THEORY SECTION

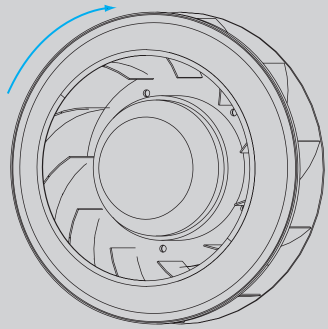
The intention of this Theory Section is to explain the basic principles of acoustics and ventilation.

The theory section concludes with a description of the parts which are integral to a ventilation unit or an air-handling unit, i.e. fans, heaters, heat exchangers and filters.

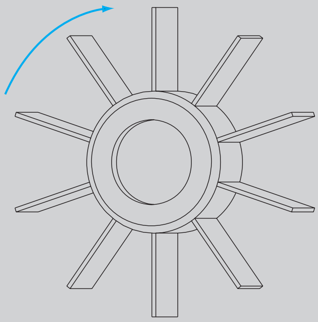
Explanatory texts and further information are provided in the margin. Some diagrams and formula also feature in the margins, together with examples of their application.

Contents

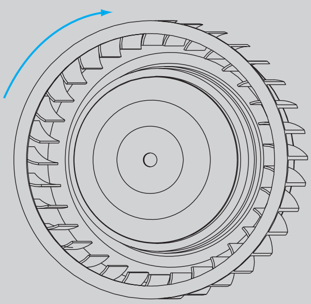
Blade profiles for radial fans
The arrow indicates the impeller's direction of rotation.



Backward curved



Straight radial



Forward curved

Fans

Fans are used in ventilating units to transport the air from various air intakes through the duct system to the room which is to be ventilated. Every fan must overcome the resistance created by having to force the air through ducts, bends and other ventilation equipment. This resistance causes a fall in pressure, and the size of this fall is a decisive factor when choosing the dimensions of each individual fan.

Fans can be divided into a number of main groups determined by the impeller's shape and its operating principle: radial fans, axial fans, semi-axial fans and cross-flow fans.

Radial fan
Radial fans are used when a high total pressure is required. The particular characteristics of a radial fan are essentially determined by the shape of the impeller and blades.

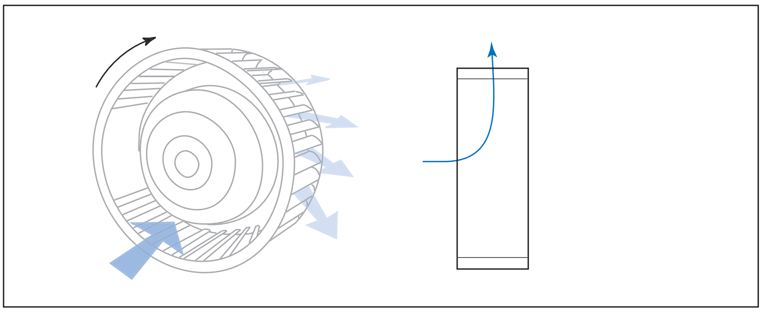


Figure 24: The air stream through a radial fan with forward-curved blades

Backward-curved blades (B impeller): The air volume which can be delivered by backward-curved blades varies considerably according to the pressure conditions. The blade form makes it less suitable for contaminated air. This type of fan is most efficient in a narrow range to the far left of the fan diagram. Up to 80% efficiency is achievable while keeping the fan's sound levels low.

Backward-angled straight blades (P impeller): Fans with this blade shape are well suited for contaminated air. Up to 70% efficiency can be achieved.

Straight radial blades (R impeller): The blade shape prevents contaminants from sticking to the impeller even more effectively than with the P impeller. No more than 55% efficiency can be achieved with this type of fan.

Forward-curved blades (F impeller): The air volume delivered by radial fans with forward-curved blades is affected very little by changes in air pressure. The impeller is smaller than the B impeller, for example, and the fan unit consequently requires less space. Compared with the B impeller, this type of fan's optimal efficiency is further to the right on the diagram. This means that one can select a fan with smaller dimensions by choosing a radial fan with an F impeller rather than a B impeller. An efficiency of approximately 60% can be achieved.

Axial fan
The simplest type of axial fan is a propeller fan. A freely-rotating axial fan of this type has a very poor efficiency rating, so most axial fans are built into a cylindrical housing. Efficiency can also be increased by fitting directional vanes immediately behind the impeller to direct the air more accurately. The efficiency rating in a cylindrical housing can be 75% without directional vanes and up to 85% with them.

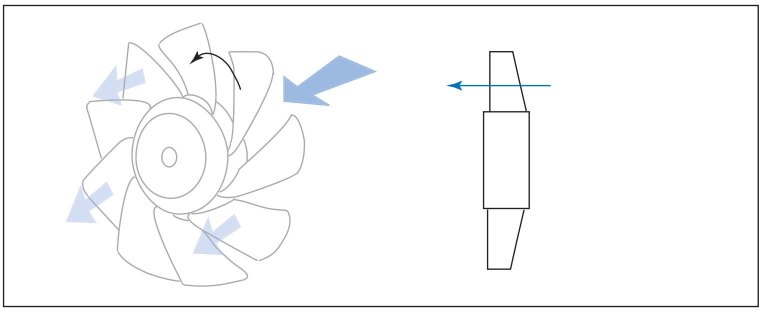


Figure 25. The air flow through an axial fan

Mixed flow fan
Radial impellers produce a static pressure increase because of the centrifugal force acting in a radial direction. There is no equivalent pressure increase with axial impellers because the air flow is normally axial. The mixed flow fan is a mixture between radial and axial fans. The air flows in an axial direction but then is deflected 45° in the impeller. The radial velocity factor which is gained by this deflection causes a certain increase in pressure by means of the centrifugal force. Efficiency of up to 80% can be achieved.

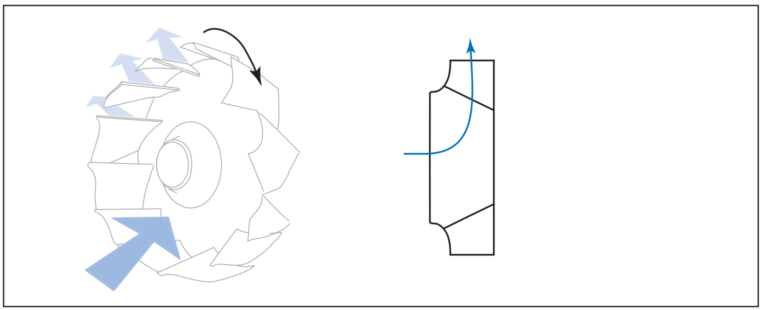


Figure 26. The air flow through a mixed flow fan

Cross-flow fan
In a cross-flow fan the air flows straight across the impeller, and both the in and out flow are in the periphery of the impeller. In spite of its small diameter, the impeller can supply large volumes of air and is therefore suitable for building into small ventilation units, such as air curtains for example. Efficiency of up to 65% can be achieved.

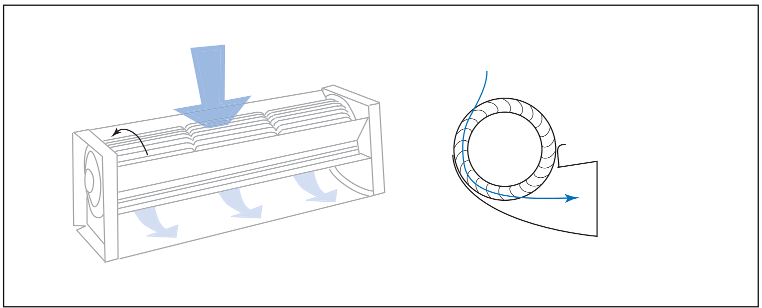


Figure 27. The air flow through a cross-flow fan

Theoretical calculation of the system line

$$\Delta P = k \cdot q_v^2$$

where
ΔP = the fan's total pressure (Pa)
qv = air flow (m^3/h or l/s)
k = constant

Example
A certain fan produces an air flow of 5000 m^3/h at a pressure of 250 Pa.

A. How does one produce a system line in the diagram?

a) Mark the point on the fan curve (1) where the pressure is 250 Pa and the air flow is 5000 m^3/h.

Enter the same value in the formula above to obtain a value for the constant k.
$k = \Delta P/q_V^2 = 250/5000^2 = 0.00001$

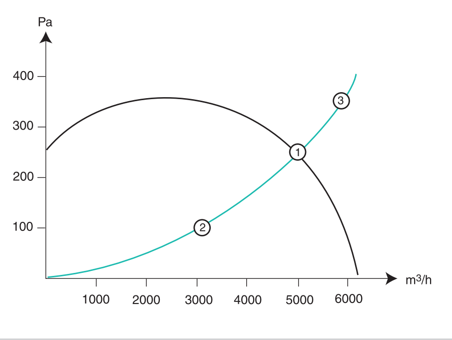
b) Select an arbitrary pressure reduction, for example 100 Pa, calculate the air flow and mark point (2) in the diagram.

$$q = \sqrt{100/(0{,}00001)} = 3162\ m^3/h$$

c) Do the same thing for 350 Pa and mark point (3) in the diagram.

$$q = \sqrt{350/(0{,}00001)} = 5916\ m^3/h$$

d) Now draw a curve that indicates the system line.



Fan curves
The fan diagram indicates the fan's capacity at different pressures. Each pressure corresponds to a certain air flow, which is illustrated by a fan curve.

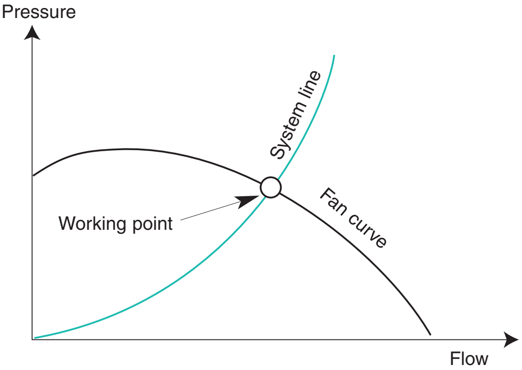


Figure 28. Curves in a typical fan diagram

System lines
The duct system's pressure requirement for various air flows is represented by the system line. The fan's working point is indicated by the intersection between the system line and the fan curve. This shows the air flow which the duct system will produce.

Each change of pressure in the ventilation system gives rise to a new system line. If the pressure increases, the system line will be the same as line B. If the pressure reduces, the system line will be the same as line C instead. (This only applies if the rotational speed of the impeller, i.e. the revolution count, remains constant).

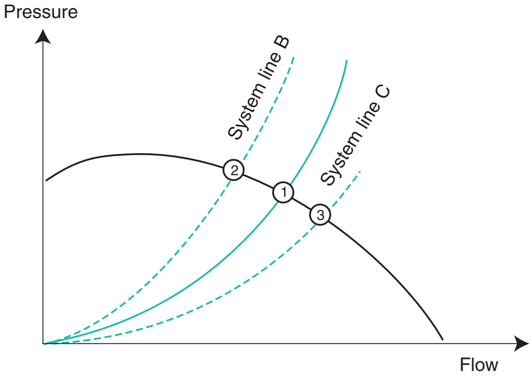


Figure 29. Changes in pressure give rise to new system lines

If the ventilation system's actual pressure requirement is the same as system line B, the working point will move from 1 to 2. This will also entail a weaker air flow. In the same way, the air flow will increase if the system's pressure requirement corresponds instead to line C.

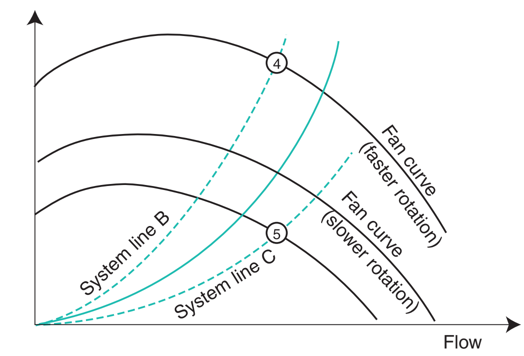


Figure 30. Increase or reduction of the fan speed

To obtain the same air flow as calculated, one can in the first case (where the system line corresponds to B) quite simply increase the fan speed. The working point (4) will then be at the intersection of system line B and the fan curve for a higher rotational speed. In the same way, the fan speed can be reduced if the actual system line corresponds to line C.

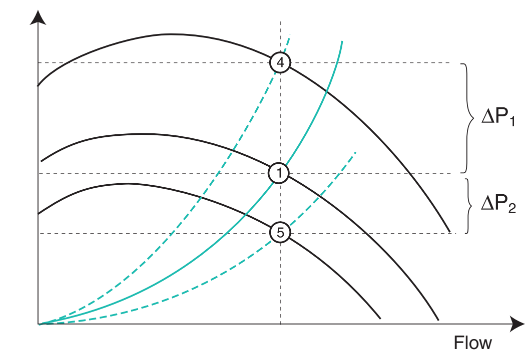


Figure 31. Pressure differences at different rotational speeds

In both cases, there will be a certain difference in pressure from that of the system for which the dimensioning has been calculated, and this is shown as DP1 and DP2 respectively in the figure. This means that if the working point for the calculated system has been chosen so as to give the maximum degree of efficiency, any such increase or decrease of the fan's rotational speed will reduce the fan's efficiency.

B. What will happen if the pressure in the system increases by 100 Pa, (for example because of a clogged filter)?

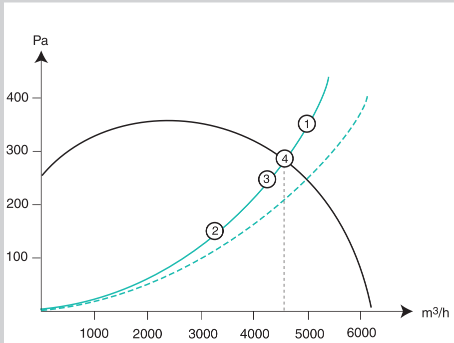
a) Calculate the constant for the new system line: $k = 350/5000^2 = 0{,}000014$

b) Select two other pressure reductions, for example 150 and 250 Pa, and calculate the air flow for them.

$$q = \sqrt{150/0{,}000014} = 4225 \text{ m}^3/\text{h}$$

$$q = \sqrt{250/0{,}000014} = 3273 \text{ m}^3/\text{h}$$

c) Plot in the two new points (2 and 3) and draw in the new system line.



The new working point (4) is located at the intersection between the fan curve and the new system line.

This diagram also indicates that the pressure increase causes a reduction of the air flow to approximately 4500 m³/h.

Definition of the system line

$$L = 10 \cdot \sqrt{\frac{\Delta P_d}{\Delta P_t}}$$

where
L = the fan's system line
Δp_d = dynamic pressure (Pa)
Δp_t = total pressure (Pa)

Efficiency and system lines

To facilitate the selection of a fan, one can plot in a number of considered system lines in a fan diagram and then see between which lines a particular type of fan should operate. If the lines are numbered 0 to 10, the fan will be completely free-blowing (maximum air flow) at line 10 and will be completely choked (no air flow at all) at line 0. This then means that the fan at system line 4 produces 40% of its free-blowing air flow.

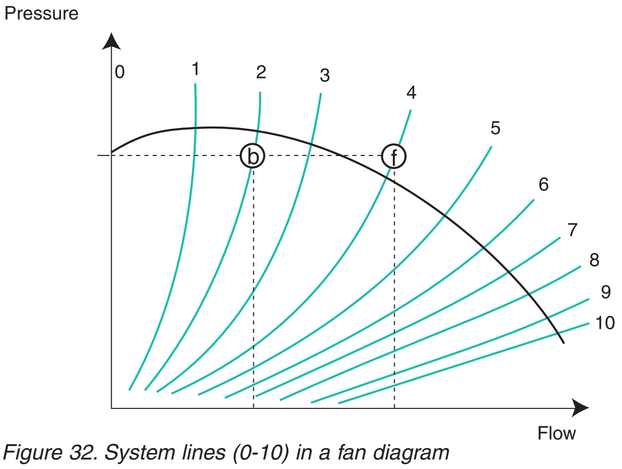


Figure 32. System lines (0-10) in a fan diagram

Each fan's efficiency remains constant along one and the same system line. Fans with backward-curved blades frequently have a greater efficiency than fans with forward-curved blades. But these higher levels of efficiency are only achievable within a limited area where the system line represents a weaker air flow at a given pressure than is the case with fans with forward-curved blades.

To achieve the same air flow as for a fan with forward-curved blades, while at the same time maintaining a high level of efficiency, a fan with backward-curving blades in a larger size would have to be selected.

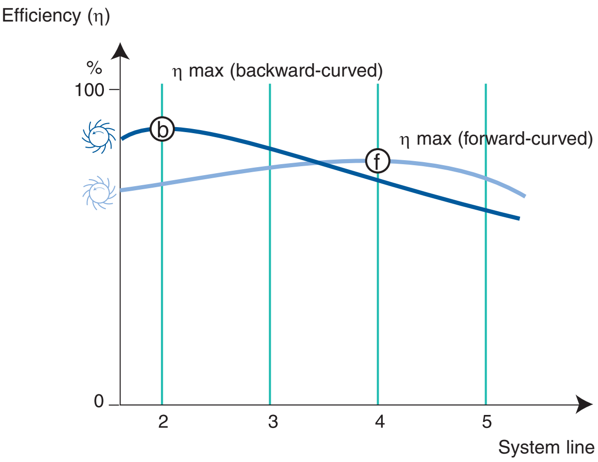


Figure 33. Efficiency values for the same size of radial fan with backward-curved and forward-curved blades respectively

Fan application

It is assumed in the fan diagram that the fan's connections to the inlet and outlet are designed in a specific way. There must be at least 1 x the duct diameter on the suction side (inlet) and 3 x the duct diameter on the pressure side (outlet).

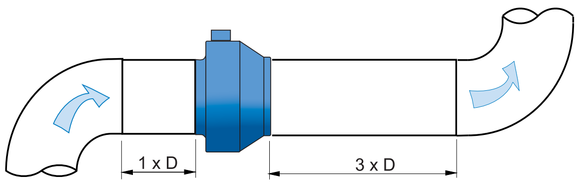


Figure 34. Correctly installed duct fan

If the connections are different from this, there could be a greater pressure reduction. This extra pressure drop is called the system effect or system dissipation, and can cause the fan to produce a smaller volume of air than indicated in the fan diagram. The following factors must be considered in order to avoid system dissipation:

At the inlet

- The distance to the nearest wall must be more than 0.75 x the inlet's diameter
- The inlet duct's cross-section must not be greater than 112% or less than 92% of the fan inlet
- The inlet duct's length must be at least 1 x the duct diameter
- The inlet duct must not have any obstacles to the air flow (dampers, branching or similar)

At the outlet

- The angle at the reduction of the duct cross-section must be less than 15°
- The angle at the enlargement of the duct cross-section must be less than 7°
- A straight length of at least 3 x the duct diameter is required after a duct fan
- Avoid 90° bends (use 45°)
- Bends must be shaped so that they follow the air stream after the fan

Specific Fan Power

There are now stringent requirements to ensure that power consumption in a building is as efficient as possible so as to minimise energy costs. The Svenska Inneklimatinstitutet [Swedish Inner Climate Institute] has introduced a special concept known as the Specific Fan Power (SFP_E) as a measurement of a ventilation system's energy efficiency.

The Specific Fan Power for an entire building can be defined as the total energy efficiency of all the fans in the ventilation system divided by the total air flow through the building. The lower the value, the more efficient the system is at transferring the air.

The recommendations for public sector purchasing and similar are that the maximum SFP_E should be 2.0 when maintaining and repairing ventilating units, and 1.5 for new installations.

Efficiency of a fan

$$\eta = \frac{\Delta P_t \cdot q}{P}$$

where
ΔP_t = total pressure change (Pa)
q = air flow (m³/s)
P = power (W)

Specific Fan Power

The Specific fan power for an entire building

$$SFP_E = \frac{P_{tf} + P_{ff}}{q_f} \ (kW/m^3/s)$$

where
P_{tf} = total power for air supply fans (kW)
P_{ff} = total power for air exhaust fans (kW)
q_f = dimensioned air flow (m³/s)

Theoretical calculation of a fan's power consumption

$$P = \frac{p_t \cdot q}{\eta_{fan} \cdot \eta_{belt} \cdot \eta_{motor}}$$

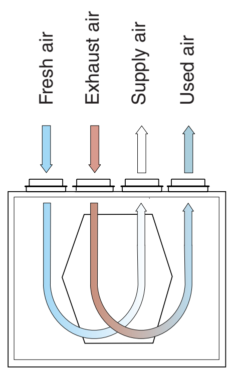
where
P = the fan's consumption of electric power from the network (kW)
p_t = the fan's total pressure (Pa)
q = air flow (m³/s)
η_{fan} = the fan's efficiency
η_{belt} = efficiency of the transmission
η_{motor} = efficiency of the fan motor

Thermal efficiency

$$\eta = \frac{t_i - t_u}{t_f - t_u}$$

where
t_u = outside air temperature
t_f = exhaust air temp. (no heat recovery)
t_i = supply air temp. (after heat recovery)

Counterflow plate heat recovery units
The air streams (exhaust and supply air) pass in opposite directions through the entire heat recovery unit, which results in an efficient recovery of heat.



Heat recovery units

In a ventilating unit, it is often economical to attempt to recover the heat which is contained in the exhaust air and use it to warm the supply air. There are several methods for achieving this type of heat recovery.

Plate heat recovery units
The exhaust air and supply air pass on each side of a number of plates or lamellae. The exhaust- and supply air are not in contact with each other which results in low leakage. There may be some condensation in a plate heat recovery unit, so they need to be fitted with condensation drains. The drains should have a water seal to prevent the fans from sending the water back into the unit. Because of this condensation there is also a serious risk of ice formation, so some type of defrosting system is also needed. Heat recovery can be regulated by means of a bypass valve which controls the intake of exhaust air. Plate heat recovery units have no moving parts. High efficiency (50-90%).

Rotary heat recovery units
Heat is transferred by a rotating wheel between exhaust and supply air. This system is open and there is a risk that impurities and odours will be transferred from the exhaust to the supply air. This can be avoided to some extent by correct designed ventilation system with the right pressure conditions or by positioning the fans in a preventing way. The degree of heat recovery can be regulated by increasing or decreasing the rotational speed. There is little risk of freezing in the heat recovery unit. Rotary heat exchange units contain moving parts. High efficiency (75-85%).

Battery heat recovery units
Water, or water mixed with glycol, circulates between a water battery in the exhaust air duct and a water battery in the supply air duct. The liquid in the exhaust air duct is heated so that it can transfer the heat to the air in the supply air duct. The liquid circulates in a closed system and there is no risk of transferring impurities from exhaust air to supply air. Heat recovery can be regulated by increasing or decreasing the water flow. Battery heat recovery units have no moving parts. Low efficiency (45-60%).

Chamber heat exchangers
A chamber is divided into two parts by a damper valve. The exhaust air first heats one part of the chamber, then the damper valve changes the air stream so that the supply air is heated by the warmed-up part of the chamber. Impurities and odours can be transferred from exhaust air to supply air. The only moving part in a chamber heat exchanger is the damper valve. High efficiency (80-90%).

Heat pipe
This heat recovery unit consists of a closed system of pipes filled with a liquid that vaporises when heated by the exhaust air. When the supply air passes the pipes, the vapour condenses back into liquid again. There can be no transfer of impurities, and the heat recovery unit has no moving parts. Low efficiency (50-70%).

Heating batteries

In most cases the outside air is colder than the required temperature for the supply air, so it is often necessary to warm the air before it enters the building. The air can be warmed in a heating battery, by using either a hot water, or an electric heating battery.

Electric-heating battery
An electric-heating battery consists of a number of enclosed metal filaments or wire spirals. They create an electrical resistance which converts the energy to heat. The advantages of the electric battery are: it has a small pressure drop, it is easy to calculate the power and it is inexpensive to install. The disadvantage is that the metal filaments have a considerable heat inertia so the electric battery has to be fitted with overheating protection.

Water-heating battery
Crossflow water-heating batteries are the most common type of water-heating batteries in ventilation units. The water flows at right angles and in the opposite direction to the air stream. The water is conducted from below and flows upwards through the battery, and this allows any air bubbles to collect at the highest point where they can be easily drawn off via a ventilating pipe.

Water-heating batteries have to be protected against ice formation to ensure they do not crack as the result of freezing. The greatest risk of this happening is actually when the air temperature is immediately below 0°C. Most water batteries therefore have a frost guard which stops the intake of fresh air when there is a risk of freezing. Because still water freezes faster than flowing water, it is also usual to fit an internal pump which keeps the water flowing through the battery.

The air velocity through the battery, calculated for the entire front area, should be dimensioned to 2-5 m/s. The water velocity should not be below 0.2 m/s, as this could cause difficulties with venting. Nor should the water velocity be higher than 1.5 m/s in copper pipes or 3 m/s in steel pipes, as this could lead to erosion of the metal pipes.

Filters
There are two reasons for using filters in an air-handling unit: to prevent impurities in the outside air from entering the building and to protect the unit's components from contamination.

An analysis of the impurities in the air indicates that among other things the air contains soot particles, smoke, metallic dust, pollen, viruses and bacteria. The particles vary in size from less than 1 µm to whole fibres, leaves and insects. It is thought that these pollutants are a significant contributing factor in the cause of many asthmatic and allergic conditions, and it is therefore important for people to protect themselves against them.

Since as much as 99.99% of all particles in the air are smaller than 1 µm, it is necessary to use filters in a ventilation system that are adequately fine-meshed. The filter's capacity to trap particles is called its Dust Holding Capacity and filters are often divided into three classes depending on this capacity: coarse filters, fine filters and absolute filters.

Filter classes

Coarse filter	EU1 to EU4
Fine filter	EU5 to EU9
Absolute filter	EU10 to EU14

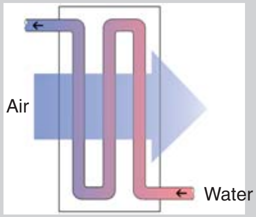
The coarse filter essentially only traps particles larger than 5 µm, and has virtually no effect at all on particles smaller than 2 µm. This means, therefore, that it does not trap soot particles, which are the most prevalent impurities in the outside air. Fine filters should be fitted in a ventilation unit instead. The best fine filters work effectively with particles larger than 0.1 µm, and therefore trap the most important impurities in the outside air.

Water-heating battery
The power input (kW) to a water-heating battery in a ventilating unit is:

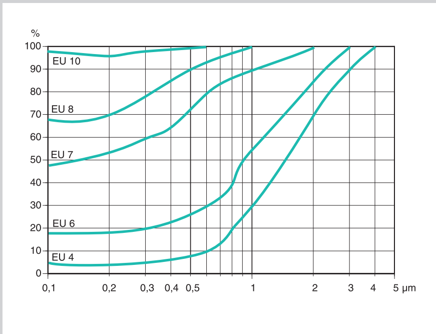
$$Q = \frac{L \cdot 1{,}2}{3600} \cdot (t_i - t_u) \cdot (1 - \eta)$$

where
L = the air flow (m³/h)
t_i = required supply air temperature (°C)
t_u = dimensioned outside temperature (°C)
η = the efficiency of the heat recovery unit

Water battery
The hot water should be conducted in the opposite direction to the air, otherwise it will cool too quickly and the water battery's warming of the air will not be as efficient.



Dust Holding Capacity for different filter classes



Pressure drop
The pressure drop caused by a completely clean filter is called the start pressure drop, and this is somewhere between 80 and 120 Pa for fine filters. After impurities have been trapped by the filter, the pressure drop will increase and the air flow will be reduced. Eventually there will be a pressure drop which makes the filter no longer usable. For fine filters this will be between 200 and 250 Pa. It is usual for filters in a unit to be fitted with some kind of filter monitor which constantly measures the pressure drop caused by the filter. This can give a signal when a pre-set pressure drop has been reached and it is time to replace the filter. In any event it is advisable to replace the filter twice a year, irrespective of whether or not the final pressure drop has been reached, so as to prevent the dirt in the filter becoming a breeding ground for bacteria.

Suppliers of filters have been debating for a long time as to whether glass fibre or synthetic fibre provides the best filter material. Some research has been carried out, but without any clear results. It appears, however, that glass fibre filters maintain a better Dust Holding Capacity throughout their working life.

Just as important as the selection of the filter material is the need to ensure that there is a good seal around the filter to prevent dirt and dust passing around the edge. The filter housing should be designed so that repeated filter replacements can be made without any space developing between the filter and the housing. It is also important to protect the filter from moisture as this can alter the characteristics of the filter fibres and impair its Dust Holding Capacity. Glass fibre filters are more susceptible to the effects of moisture than synthetic filters.