ENERGY SAVING AND ACOUSTICAL OPTIMIZATION - FAN RETROFIT FOR EXISTING INSTALLATIONS

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SUMMARY

Many Climate-, Air Conditioning and Ventilation units are using fans which are not state of the art. Over the last decades there was a noticeable improvement in the area of fan efficiency on the one hand and noise on the other hand.

Therefore, Fan Retrofit allows improving energy efficiency and acoustic behavior of fans in existing systems. This paper shows different approaches for Retrofit solutions. With using modern motors based on the synchronous principle (e.g. EC-motors), a significant reduction in energy consumption, especially in part load conditions, can be achieved compared to motors based on the asynchronous principle (AC-motors).

Aerodynamic optimizations on the other hand allow reducing noise emission and energy consumption drastically. This includes replacement of fans with forward-curved impellers by fans with backward-curved impeller, using flow straighteners, Diffusers, Winglets and Guide Vanes.

The combination of motor improvement and aerodynamic improvement offers a chance to reach best performance within existing installations.

INTRODUCTION

Estimations show that energy consumption of fans with electric drives will rise from 344 TWh in 2005 up to 560 TWh until 2020 within the EU. This corresponds to the energy production of roughly 140 large power plants (4 TWh per power plant).

With improving fan efficiency there is a chance for energy saving up to 34 TWh until 2020. This corresponds to a reduction of the CO_2-emission of 16 million tons per year or 8.5 power plants [1], [2].

More than 50 % of the existing Climate- and Air Conditioning units in offices or industrial buildings are older than 25 years [3]. During this period there was a noticeable increase in efficiency of modern fans related to optimizations of electric motors and improvements on the aerodynamic side.

The biggest potentials for energy saving lies in the replacement of old-fashioned fans and an adapted control-strategy that can deliver "tailored ventilation" based on the needs of the people who live or work inside the building. Replacing inefficient components is one way to improve existing units and typically much cheaper than buying a new Climate- or Ventilation unit. Therefore Retrofit of fans increases the lifetime of existing units for many years. As the replacement is done within the existing building environment usually no additional licenses are needed from public authorities for these projects.

A second way is to replace modules within the units that may have more functions integrated than just ventilation.

Retrofit itself will not only have a positive impact on environment and the financial expanses of companies, with the new and improved control function of the fans it might also increase the comfort for users and at the same time there is the chance to decrease the noise level.

The overall efficiency of fans is mainly influenced by the motor and aerodynamic components like impeller or housing. The following sections show possibilities to improve noise and efficiency of the motor and also for different aerodynamic components.

IMPROVEMENT OF ELECTRIC DRIVE / ELECTRIC MOTOR

One of the key components of fans is the electric motor. The motor itself is part of the Ecodesign Regulation for motors (2009/640/EC). Old Climate-, Air Conditioning and Ventilation units often use asynchronous or induction motors (AC-motors). Replacing these motors with the more efficient (synchronous, Electronically Commutated) EC-motors will raise the motor efficiency about 5-15 %, depending on the efficiency grade and the shaft power of the motor used at the moment. Motors integrated in fans however are not part of the regulation itself but can of course be compared to the values demanded by the Ecodesign directive. Such comparison reveals that EC-motors far surpass the efficiency level specified in this. EC-motor technology is thus the better alternative when planning energy-efficient devices and installations. Figure *1* compares the maximum motor efficiency of AC- and EC-motors at different shaft power. Typical AC-motors reach efficiency values within the IE-classes 1-3, EC-motors are normally within the classes 4 and 5.

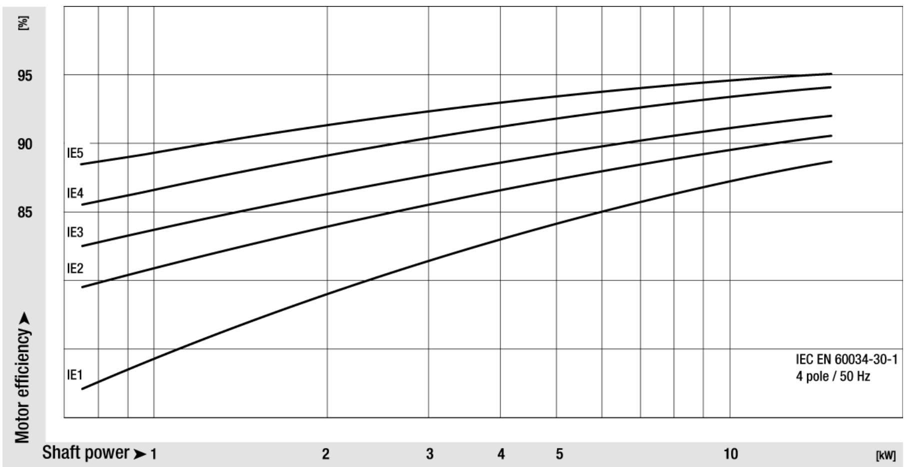


Figure 1: Motor efficiency for AC- and EC-motors at different shaft power

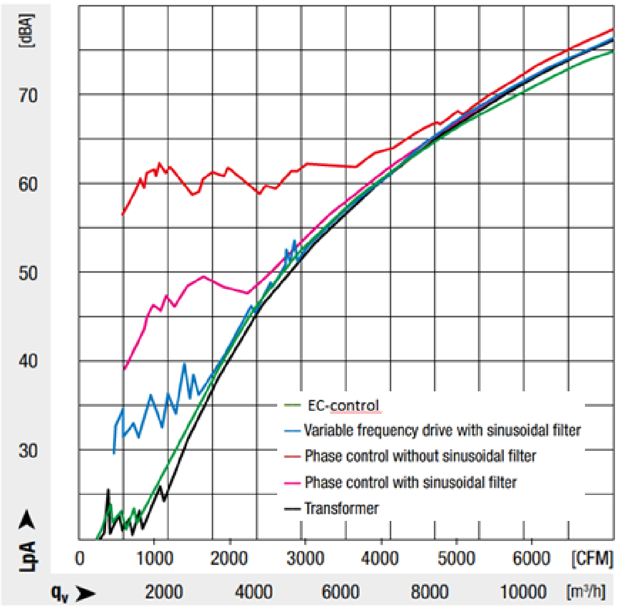
Motors integrated in fans often use the external rotor motor principle shown in Figure 2. Reasons for using this principle are the space-saving design and ideal cooling of all motor components as the motor is located within the airstream.

Figure 2: External rotor motor in AC- and EC-technology

AC-motors work as an asynchronous motor and are also well known as Induction motors. The main losses of an AC-motor are the induction currents within the stator winding and the losses inside the cast squirrel-cage rotor.

EC-motor operation is based on the principle of a synchronous motor. In comparison to AC-motors the EC-motor uses electronical commutation and permanent magnets to reduce losses within the motor. The more compact stator winding and the missing induction currents within the rotor are additional reasons for better efficiency of EC-motors.

Today's EC-motors have different control functions integrated within the electronics. To suit the area of application the speed of fans has to be adapted. With AC-technology, speed setting often involves more installation work and is typically associated with an increase of noise and power consumption. EC-motors with integrated electronics are therefore the more ecological and less expensive solution, at least with regard to the operating costs. They offer highest efficiency and optimum noise over the entire speed range. Figure 3 shows curves for noise and power consumption at full speed and part load for different control options of AC-motors compared to EC-motors.



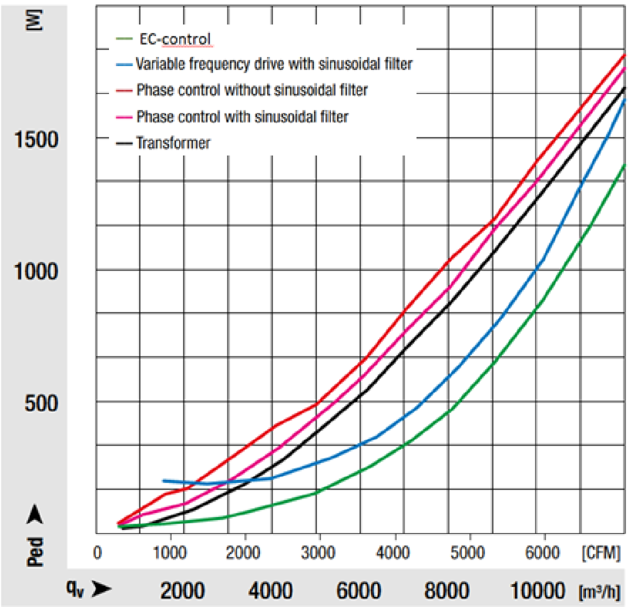


Figure 3: Noise characteristics and Power consumption of AC- and EC-motors

With EC-motors, speed setting is already implemented by the integrated commutation electronics. Using electronic switches the motor currents are switched on and off on the basis of the rotor position. The variable speed option can be used to adapt fan speed to suit requirements. This significantly increases efficiency in part load operation. Table 1 shows the huge power saving potential of EC-motors compared to AC-motors with Variable Frequency Drive (VFD) – especially at part load.

Table 1*: Power saving of EC-motor compared to AC-motor with VFD*

		FAN SPEED			
		100 %	75 %	50 %	25 %
POWER	EC-motor	1400 W	650 W	250 W	70 W
	AC-motor with VFD	1660 W	780 W	340 W	175 W
	Power saving of EC-motor	-16 %	-17 %	-27 %	-60 %

Based on the electric motor installed within existing systems there is a huge potential for energy saving and noise reduction. EC-motors should therefore be chosen for Retrofit to reach best efficiency and lowest noise over the entire speed range. Due to the additional electronics EC-motors normally have a higher price compared to AC-motors. However if one considers the life cycle costs the larger investment pays off due to the much lower operating costs. For Retrofit projects AC-fans can typically be replaced by EC-fans one-to-one as the relevant outer dimensions often keep the same.

AERODYNAMIC OPTIMIZATION

The impeller is the crucial component with regard to accelerating the air and generating work in the form of pressure. Only a few design principles have proven successful when it comes to moving air. Well known types are axial, centrifugal, diagonal and tangential impellers. The designations relate to the principal direction of flow through the impeller. With axial fans, the inflow is in axial direction and the air also leaves the fan in axial direction. A distinction is made between two types of centrifugal impeller: Impellers with forward-curved blades and impellers with backward-curved blades. As with axial impellers, both of these feature axial inflow, but the air is blown out in a centrifugal direction. Centrifugal impellers with backward-curved blades can be provided with scroll housing – centrifugal impellers with forward-curved blades have to have a scroll housing to function efficiently.

The following sections show possibilities to increase aerodynamic efficiency of axial and centrifugal fans. With choosing the appropriate fan for a given application there is also a chance to reduce noise.

Centrifugal fans – Increased efficiency with backward-curved impellers

As mentioned before there are two types of impellers used in centrifugal fans (forward-curved and backward-curved impellers, see Figure *4*).

Figure 4:Centrifugal fans with forward-curved (left) and backward-curved impeller (right), with and without scroll housing

Typical forward-curved impellers have a high number of short blades that are used to accelerate the air entering the impeller through the inlet nozzle. Static pressure is generated by decelerating the air velocity within a scroll housing afterwards. The necessity to decelerate the airstream is also the reason why forward-curved fans have to have a scroll housing while using them in real applications. The high losses of fans with forward-curved impellers are generated during conversion of dynamic pressure into static pressure.

Fans with backward-curved impellers have much lower dynamic losses as static pressure is already generated within the impeller. For a typical backward-curved impeller the airstream will follow the shape of the blade while the air passes through the impeller. The deceleration of air velocity takes place directly inside the impeller and requires no additional components. Nevertheless with an additional scroll housing the dynamic energy of backward-curved fans can be further reduced to reach best efficiency values.

With a change from inefficient forward-curved blowers to fans with backward-curved impellers there is a chance to reduce electrical power consumption about 30 % (Figure 5).

A typical application for fans with backward- and forward-curved blades are residential ventilation units. Measurements in real applications show that changing from a forward-curved impeller to a backward-curved impeller with scroll housing can reduce the electrical power consumption from 220 W to 135 W. With a typical run-time of 2000 hours and energy costs of 0.29 €/kWh the annual monetary saving is about 50 €.

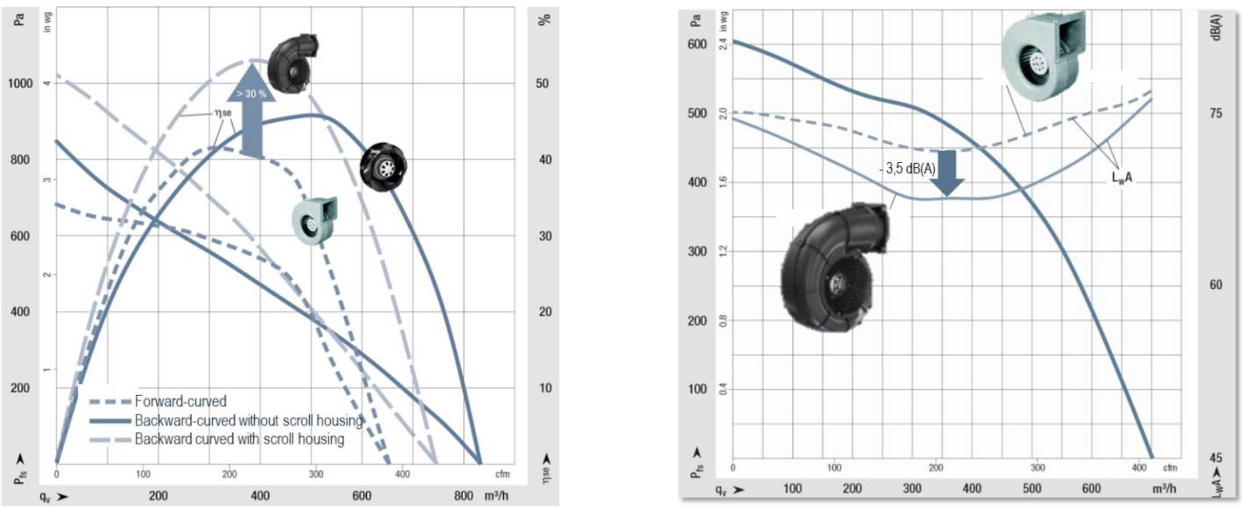


Figure 5: Efficiency increase and noise reduction with replacing fans with forward-curved impellers by backward-curved impellers with scroll housing

Unfortunately the installation space for a backward-curved blower is often larger than for a fan with forward-curved blades. For the comparison shown in Figure 5 the fan with forward-curved impeller used an impeller with diameter 160 mm while the backward-curved fan was size 190 mm. Typically not only the fan diameter but also the scroll housing is larger for backward-curved fans.

Thus, for Retrofit projects one needs to pay special attention to the available space for the fan as the more efficient backward-curved fan also requires more room within existing systems.

Figure 6 shows a dimensional comparison for the two fan types. Both fans can reach similar air performance.

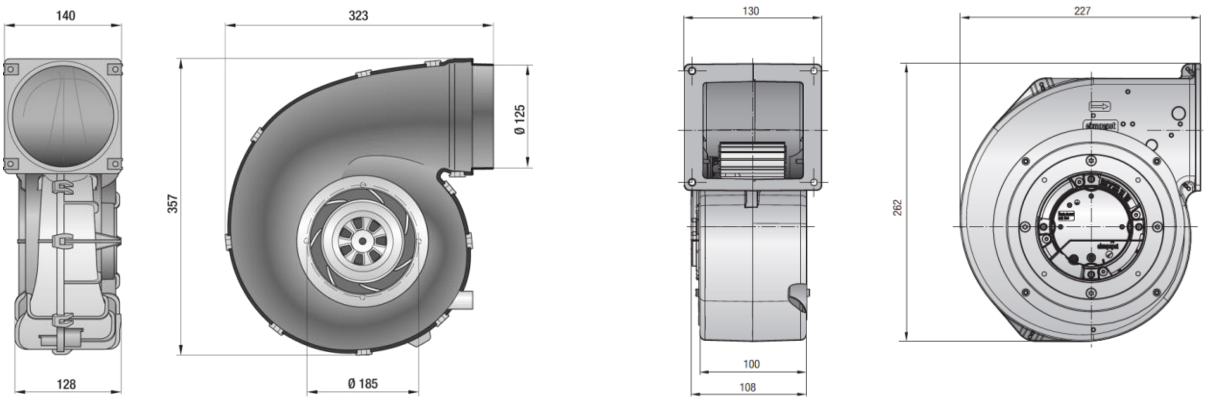


Figure 6: Dimensions of scroll housing for fan with backward-curved impeller size 190 mm (left) and forward-curved fan with impeller size 160 (right)

Centrifugal fans – Noise reduction with optimized installation and improved inflow conditions

As noise is always critical with installing fans in different applications one needs to pay special attention to installation space and inflow conditions of fans. Figure 7 shows the effect of different inflow restrictions on noise and power consumption for backward-curved fans compared to the "fan only" configuration. The first letter "H - High" and "L - Low" represents the distance between the top cover of the box and the inlet ring of the fan. The figure behind stands for the number of openings where air is able to enter the box from the side. Special measurement setups are the version with Heat Exchanger "HEX" and "L1D" where an additional diagonal sheet metal part was installed.

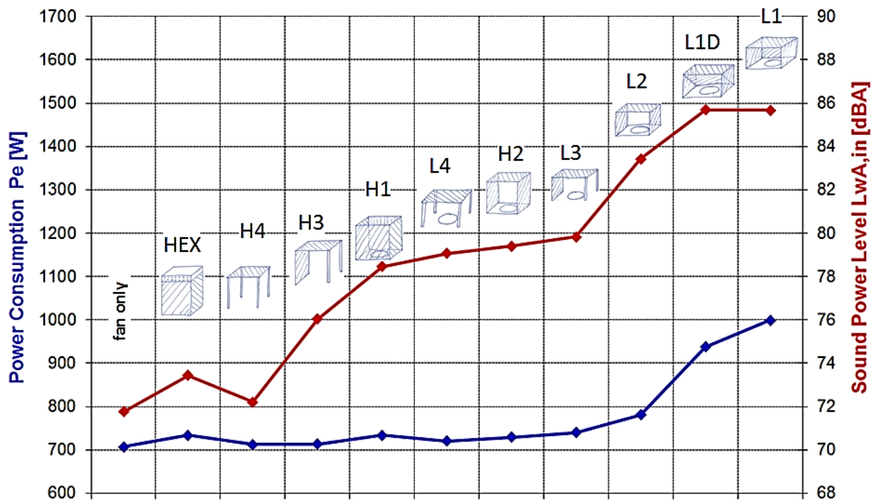


Figure 7: Effect of different inflow restrictions on noise and power consumption for backward-curved fans

General rule is, that the distance to walls in axial direction should be as large as possible ($\geq 1 \cdot D_{impeller}$). Additionally the airflow from the sides should not be influenced by walls or other installations positioned within the airstream. If some installations can not be placed outside the airstream the number of these should be as less as possible. As an overall rule inflow restrictions have a big influence on noise level while the effect on power consumption is only visible for vary bad installations with small space on the inlet side of the fan. A possible explanation for this effect is that typical inflow restrictions will increase the turbulent kinetic energy of the airstream on the inlet side of the fan. Thus for backward-curved fans a higher turbulence will result in an increase of the Blade Passing Frequency (BPF) of the fan. To avoid this disadvantage there is a chance to use additional components like Filters, Heat exchangers or FlowGrid to get a more uniform flow and reduce the inflow turbulence drastically.

FlowGrid is a flow straightener that reduces unwanted inflow disturbances with the target to reduce noise while keeping the same airflow. It can be installed together with the existing inlet ring without any additional parts required. Real applications like heat pumps or air conditioning units have huge differences with positioning the fan inside the application or with openings for inflow and outflow. Depending on the installation situation there might be a high nonuniformity within the airflow and the airstream can also contain unsteady flow parts. The turbulent flow leads to pressure fluctuations on the leading edge of the impeller that increases noise especially in the low frequency range and also raises tonal noise components like BPF. The BPF is the frequency generated by the fan speed times the number of blades and it's harmonics.

Measurements in real applications show a benefit for the overall noise level as well as for the reduction of the BPF. With the example shown in Figure *8* the overall noise sound power level was reduced by 2.8 dB(A), the tonal noise is reduced by 10 dB(A). For applications like air purifiers which are used in the residential area of people this is a drastic improvement and will improve the acceptance of the noise generated by this kind of application. In some applications FlowGrid can also be a cost saver as the noise reduction might reduce the necessity for a silencer or noise absorbing material.

Figure 8: Centrifugal fan with FlowGrid installed in an air purifier

Axial fans – improved efficiency and optimized noise behavior

Many of today's applications use axial fans. Over the last years there was a remarkable increase in efficiency for this type of fan while reducing noise at the same time.

The following section shows milestones on the way to reach best efficiency and lowest noise values with modern axial fans.

Figure *9* illustrates examples of axial fans that represent these steps. From left to right:

- Axial fan with aluminum die-cast blade
- Axial fan with plastic blade
- Axial fan with plastic blade and additional Diffuser
- Axial fan with increased diameter and additional Guide Vanes

Figure 9: Different generations of Axial fans

In the past the aerodynamic parts of typical axial fans were made of sheet metal or aluminum die-cast. The aerodynamic possibilities were therefore limited to very simple geometries. Changing to plastic impellers then opened a wide range of possibilities to create new and aerodynamically optimized geometries. For example there was a chance to use aerodynamic profiles for the blades instead of blades with constant thickness. Not only the blade itself but also the section on the blade tip can be improved by changing the material of the blade. The region between the rotating part (impeller) and the standing part (wallring) has a high contribution to the noise level of axial fans. Reducing the losses in that section has a positive effect on noise. The so called Winglet at the blade tip reduces the airstream between pressure side and suction side of the blade. Figure *10* shows the vortex at the blade tip that is driven by the pressure difference between pressure and suction side of the blade. Winglets reduce the interaction between the vortex and the blade surface which results in lower noise.

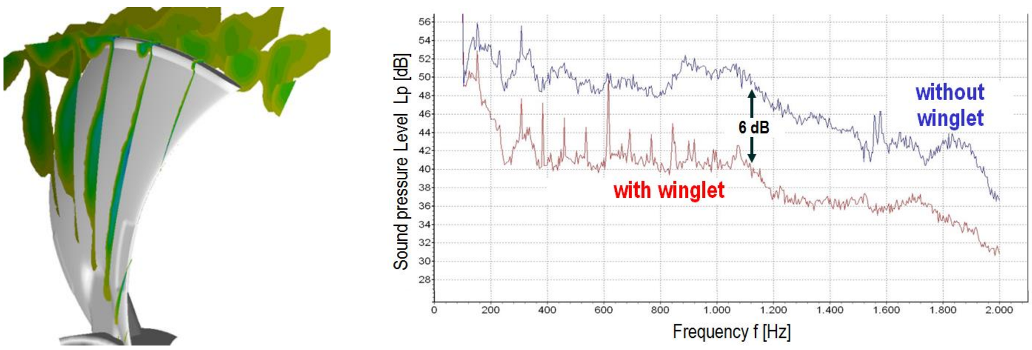


Figure 10: CFD simulation of losses at the blade tip & the positive effect of Winglets on the overall noise level

The biggest efficiency loss for axial fans is caused by the kinetic energy at the outlet of the fan (discharge losses). Figure *11* reveals the typical aerodynamic losses within an axial fan. To reduce the dynamic pressure it is necessary to increase the outlet area and as a result of that to reduce the outlet velocity.

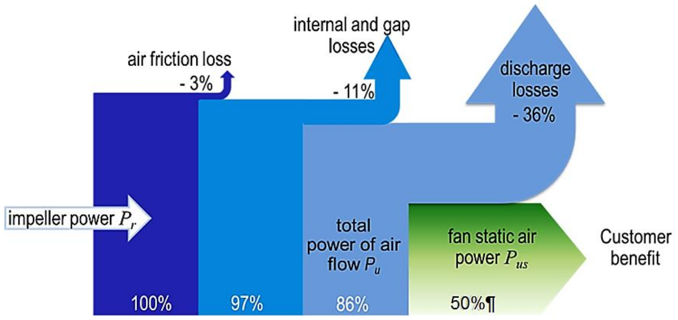


Figure 11: Analysis of aerodynamic losses for a typical axial fan

For increasing the outlet area of the fan it is necessary to install an additional Diffuser. A Diffuser is a device for reducing the velocity and increasing the static pressure of a fluid passing through a system. Diffusers can increase the overall efficiency of the fan by more than 20 %, especially in the low pressure region of the fan curve where air velocity is highest. An additional Inner Diffuser will have a positive effect on airflow inside the Diffuser as it can avoid flow separations in the hub region. Figure *12* shows pictures of a fan with and without Diffuser and points out the positive effect on air performance and efficiency of a typical axial fan.

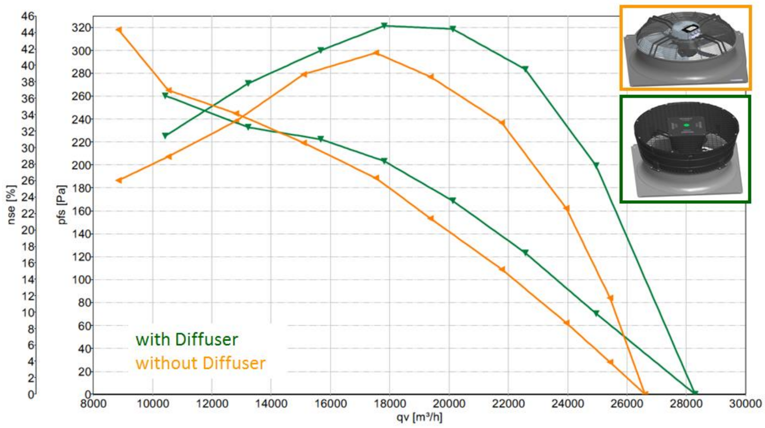


Figure 12: Fan Curve of a typical axial fan with and without Diffuser

The same effect as with a Diffuser can be reached by increasing the impeller diameter while keeping the same installation space for the fan. A larger outlet area reduces the discharge losses and therefore increases the overall efficiency. The huge benefit of the larger diameter is that no additional parts are necessary to reach the high efficiency that previously could only be reached by installing an additional Diffuser.

Guide Vanes (Figure *13*) are well known for a long time but haven't been used within typical low pressure axial fans in the past. As energy efficiency becomes more important, this picture changes slowly. Guide Vanes are used to reduce the swirl created by the rotational speed of the fan. The flow component "circumferential velocity" is reduced by the shape of the Guide Vanes and directed into axial air velocity. The change of this flow component has a positive effect on fan pressure and results in an increase of fan efficiency. As the outflow angle of an axial fan changes along the fan curve there is a range where the Guide Vanes work best. As a consequence one needs to adapt the geometry of a Guide Vane according to the requirements in real applications.

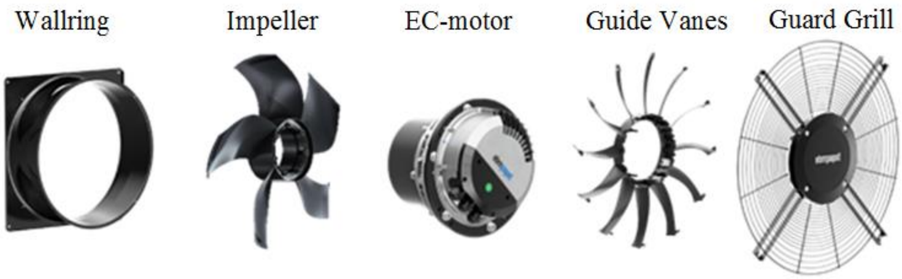


Figure 13: Axial Fan with Guide Vanes

Measurements in a working point of a typical heat exchanger (20,000 m³/h @ 120 Pa) show that over a period of less than 15 years the power consumption Pe of an axial fan was reduced from 2.6 kW to 1.47 kW (-43 %) with switching from AC- to EC-motor and using the latest aerodynamically optimized geometries as described above (Winglets, Diffuser, Guide Vanes). At the same time the sound power level LwA was reduced from 89 dB(A) to 78 dB(A), -11 dB(A); Figure *14*.

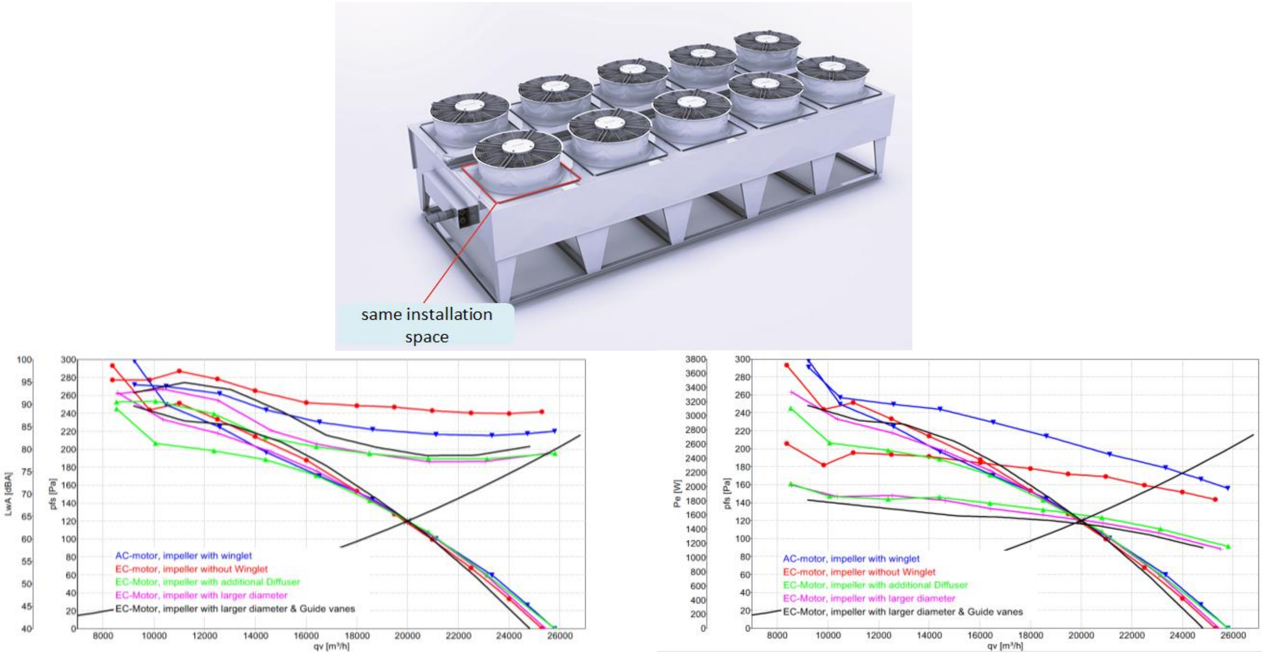


Figure 14: Typical heat exchanger with 10 axial fans installed (top);
Improvement of noise and power consumtion for different generations of axial fans (bottom)

CONCLUSION

Fan Retrofit offers a wide range of possibilities to improve acoustics and the efficiency of existing installations. Approaches for improvement are the change from inefficient asynchronous AC-motors to highly efficient synchronous EC-motors as well as using more efficient aerodynamic solutions like backward-curved impellers (with and without housing) and axial fans with diffusers and/or guide vanes. Acoustical behavior of fans is improved with new blade geometries and Winglets for axial fans and with flow straighteners like FlowGrid for inflow conditions with high turbulences. Existing installations can typically be improved with only small effort and a very short payback period for the investment, because fans can often be replaced within the same footprint and the better efficiency of the fan saves a lot of energy.

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„fast zwei Drittel der untersuchten Anlagen wurden vor 1989 installiert“