SO<sub>2</sub>. Moreover, the fine dust fraction will contain particularly large amounts of noxious substances like PAH and heavy metals. In short, fine dust must be considered as a serious pollutant, especially in urban areas (Verhoeff 1995, Ackermann-Liebrich 1996, EPA 1996).

A general review of the permitted upper limits for pollutants is currently taking place in the EU, with much more stringent limits becoming applicable from 2010 onwards. Although all the pollutants mentioned here can be detrimental to public health, a recent study identified the concentration of nitrogen dioxide (NO<sub>2</sub>) alone as a usable working criterion of air quality. (Metz et al 2000). A maximum annual average norm of 40 µg/m<sup>3</sup> was set for this pollutant from 2010 onwards. The same limit will apply to fine dust PM<sub>10</sub>.

Vehicle traffic is an important source of air pollution, and relatively high concentrations of these substances are to be expected, particularly in the vicinity of motorways.

Table 1 - primary pollutants of outside air

Pollutant	Gaseous	Particulate	Precursor
SO <sub>2</sub> - sulphur dioxide	o		o
CO - carbon monoxide	o		
VOCs - volatile organic compounds	o	o	o
PACs - polycyclic aromatic hydrocarbons	o	o	
Fine dust - PM 10 - PM 2,5		o	o
Black smoke		o	
NO <sub>x</sub> - nitrogen oxides	o		o
Heavy metals (arsenic, cadmium, copper, lead, zinc)		o	

### 4. AIR FILTERS



Air filters have an important dual function in mechanical ventilation systems:

- Keeping air handling units and air ducts clean. A filter of too low an efficiency or which is not functioning properly will eventually cause the pollution of any air transport system, with deleterious consequences for air hygiene.
- The exclusion of possibly toxic fine dust from the indoor environment, which is particularly prevalent in outside air in urban and heavy-traffic areas.

Apart from HEPA filters, the mechanical filters that are most widely used in HVAC engineering are not particularly effective in removing fine dust from the airstream. Electrostatic filters are effective for this purpose, but they are seldom used in comfort systems because of the high capital outlay required.

The quality of the mechanical air filters used in comfort systems has risen in the past twenty years. A filter efficiency of 50% was fairly common in the early 1980s. Now, however, filters with an efficiency of 85% are widely used in office buildings. The ASHRAE Handbook HVAC Systems and Equipment (ASHRAE 1996) gives useful advice on the selection and maintenance of air filters for HVAC systems. It does not however give any information about the potential undesirable effects of filters on the indoor environment (see below).

The above mentioned efficiencies relate to a particle size of 1 mm.

## 5. MOISTURE AND FILTERS

Air filters must be kept dry, but this rule is all too often disobeyed - not infrequently with disastrous consequences. Filters get wet when mist-laden air is drawn into the system. Mist droplets have a particle size ranging from 2 to 50  $\mu\text{m}$  and are thus efficiently captured by the above-mentioned air filters.

A sometimes recommended method of reducing this problem is to mount a good mist eliminator behind the intake grille. This can do no harm, of course, but mist eliminators are incapable of capturing aerosols finer than 10-15  $\mu\text{m}$ . It also means adding a component to the system which involves a higher capital outlay, a higher fan power, and additional maintenance (cleaning).

Wet filters cause corrosion problems. They emit harmful aerosols and unpleasant odours. Moreover, micro-organisms flourish in the environment of a wet filter, where ample nutrients (dust), water and air are available to them. The disaster becomes complete when a wet filter freezes up, blocking the airflow, resulting in mechanical damage to the system.

The above-mentioned problems have become more acute since systems operating on 100% outside air have been adopted wholesale as a measure against Sick Building Syndrome. Without protection against wetting of the filter, the remedy becomes worse than the disease!

Ways of tackling these problems will be discussed below. First, however, it will clarify matters to go into the above mentioned problems in more detail.

## 6. ODOUR EMISSION FROM AIR FILTERS

Air filters remove dust from the air, but after a while they emit odours which people find musty and unpleasant. Extensive research revealed that 40-60% of the odour nuisance in ventilated rooms was caused by the ventilation system itself. (Fanger 1987, Bluyssen 1990, Pejtersen 1994, Hujanen et al 1991). P.O. Fanger, called this odour emission "*hidden olfs*". The effect is aggravated by a wet air filter.



## 7. MICROBIOLOGICAL GROWTH IN AIR FILTERS

Several researchers have come to the conclusion that the dust collected in an air filter can be an effective nutrient medium for microbiological growth, particularly when the temperature and humidity are also favourable to micro-organisms. (Elixman 1989, Martikainen 1990) The result is intensified odour emission. Some investigators consider that mould is capable of growing through the filter material and emitting fungal spores on the clean side in the filtered air.

## 8. CORROSION IN FILTER SECTIONS

Dust has absorbent properties which are to some extent comparable to those of activated carbon. It is thus capable of adsorbing acids and salts from the air. If the air filter gets wet, these substances may be leached out, resulting in the deposition of a corrosive liquid in the bottom of the filter section. This will cause serious damage to the frames of the filter cells and the material of the filter sections, possibly resulting in air leaks. Additional maintenance costs also arise. Locations at high risk include maritime and industrial areas - the latter particularly where acids (e.g. from refineries) or salts (e.g. from galvanizing plants) are likely occur in the air.

As a safety measure, corrosion-resistant filter frames should be used, in combination with protection of at least the base of the filter section. e.g. with a high-grade epoxy coating.

*A much safer solution is to ensure that the air filters never get wet!*

## 9. MOISTURE PENETRATION

If the filter becomes saturated, the captured harmful and corrosive fluid will not only collect in the filter base, but will to some extent be carried on the airflow in the form of droplets or aerosols. Some manufacturers place an eliminator behind the filter section to offer some protection to the downstream sections of the system. As explained above, however, mist eliminators cannot arrest aerosols, which release its frequently harmful liquid phase further downstream in the system or in the building, with possible ensuing problems.

*A much safer solution is to ensure that the air filters never get wet!*

## 10. FREEZING UP

Air filters which are in direct contact with the incoming flow of outside air can freeze up under certain weather conditions, e.g.

The filter is already wet and the temperature drops below freezing point. This is a dangerous situation; the moisture freezes around the fibres and the filter becomes impermeable to air. There is a risk of the filter rupturing.

Air containing a "freezing fog" (supercooled water aerosols) is drawn in and the droplets form a deposit of ice on the filter. The consequences are the same as above. Weather of this kind usually persists for at most a few hours.

Airborne snow particles are conveyed on the airstream and captured by the filter in a similar way to dust.

## 11. COMBATTING THE PERILS OF AIR FILTERS



The word "*perils*" has been chosen deliberately, for this is not simply just another of the many problems in our professional field where technology displays its user-unfriendliness. A filter penetration can produce immediate and long-term hazards to health because it results in contamination of the air handling system which is difficult, time-consuming and expensive to redress.

As stated emphatically above, keeping air filters dry is the best way to combat their perils. Two points must be taken into account:

1. Rain must be excluded by careful placing, dimensioning and execution of the air intake.
2. Water droplets and aerosols which cannot be otherwise excluded must be evaporated before they reach the air filter.

The German standard DIN 1946 states that the relative humidity in an air filter must not exceed 90%. This is an excellent working basis for safe operation with sufficient error tolerance.

Persistent mist may be regarded as the highest-risk situation, which thus merits further analysis. Mist is an aerosol of microscopic water droplets suspended in air; the water content can range from 100 to 200 mg/m<sup>3</sup>, depending on the altitude. (In clouds, the water content near the top can rise to 500 - 1,000 mg/m<sup>3</sup>, although ventilation air is rarely sucked in at that altitude!)

The particle size in a water aerosol varies from 2 to 50 µm. In the outside atmosphere at approx. 10 m above ground level, the particle size will normally be in the range 10 to 20 µm.

The heating capacity needed to dry misty air to a relative humidity of 90% can be calculated as approximately 3 kW per m<sup>3</sup>/s air displacement. See table 2. The values given are based on an assumption of 1 m<sup>3</sup>/s flow of air at 20°C and 200 mg/m<sup>3</sup> liquid moisture content.

Table 2 – Calculation of the heating capacity for drying misty air to 90% R.H.

Outdoor temperature	°C	10	
Air volume at 10°C	M <sup>3</sup> /s	0,96	283/293 * 1,0
Liquid to be evaporated	Mg/s	193	200 * 0,96
Latent heat of evaporation	KJ/kg	2.478	
Thermal capacity for evaporation	KW	0,50	193 * 10 <sup>-6</sup> * 2.478
Drying from 100% > 90% R.H. Δh	KJ/kg	2,0	
Thermal capacity for drying	KW	2,40	1,2 * 2,0
Total thermal capacity	KW/(m <sup>3</sup> /s)	2,9	0,50 + 2,40

## 12. FILTER DRYING SYSTEMS

The following systems may be applied:

12.1 - Smooth heating coil downstream from air intake.

12.2 - Infrared heating of filter bank.

12.3.- Recirculation of warm air.

### 12.1 Smooth Heating Coil

The heating coil must be smooth to prevent the accumulation of contaminants and to facilitate cleaning. Because of the corrosion risk, an execution in copper is preferable.

The heating coil may be connected to the central heating system, but it must be protected against icing up. Except in HVAC systems using heat recovery, the coil can also operate as a pre-heater. The efficiency of heat recovery would be impaired at low outdoor temperatures by the inclusion of a pre-heater. Frost protection by means of antifreeze fluid would be the obvious



alternative in this case. For this solution, however, a hydraulic separation in the form of a heat exchanger is required between the heating system and the heating coil.

## 12.2 Infrared Heating

An installed capacity of 3 kW per m<sup>2</sup> of face area has been mentioned as a value obtaining in practice. Given a maximum inflow velocity of e.g. 3 m/s and an accompanying air flow of 3 m<sup>3</sup>/(s.m<sup>2</sup>), the installed capacity is 1 kW per m<sup>3</sup>/s, i.e. one third of the value calculated in table 2. This capacity is more than sufficient to evaporate mist droplets, but the resulting lowering of relative humidity is no more than a few percent. The value of 90% recommended in DIN 1946 is certainly not obtainable.

The infrared lamps are situated in unfiltered air and will inevitably get dirty in the course of time. At switching on the high temperature of the radiation lamps will decompose and burn the accumulated material. This results in severe odour emission and can even be a potential fire hazard.

## 12.3 Recirculation of Warm Air

In this system, a small portion of the air flowing through the air handling unit is recirculated with simultaneous heating. The warm air is injected into the outdoor airstream, producing the desired drying effect. See figure 1.

Outdoor Air is drawn in from the left and is filtered, heated, cooled and humidified in the Air Handling Unit (AHU). If the relative humidity (RV) downstream the filter exceeds the setpoint of the humidity sensor (90%), part of the conditioned air is recirculated from the pressure side to the suction side of the AHU by opening the damper in the bypass duct. The recirculated air is heated by a heating coil in the bypass duct as much as to keep the relative humidity downstream the air filter below 90%. Good mixing of the mainstream air and the recirculated air is attained by a special mixing device.

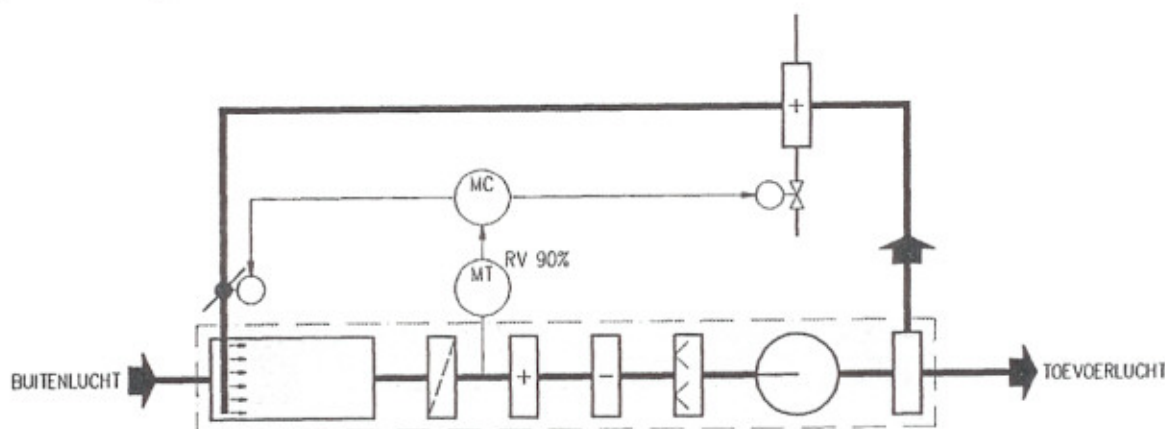


Figure 1 – The Best Way to Keep the Filter Dry

The dimensions of the system may be calculated as follows (example):

- Recirculation rate 10% of nominal air flow rate
- Temperature increment of recirculation air approx. 25 K above outside temperature
- Thermal capacity:  $0.1 \times 1.2 \times 1.0 \times 25 = 3 \text{ kW}$ .

In misty weather, a temporary reduction of the air supply flow rate by 10% is accepted. This will generally not cause any problems. An automatic flow control can be used if required to uphold the nominal air flow rate.

If the ventilation or air handling system concerned already has a recirculation option, this can of course be used for this purpose. A recirculation option is in any case recommended for use in emergency situations such as serious outside air pollution or a heat generation failure resulting in a deficit of available thermal capacity.

### 13. CONCLUSION

HVAC engineers carry a major responsibility for the quality of the indoor environment and indoor air. Ventilation using dry air filter can make a considerable contribution here. Problems of HVAC systems can moreover be avoided as long as the 'first principle of air filter technology' is adhered to: KEEP THE FILTER DRY. The technology required for this is simple and immediately applicable.

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