DEA & EESD
Energy Partnership Programme
between Viet Nam and Denmark

Technology catalogue for energy efficiency in blower and fan systems

Viegand Maagøe

AIM AND CONTENTS OF CATALOGUE

The overall aim of the catalogue is to describe solutions and measures to address when planning and purchasing new large fans or blowers for exhaust systems, process fans etc. or when planning to rehabilitate existing systems.

The catalogue aims at creating an understanding of efficiency questions for large fans and blowers used in e.g. exhaust systems, drying processes, material transport. The catalogue does not cover the topic regarding HVAC and room ventilation systems.

Besides covering efficiency questions, the catalogue also aims to create understanding when sourcing for new equipment; what should be considered when buying new equipment and the procurement process.

The catalogue has the following sections:

- Section 1: Improving energy efficiency of large fan and blower systems.
- Section 2: Selection and equipment of new fan and blower installations.
- Section 3: The procurement process for new fan and blower systems.

In the annex of the catalogue, more detailed information can be found:

- Annex: Selected national and international suppliers of large fans and blowers.

The catalogue further describes cases for rehabilitating fan installations as well as the business case for replacing old in-efficient fans and blowers with new high-efficiency ones.

Content

1 Improving energy efficiency of large fan and blower systems

The energy usage for large fans and blowers in Vietnamese industry represents a significant part of the overall energy usage by example:

- In the cement industry
- In the iron and metal industry
- In wood processing industry
- In individual processes like for example drying chambers and kilns
- Etc.

Below in Figure 1, an example of a large process fan system is shown.

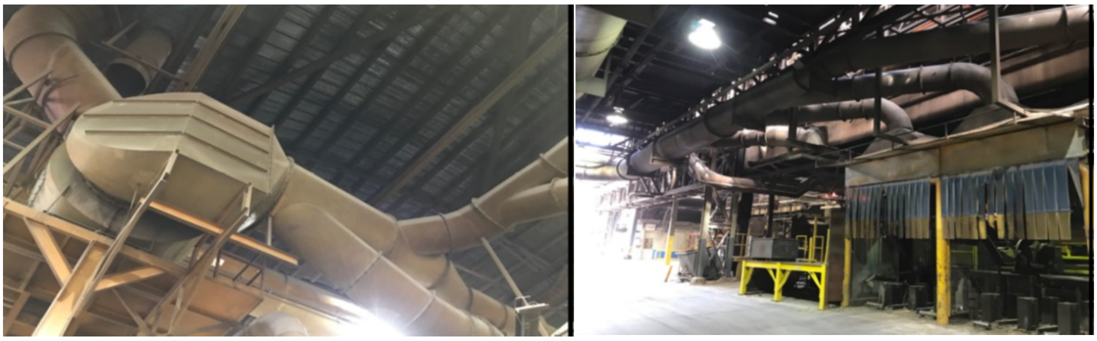


Figure 1 Large fan in the iron and metal industry.

This section presents key elements in the energy usage for large fan and blower systems and which options that can be considered in order to reduce energy consumption.

1.1 Large fan and blower systems

Fans and blower systems differ from each other by the method to move the air and by the system pressure they operate against. Fans and blowers are both used for inlet and exhaust streams. Figure 2 illustrates a simple process fan used to provide hot air to a spray dryer.

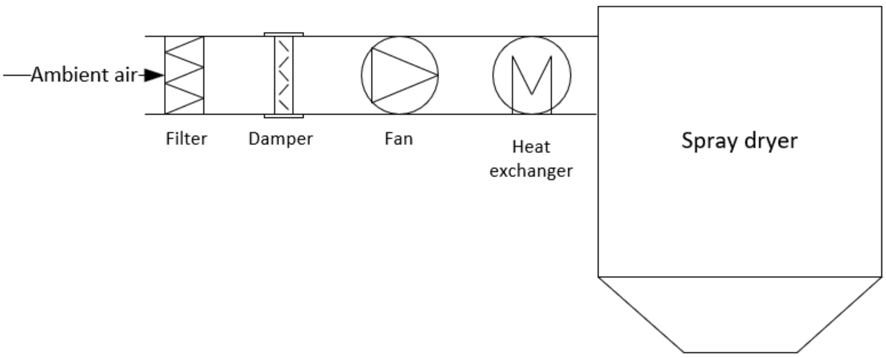


Figure 2 Schematic of a simple process fan for a drying process.

Another typically system is shown by Figure 3 which illustrates a simple exhaust system from multiple processes where contaminated air is removed from the process and working air to be blown out into the open.

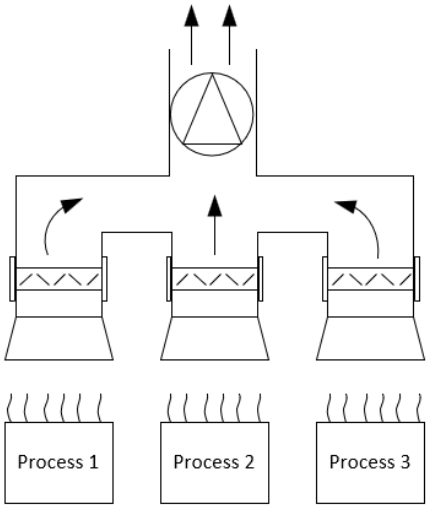


Figure 3 Schematic of simple exhaust system.

The American Society of Mechanical Engineers (ASME) have made the following definitions between fans and blowers, see Table 1.

Table 1 Definition of a fan and blower by ASME [1].

Equipment	Specific pressure ratio
Fan	Up to 1.11
Blower	1.11 to 1.20

Blowers are used to direct air or gasses to a certain point or particular direction by a fan and controlled channels, where a fan circulates air throughout a defined space.

Blowers can be of very significant size – up to several hundred kWs while fans typically are much smaller.

1.1.1 Observations made in Vietnamese industry

From visits to several Vietnamese industries, significant energy saving potentials have been observed, by example by the following measures:

- Many fans are old with fairly low efficiency compared to modern technology.
- Often capacity of fans is controlled with dampers and not VSDs.
- Ducts and channels transporting air or gasses have leaks allowing false air to enter the systems.
- Ducts and equipment are dirty increasing pressure losses.
- Control strategies are simple and often with manual on/off-control of operation.
- In exhaust systems, ducts not in use are shut off manually or cannot be.

For such reasons, it must be expected that auditing of fans and blower systems can achieve significant energy savings.

1.2 Fan efficiency

The efficiency of a fan/blower depend on several conditions such as the fan type, angle of the blades, the pressure ratio, housing, speed etc.

Manufacturers generally use two ways of defining the efficiency of a fan:

- The mechanical/total efficiency

- The static efficiency

Both express how well the fan converts the electrical power into flow and pressure. The **static efficiency** is calculated based on the input power to the fan and the difference in *static pressure* before and after the fan. The static pressure is the potential energy put into the system by the fan.

The **total efficiency** is calculated based on the input power to the fan and the difference in *total pressure* before and after the fan. The total pressure is the sum of the static pressure and *dynamic/velocity pressure*. The dynamic pressure is the pressure along the line of the flow resulting from airflow through the duct. If the dynamic pressure is known, then the air flow velocity can be calculated and vice versa.
In the European Union minimum requirements for the static and total efficiency are stated in EU327/2011 [2] for different type of fans. Figure 4 shows the minimum total efficiency for selected fans based on the power input. As presented, efficiency requirement increases with the size of the ventilator.

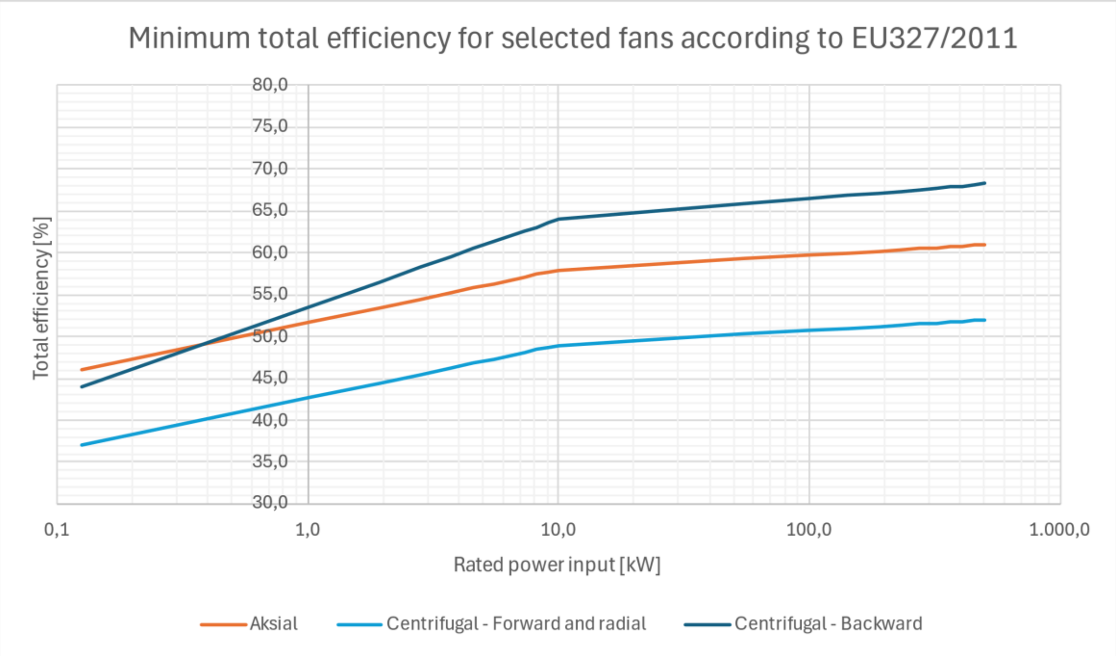


Figure 4 Minimum required total efficiency for selected ventilators according to EU327/2011 [2].

Figure 4 presents the minimum required efficiency for fans, but the available fans on the market are seen to have higher efficiencies. The peak fan efficiency for selected fans is listed in Table 2. Table 2 only present the fan efficiency, and not the total efficiency. For this the motor and VFD-efficiency (variable frequency drive – efficiency) must be added.

Table 2 Peak fan efficiency for selected fans. For the total efficiency, motor and VFD-efficiency must be added.

	Axial fans			Centrifugal fans		
	Vane	Tube	Propeller	Radial	Backward	Forward
Peak efficiency range	80%-90%	60%-70%	45%-50%	60%-70%	75%-85%	50%-60%

If the efficiency of the fan is below the requirements presented in in EU327/2011 it is highly recommended to replace the current fan with a new and more efficient one. *How to measure the fan efficiency is described in section 1.2.1.*

The efficiency of a fan does always depend on the operating conditions, which is why the obtainable peak efficiency can only be found by contacting a supplier.

Diagnosis of situation:

The following steps to be followed.

- Measure static and total pressure according to section 1.2.1 together with the power consumption.
- Calculate the total efficiency of the fan/blower. If the efficiency is below the requirements in EU327/2011, the fan should be replaced.
- If the fan is to be replaced, firstly check whether it is possible to reduce the airflow or pressure demand.
- Contact supplier with updated data for operation for a new fan.

1.2.1 Measurements of the fan efficiency

The fan efficiency can be measured with the use of a manometer and a pitot tube. Figure 5 shows how the different pressures are measured in duct.

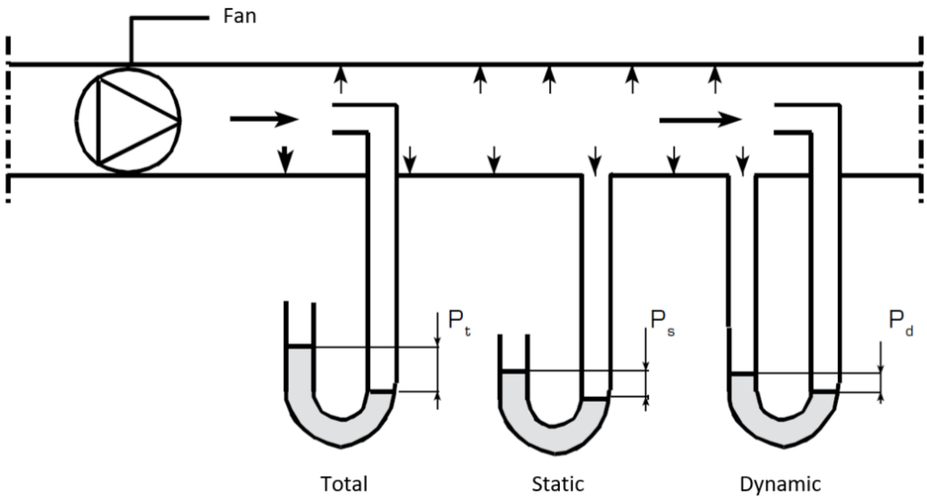


Figure 5 Illustration on how to measure the static, dynamic and total pressure in a duct [3].

To measure the static and total efficiency the difference in static and dynamic pressure over the fan must be known, meaning that the pressures shall be measured before and after the fan, see Figure 6.

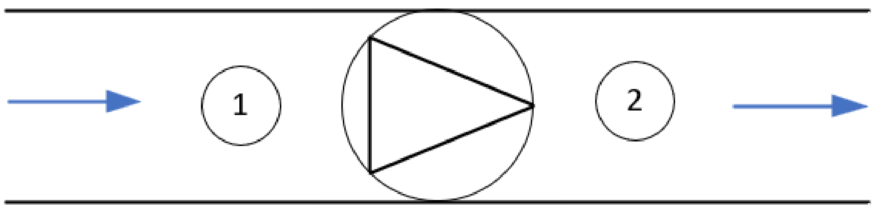


Figure 6 Measurement points to determine the efficiency of a ventilator.

The static efficiency is then calculated by:

$$\eta_{static} = \frac{(p_{s2} - p_{s1})\ [Pa] \cdot \dot{m}_v \left[\frac{m^3}{s}\right]}{P_{in}\ [W]}$$

The total efficiency is calculated by:

$$\eta_{total} = \frac{((p_{s2} + p_{d2}) - (p_{s1} + p_{d1}))\ [Pa] \cdot \dot{m}_v \left[\frac{m^3}{s}\right]}{P_{in}\ [W]}$$

1.3 Motor efficiency

Today's best fans include an electric motor in brushless direct current (DC) technology, also known as electronically commutated motors (EC motor), with an integrated frequency converter for step-less load control and an impeller with low aerodynamic losses.

Fans should at best be direct-driven, i.e. the fan impeller is directly mounted on the electric motor shaft. In the range of higher flows and pressures, the EC motors are not yet available. In that range the best available technology of motor is an AC electric motor of the efficiency rating IE4 with a variable frequency drive.

The difference between an EC and AC motor is that the AC motor can be very efficient at full load. However, when used in part load the losses in the AC motor becomes severe compared to the EC motor, which has an in-built frequency converter.

Figure 7 presents the difference between the minimum required efficiency for a motor of IE2 and IE4 class based on the EU regulation EU2019/1781 from 04-01-2023 [4].

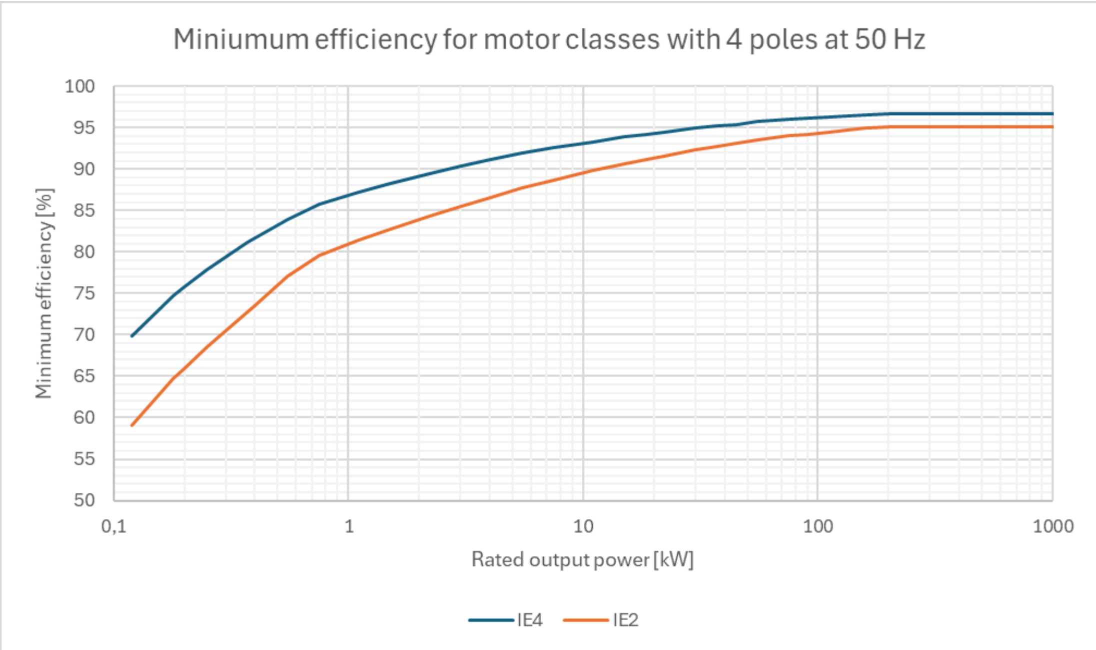


Figure 7 Minimum required efficiencies for different motor classes based on EU2019/1781 from 04-01-2023 [4].

Based on Figure 7 and the rated output power of the motor one can save up to 10% of the electrical consumption by changing a IE2 motor with a IE4 motor. Table 3 shows the range of minimum required efficiency for a motor based on the efficiency class and number of poles. A more detailed overview can be found in EU2019/1781.

Table 3 Minimum required efficiencies for different motor classes in EU with different number of poles and rated output power from 0.12 kW to 1000 kW at 50 Hz. The lowest efficiency is with 0.12 kW output power and the highest number is with 1000 kW output power. From EU2019/1781 from 04-01-2023 [4]

Motor classes	2 poles	4 poles	6 poles	8 poles
IE2	53.6%-95%	59.1%-95.1%	50.6%-95%	39.8%-93.5%

IE3	60.8%-95.8%	64.8%-96%	57.7%-95.8%	50.7%-94.6%
IE4	66.5%-96.5%	69.8%-96.7%	64.9%-96.6%	62.3%-95.4%

Besides the motor classes covered by EU regulation a more efficient motor class IE5 exist. This class can, depending on application and conditions, reduce the energy losses with up to 40% [5] compared to IE3. This large saving is due to that the IE5 motor does not require electricity to be routed to the rotor.

The efficiency improvements are clearly most evident for smaller motors and for motors with high number of operation hours per year a replacement due to energy costs can be feasible. A motor survey is a good and systematic way of getting an overview of which motors can be changed justified by electricity savings.

For the remaining motors a policy for substitution with more energy efficient motors shall be developed so the maintenance department can act accordingly.

In general, it is always recommended to buy motors with the highest efficiency. However, depending on the situation it cannot always make sense to change a IE4 motor with a IE5 motor when the current motor also has a VFD. Due to higher efficiency the IE5 motor can run with higher rpm (rotations per minute) from a reduced slip in the rotor, but if the fan or blower cannot utilize the extra rpm, then no savings will be obtained.

Diagnosis of situation:

The following steps to be followed.

- Check the motor class for the motor connected to the fan.
    - If not possible from rating plate, contact supplier.
- Check the operating hours for the specific motors as the savings is highly related to the operating hours for the specific motor.
- If the motor class is below IE4, contact the supplier to find out if it is possible to replace the current motor with a more efficient one.

Case 1: Replacing low-efficient fans and motors

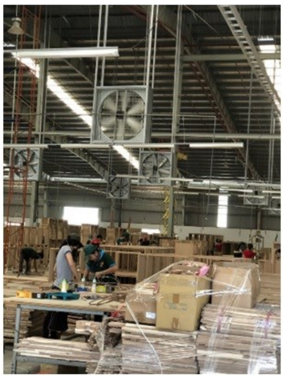
Company name: THINH VIET II MANUFACTURING CO., LTD	
Address: DT 746 Street, Binh Khanh Hamlet, Khanh Binh Commune, Tan Uyen District, Binh Duong Province.	
Project summary: Improvement of ventilation system for the factory (using ultra-energy-saving fans).	
Year of implementation: 2020	
Status before implementation	**Result**

Thinh Viet is one of the leading furniture manufacturers in Binh Duong Province, Vietnam.

During the production of wooden furniture, a large amount of wood dust is generated, affecting the working environment of workers. The ventilation fan system requires a large number of fans, resulting in a considerable consumption of electricity (with about 10 working hours/day and 300 working days/year).

The use of conventional 3-phase AC motors has low efficiency ranging from 70 to 75%. Therefore, the factory has chosen STEELFAN - 138A ventilation fan equipped with a brushless DC inverter motor.

The factory has installed 66 STEELFAN - 138A ventilation fans equipped with brushless DC inverter motor.



Pictures of new ventilation system

Results of the project:	
Total investment cost:	69.3 million VND
Energy savings:	91,080 kWh/year
Cost savings	227.7 million VND
Payback period	3.8 years

1.4 Efficiency of belts and drives

In many applications the fan is connected to the motor through a belt drive which adds additional energy losses up to 10%. This can be higher if the belts are not properly maintained or if the gear adjustment is incorrect. In general, it is most efficient if the fan has direct drive to reduce the losses.

However, in some cases it can be necessary to use belts to physically separate the motor from the fan. This can be due to a risk of the fan being suddenly blocked from items in the channel resulting in the case of direct drive that the motor will fail.

In this case a belt can help protect the motor, as it will still be able to run, but instead the belt will eventually fail. In other cases, due to lack of space, a belt is needed to connect the fan and motor. Figure 8 shows two cases for belt driven ventilators where in the left picture the belt should be avoided and in the right picture the belt is necessary due to space limitation for the service area.

For axial fans the direct drive solution can also be challenged if the air stream e.g. has high temperatures or chemical exposure which can affect the motor lifetime. In such cases it is important to have a dialog with the supplier of what is possible. It can be solved with a more resistant motor, or possibly a belt drive. In some cases, another fan type, e.g. a centrifugal fan, can be the solution.


Figure 8 Example of belt-driven ventilators.

If belts must be used, it is recommended to select high-efficient belts to reduce slipping and energy losses. Figure 9 shows different types of belts typically used.

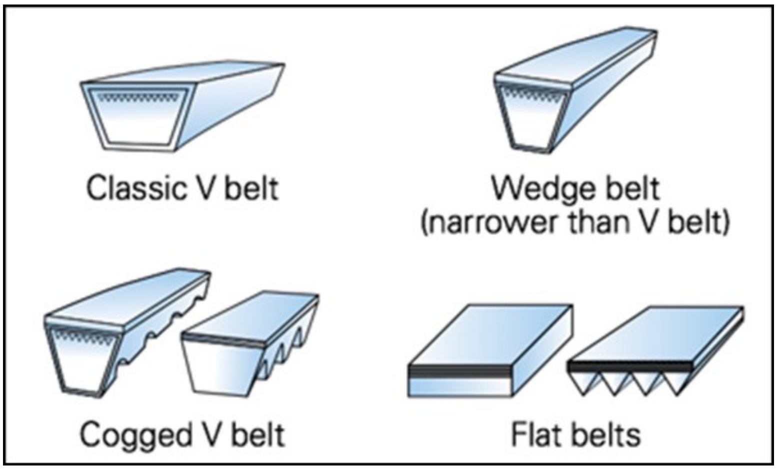


Figure 9 Schematic drawing of the most common belts [6].

Classic V-belts are the most inefficient types with losses up to 10%. Using a wedged belt, cogged belt, synchronous belt, or similar types of high-efficient belts can lower the energy loss to approximate 1% of the total electricity used by the fan or blower. Table 4 shows different efficiencies for belt drives.

Table 4 Efficiencies for the most general belt types at installation [3]. During the lifetime the efficiencies will decrease.

	Efficiency
Direct drive	100%
Classic V-belt	93%-98%
Cogged V-belt	96%-98%
Tooth belt	97%-99%
Flat belt	97%-99%

Diagnosis of situation:

The following steps to be followed.

- Check the condition of the belts and gearing.
    - If belts are loose or vibrations occur, the belts should be changed.
    - Compare the rotations of the motor and the fan. If there is a large difference the belt should be changed.
- Check whether it is possible to change from belt drive to direct drive.
    - Contact supplier to clarify.

Case 2: Replacing belt-driven ventilator by direct drive

<table>
<tr><td colspan="2">Project Summary: A textile and dyeing enterprise in Long An has replaced the belt-driven fans with higher-efficiency direct drive fans.</td></tr>
<tr><td colspan="2">Year of implementation: 2019</td></tr>
<tr><td>Status before implementation
The ventilation fan system for ventilation was using belt-driven ventilation fans (capacity of 1.5 Hp, airflow of 33,000 m^3/h).

Ventilation fan
The belt transmission gave low efficiency due to loss of energy caused by electric wire heating, friction, elongation of belt, high slippage coefficient. As a result, there is a reduction in efficiency of the transmission from the electric motor to the propeller and reduction of its service life. In addition, the noise effect of the belt transmission was greater than that of the direct drive with the same capacity.</td><td>Result
The factory has replaced nine (9) old fans with new direct drive fans.

New fan (direct drive)
The new fan has a capacity of 1 Hp (airflow of 45,000 m^3/h) and helps reduce the power consumption > 33%.</td></tr>
<tr><td colspan="2">Result of the project:</td></tr>
<tr><td>Total investment costs:</td><td>VND 126.5 million</td></tr>
<tr><td>Power saving:</td><td>32,340 kWh/ year</td></tr>
<tr><td>Cost savings:</td><td>VND 53.3 million</td></tr>
<tr><td>Payback time:</td><td>2.4 years</td></tr>
</table>

1.5 Pressure losses in the system.

Pressure losses in the system, also termed the systems resistance, is made from the sum of static pressure losses coming from the configuration of ducts, pickups and pressure drops across equipment, e.g.

- Dampers
- Silencers
- Filters
- Heat exchangers.
- Etc.

The system resistance is highly depended on the volume air flow as the resistance varies with the square of the volume of air flowing through the system. To overcome an increased system resistance, the fan needs to increase speed resulting in an increased electricity consumption. Therefore, ducts should be as large as possible to decrease the overall system resistance from e.g. bends, twists and components.

Besides the ducts, the equipment in the system should be designed with minimum possible pressure drops. Figure 10 shows a schematic of a simple fan system for heating air.

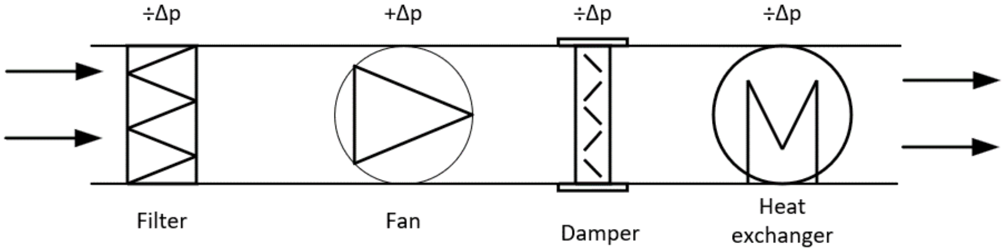


Figure 10 Schematic of a fan system for heating air.

For the system in Figure 10 the filter, damper and heat exchanger add a pressure drop to the system the fan has to overcome. In this system it should be checked if it is possible to reduce the pressure by change of the design or change the demands e.g. for the filter. This could be if the filter removes more particles than necessary*, see section 1.8 for more information*.

With regards to the damper, its function is to control the air flow, but this can be done by replacing it with a VFD to the fan. Besides reducing the pressure drop in the system, it also gives a more energy efficient control of the fan, *see section 1.7 for more information*.

The above is small changes to the system, but if larger equipment is changed or duct modification are made it can change the system resistance significantly resulting in a poor efficiency for the fan. In this case, to maintain the efficiency it can be necessary to replace the fan with a new one, designed after the new system requirements.

Pressure losses that increase through time due to fouling should always be monitored. This typically applies to filters, filtration systems and coils.

In some cases, an automatic bypass can be established for components that introduce high pressure losses, when these components are not in use, e.g. heating or cooling coils.

1.5.1 Flexible ducts

Flexible pipes used for e.g. local exhaust ventilation at a welding workplace should be avoided over long length. Instead, where possible straight ducts should be used.

1.5.2 Silencers

Silencers are used to reduce the noise level from fans and blowers. The use of silencers adds pressure drop to the system, and hereby increase the energy consumption for the fan. To reduce the pressure drop, silencers should be designed with an air velocity between the baffles of maximum 10 m/s, or 6 m/s for angle silencers [3].

1.5.3 Booster fans

Use booster fans to overcome pressure losses in smaller ducts placed far away from the main duct, instead of raising the total main pressure. Sometimes it is even more convenient to establish a small separate system, instead of installing long ducts to service a small demand far away.

1.5.4 Self-regulating constant air flow dampers and mixers

When using self-regulating constant airflow dampers and mixers in the air distribution system it is important to not use an excessively high pressure in the main ducts feeding the dampers. The main duct pressure should be set so there is exactly the right pressure across the damper fitted furthest away in the system.

1.6 Operation of fans and blowers

In the industry, it is often observed that the airflow supplied in the process does not correspond to the actual need. Often fans are supplying too much or too little air. If the fan is over-dimensioned according to the process need, unnecessary energy is used and there is an energy saving potential with replacing the fan with a smaller one designed to the process need. Reducing the airflow can introduce significant savings as a 10% reduction in the airflow reduce the energy consumption by 27%. *For more information see section 2.2.5.*

It also has significantly negative effect on the efficiency if a fan is designed to deliver medium airflow with high pressure but instead operate with high airflow with low pressure.

Another point to address is the origin of the airflow and pressure demand. If the airflow and pressure demand can be challenged and hereby reduced without compromising any legal or process requirements, the energy consumption in the fan can be reduced.

Figure 11 and Figure 12 illustrates what influence a reduced flow has on the pressure loss and power loss during a system. The example is based on a simple system shown in Figure 10.

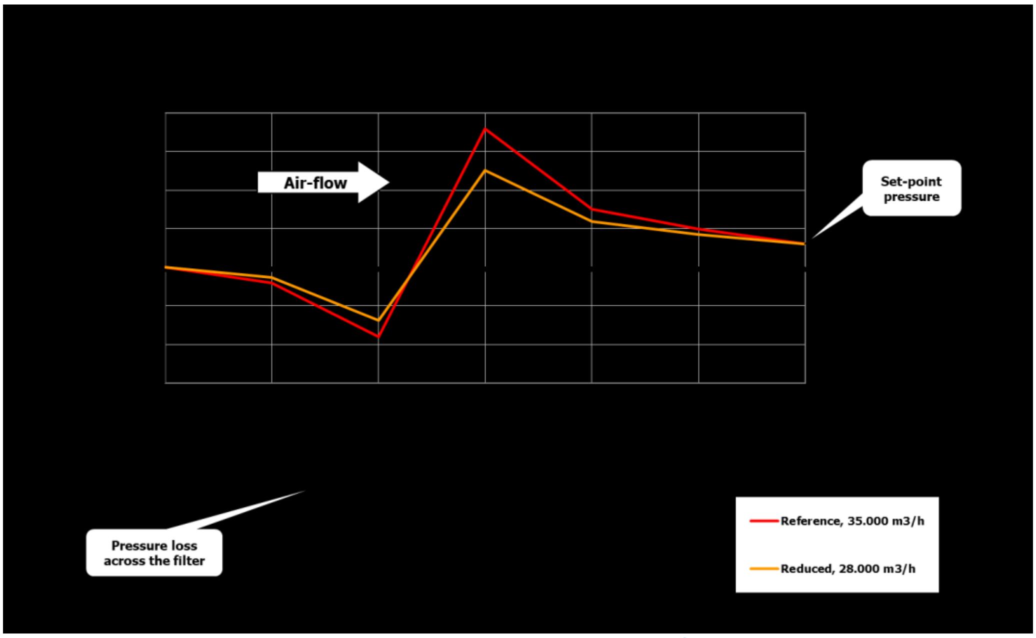


Figure 11 Example on how the pressure changes during a system. System is based on the one shown in Figure 10.

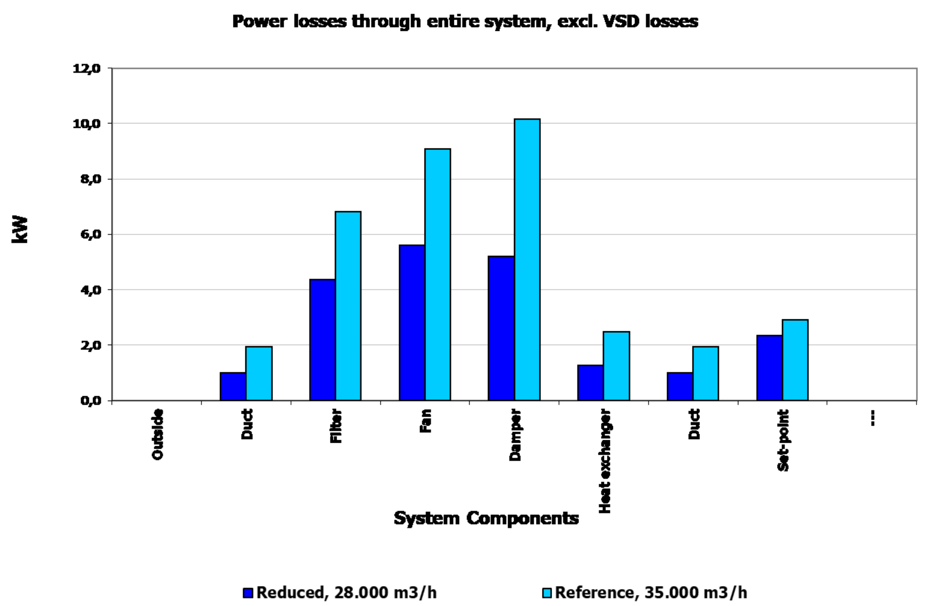


Figure 12 The results from reduced air flow and pressure from Figure 11 in terms of power losses.

By reducing the airflow in the system, a significant energy saving can be obtained.

Diagnosis of situation:

The following steps be followed:

- Investigate the process need with regards to air flow and pressure.
- Compare the design data for the fan with the operational point.

- If the design point and operational point differ significantly from each other, there may be a justification in replacing the current fan.
    - Contact an expert/supplier to find a more suitable fan for the task.

1.7 Control strategies

Depending on the dynamic range of the airflow demand, various methods of regulating the fan(s) are available.

1.7.1 Fixed speed fan

If the demand is always the same, there is no need for other regulation than on-off control of the fan, as long as the fan and its motor/drive are carefully selected to run in the optimum operating point.
Warning: It is sometimes seen that sloppy design practice results in heavily over-dimensioning, followed by commissioning trimming of the airflow by means of e.g. a variable speed drive. This results in a system that constantly operates in a less efficient operating point and should be avoided.

1.7.2 Two fans

In the case of two distinct airflow demands, where one is considerably much lower than the other, and has long operational hours in this state, it should be considered to install a separate smaller fan. By a set of on-off dampers, one can then control which fan should be running depending on the airflow demand. This can be seen in flue-gas systems, where the smaller fan is operating when the furnace is not in operation.

1.7.3 Inlet vanes

If the airflow demand varies from full 100% and down to 60%, a mechanical regulation of the fan by means of an inlet vane can be used as a preferable alternative to variable dampers. This is typically seen on very large (or older) fan installations and can be used for both radial and axial fans. This method has a decent efficiency in the higher end of the dynamic range and is definitely better than a traditional damper.

1.7.4 Variable Speed Drive (VSD)

Today, electronic variable speed drives (VSD) can handle fan motors from very small to several MWs and is by far the preferred choice in most cases. VSDs can be used for all sorts of electric motors (asynchronous, synchronous, DC, SR, etc.) if they are purposely built for the type of motor chosen.

Smaller fan motors are often equipped with built-in VSD, and even the whole fan/motor/VSD-assembly can be a one-part component. Good quality VSDs exhibit very high internal electrical efficiencies, but one should always be aware of the combined efficiency when driving the motor out of the designed range, given by frequency and voltage (this applies especially to asynchronous motors).

Figure 13 illustrates the saving potential by using a VSD instead of a damper for example. As presented the VSD introduce significant energy savings compared to the use of a damper to regulate the air flow.

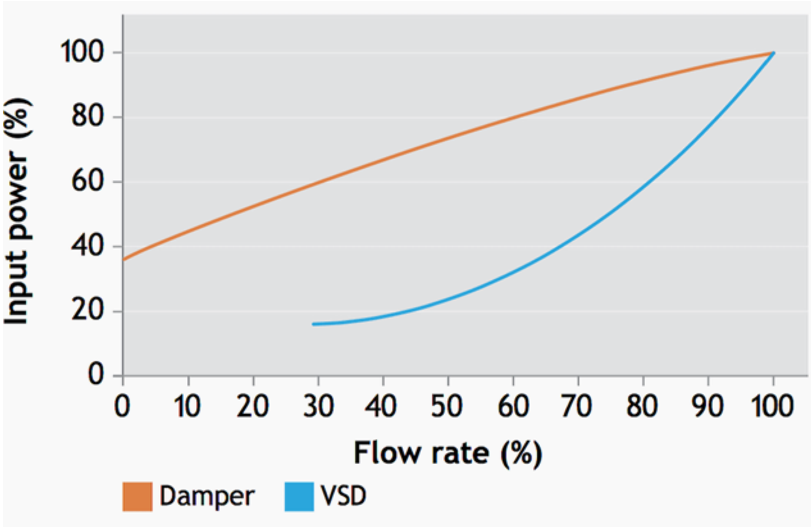


Figure 13 Comparison of input power for damper and VSD flow rate control.

1.7.4.1 Guidance for use of a VSD

VSD is a good tool to achieve energy savings if the flow has a large variation. However, it does also have limitations. A VSD can regulate the flow to below 10% of the max flow, but it should not have many operating hours at this condition. If so, it could be that the fan is over-dimensioned, or one should make use of two fans as described in section 1.7.2.
Before installing a VSD it is important to know the flow range that it should be operating in, and another important factor is that the VSD is controlled by the correct parameters. If a certain pressure is needed at a specific location, then it is this pressure that the VSD should be controlled after.
What to avoid is to install a VSD and constantly regulate the flow to e.g. 85%, as this means the fan is over dimensioned and it would be more effective to buy a new fan meeting the exact demand, see section 1.7.1.

Case 4 – Speed control by a VSD

At a welding station with multiple local exhaust ventilation the existing fans is controlled as a constant pressure system. By installing VSDs on all the fans a significant energy reduction is achieved as shown in Table 5.

Table 5 VSD on exhaust ventilation from welding. The OPEX saving is based on 1,8 million VND/MWh for electricity.

Process	Welding exhaust ventilation
Energy consumption	427 MWh/year
Project	Installing VSD on fans
Energy saving	128 MWh (30%)
Investment	1.000.000.000 VND
Payback time	4,1 years

1.7.5 To be avoided

All sorts of main-air-flow regulation techniques with high losses should be avoided both when the loss is introduced in the fan/drive or in the airflow. This is even more important with systems that have many operational hours pr year.

- Dampers that restrict the airflow by introducing pressure loss
- Dampers that bleed part of airflow away from system
- Hydraulic couplings

- Variable belt drives
- Two-and three-speed motors

Case 4: Integrating variable speed drives for blowers

<table>
<tr><td colspan="2">Company name: VRG KIEN GIANG MDF JOINT STOCK COMPANY</td></tr>
<tr><td colspan="2">Address: Lot M, Street Number 1, Thanh Loc Industrial Zone, Thanh Loc Commune, Chau Thanh District, Kien Giang Province, Vietnam</td></tr>
<tr><td colspan="2">Project Summary: Installation of VSDs to improve energy efficiency for fans.</td></tr>
<tr><td colspan="2">Year of implementation:</td></tr>
<tr><td>Status before implementation
The existing system utilizes fixed-speed motors that run at full power, regardless of the demand. This leads to inefficiencies and unnecessary energy consumption, contributing to high operational costs and a larger carbon footprint.</td><td>Result
Technology Overview: Variable Speed Drives (VSDs) are electronic systems that control the rotational speed of an electric motor by adjusting the frequency and voltage of the power supplied to the motor. VSDs offer a more energy-efficient way to operate motors compared to traditional fixed-speed systems. This technology is particularly suited to industrial applications where the demand for motor speed varies throughout the production process.

Expected Outcomes:

- Energy Efficiency: Reduction in energy consumption by allowing motors to operate at variable speeds, adjusting in real-time to the production needs.
- Cost Savings: Lower electricity bills and operational costs due to the efficient use of energy.
- Environmental Impact: Reduction in the carbon footprint of the manufacturing process by consuming less power.
- Maintenance and Longevity: Extended life of motor equipment due to reduced mechanical stress from operating at full speed constantly</td></tr>
<tr><td colspan="2">Result of the project:</td></tr>
<tr><td>Total investment cost:</td><td>1,179,450,000 VND</td></tr>
<tr><td>Energy savings:</td><td>631,744 kWh/year</td></tr>
<tr><td>Cost savings:</td><td>1,122,609,088 VND</td></tr>
<tr><td>Payback:</td><td>1.05 years</td></tr>
<tr><td>CO_2 reduction:</td><td>427,438 kg/year</td></tr>
</table>

1.8 Filter technologies

To protect equipment and secure that harmful or unwanted particles are not discharged into the surroundings, filters are both used for the inlet and outlet air. Both when it comes to filters in the inlet and outlet stream one must consider the velocity of air through the filter, the storage capacity for dust and particles and the minimum particle size that can be filtered by the unit.

As any other equipment in the air system filters add pressure drop which the fan must overcome. The pressure drop depends on the size of the particle to filter and the pressure drop increases as the particle size to filter decreases. Therefore, the filters should not filter particles smaller than necessary as it increases the size and energy consumption of the fan.
Besides the factors mentioned above it is also important to consider the temperature, moisture content and combustion possibility of the dust.

It is important that the right filter is chosen, but the most important thing is how the filters are maintained and operated. The filters should be monitored to secure that the filters are either cleaned or changed in a proper interval to ensure the pressure drop does not increase too much. Clogged filters add unnecessary load on the fan to secure the required airflow. *Maintenance is further described in section 1.9.*

1.8.1 Inlet stream

Depending on the inlet air requirements different filter technologies exist. If the filters in the inlet stream only serve to protect equipment, then filters with the grade G1-G4 or F5-F9 should be used.

If there are special requirements to the air due to the process, HEPA- or ULPA-filters can be used. The lifetime of these filters can be prolonged by installing a filter prior to the HEPA- or ULPA-filter which should be a least grade F8.

1.8.2 Exhaust stream

The filters for the exhaust streams are more complex systems compared to the filters in the inlet stream. This is because for some processes, like drying in the dairy industry, some product is carried with the exhaust air. Some of this product can be recovered in the filter system to be reused or sold as a biproduct.

1.8.2.1 Bag filters.

Bag filters work by passing air containing particulates through a set of bag-shaped filters, which trap the particles as air is forced through the filter media. To maintain the airflow and minimize pressure drop through the filter, they are cleaned at regular intervals either by being vigorously shaken or a reverse jet of air blown through them to release material on the filter. This material can then be collected and reused in the production process. The cleaning intervals should be based on a maximum allowed pressure drop over the filters.
To maintain the efficiency and ensure that there are no microbiological risks resulting from accumulation of material on the filters, these must be changed regularly. This is the case where products have more sticky properties e.g. dairy powder, which would require more frequent cleaning/replacement of filter bags.

Bag filters may be less effective on applications with exhaust gas temperatures over 240°C and applications with sticky emissions, that reduce or block the airflow through the filter bag. As the filters need to be changed regularly, from two times a year to every five years depending on the process, the maintenance costs are high [7].

1.8.2.2 Cyclones

Cyclones use the centrifugal force to remove heavier particles from the carrier gas. The efficiency of the cyclone mainly depends on the cyclones separator's geometric features and the centrifugal force applied. The smaller the cyclone separator's radius the greater the centrifugal acceleration and thereby the better for the separation. However, a smaller radius also increases the pressure drop, which affects the energy consumption for the fan negatively. This must be considered in the design phase.

Cyclones are typically used to filter particles above 10 µm, but high performances cyclones exist that can filter particles down to 2.5 µm [7]. Construction costs are relatively high, but the operational costs will be lower compared to other technologies due to the low pressure drop.

1.8.2.3 Electrostatic precipitator

Electrostatic precipitators filter the air by providing the particles with an electric charge, allowing them to be separated under the influence of an electric field.
These precipitators can filter particles down to 0.1 µm without introducing a large pressure drop to the system. Electrostatic precipitators operate with a pressure drops down to 0.001 bar to 0.004 bar and have low energy requirements [7].

1.8.3 Operation

The choice of filter depends on the application, such as the maximum size of particles acceptable after the filter as well as the maximum acceptable pressure drop. The pressure drop both dictates the type of filter, but also how often the filter must be cleaned or changed.
In some cases, it can make sense to install filters in series, for example a cyclone followed by a bag filter. With this setup, the cyclone removes the larger particles before the air enters the bag filter. This prolongs the lifetime of the bag filter, which filters the smaller particles the cyclone cannot separate from the air.

1.9 Maintenance

Significant energy savings may be achieved if maintenance is performed regularly and besides it can extend the lifetime of the equipment and system and help keep the performance high. Bad maintenance can make a system very inefficient. A total check of the complete system should be performed regularly.

1.9.1 Fan and motor

The fan and motor should be checked regularly to secure the performance. It should be checked that the fan is intact, e.g. no blades are broken, the ball bearing between motor and fan is not damaged or soiled. Furthermore, it should be checked that the fans turn in the right direction. If the fan and motor are not properly maintained it can lead to unstable operation and an increased electricity consumption..

1.9.2 Air channels

The air channels should be checked for leakages or damages regularly. These may increase the pressure or flow requirements of the fan or blower.
Besides checking the air channels for leakages and damages, they should also be cleaned regularly to decrease the system resistance.

1.9.3 Filters

Filters should be changed regularly based on a criterion for maximum allowable pressure drop, which should be monitored automatically, providing a signal when it is time for change. If filters are not changed regularly, they risk clogging, leading to an increased pressure drop which the fan must overcome by increasing speed. If this is not possible, the airflow in the system decreases instead.
Even though the filters are monitored automatically with regards to replacement, they should still be checked physically to ensure that none is teared leading to unwanted particles passes the filters.

1.9.4 Belts

As mentioned in section 1.4, belts should be avoided where possible. However, if belts are needed, they must be checked regularly to ensure their performance. Belts should be checked whether they have started to become loose and needs tightening or changing. If the belt has become loose, it starts to slip, the fan cannot provide the wanted airflow and the efficiency decreases significantly. Loose belts also risk breaking or hopping off the pulleys. Besides the belts, the pulley should be undamaged, and all bearings should spin freely without vibrations.

1.9.5 Damper

As mentioned in section 1.7 dampers should not be used to control the airflow. Instead, use a VFD. If dampers are used the mechanics should be checked regularly to ensure nothing is damaged and that it functions as wanted. If the dampers are designed to be able to fully open and/or fully close, check that this actually happens. If the damper has problems with the correct opening settings this can either lead to a decreased airflow in the system or an increased electricity consumption for the same airflow.

1.9.6 Control system

Ensure that the control system is regularly serviced, including cleaning of internal fans and filters. Update and back-up the system, and make sure that the graphics and component numbers are up to date. Verify that belts and the motors are in good condition, and that any speed chosen matches the one programmed by the control system.

1.10 Other energy savings possibilities

1.10.1 Reduce idling consumption

If the process that sets the air demand is idling or stopped, the air system should also automatically reduce airflow to a minimum or be turned off. A signal should be sent from the process control system to the system that controls the fans and/or dampers.

1.10.2 Improve fume hoods and suction points

Fume hoods, LAF-benches and other local exhaust ventilation systems represent a wide field of very specialized knowledge, but some general energy saving techniques will apply:

- If more extraction points are connected to one single exhaust ventilation it is common practise to signal the demand for air flow and pressure from each point to a controller that computes the total demand for airflow to both extract ventilation and very importantly also the system that supplies replacement air.
- Heat exchange from extracted air to replacement air is sometimes feasible, but one must be aware that the extracted air can be polluted in many ways, and even corrosive. To avoid cross contamination, heat recovery can be done using two separate heat exchangers coupled with a liquid circuit transmitting the heat from the one heat exchanger to the other. Such a system may also include a heat pump.
- Smaller extraction points connected to one single exhaust ventilation should always be equipped with automatic or manual closing-dampers that signal to the ventilation to stop when all dampers are closed.

Case 4: Replace centralised exhaust by separate point exhaust fans

A shoe factory in Ho Chi Minh replaced large exhaust fans with small exhaust fans for each grinding position.

Figure 1.10.1: Replace large exhaust fans with small exhaust fans

The large exhaust fan has an operating capacity of 24kW, vacuuming dust for 26 grinding positions, equivalent to an electrical power consumption of about 0.92 kW/ grinding position.

The factory has invested in an exhaust from each grinding position, including a small 3Hp exhaust fan motor, and a separate dust filter bag. The operating power of the fan is measured at about 0.33 kW/ grinding position. Corresponding to a savings potential of about 64%.	
Energy saving: 28,400 kWh/year	**Investment:** 260 million VND
Cost saving: 54 million VND/year	**Payback period:** 4.8 years

2 Selection and equipment of new fan and blower installations

The selection of a new fan or blower depends on volume flow rate, pressure, type of material handled, space limitations and efficiency. Besides choosing the fan or blower, another significant element is also to choose the correct control strategy for the specific purpose.

This section aims at providing guidance on selection of the correct type of fan and control strategi for a specific need.

2.1 Operational demand

Prior to ordering any new fan or blower, it is important to analyse the process demand and optimize it and one should therefore be precise with regards to air flow and pressure needed. For some cases, the airflow is dictated by the process requirements, e.g. determined from heat transfer rates or flue gas quantity to be handled. In other cases, like in process ventilation, the airflow is highly depended on the system build up. *This is described further in section 2.1.1*.

The precise system resistance is typically more difficult to predict or compute but non the less a very important factor for the system characteristic. In the optimum case a detailed analysis is performed to determine the pressure drop across length, bends, contractions and expansion in the duct system, pressure drops across equipment like heat exchangers, filters etc. This should be added to the pressure requirement to the process. During this process, the pressure drop should also be minimized as much as possible as described in section 1.5. With a known system characteristic, different operating modes can be developed and tested with the aim of implementing high energy efficient solutions.

It is often seen that large safety margins are added to such an analysis resulting in over-sized fans, which then operates outside its design point with a poor efficiency to follow. It is therefore important that the airflow and pressure are determined as accurate as possible to achieve the efficiency from a fan’s design point.

2.1.1 Process ventilation

Before buying a new fan for process ventilation, the system should be designed so the contamination is removed with minimized air to reduce the energy consumption during operation. Figure 14 illustrates different principles for process ventilation, *which are described further in section 2.1.1.1 to 2.1.1.5*.

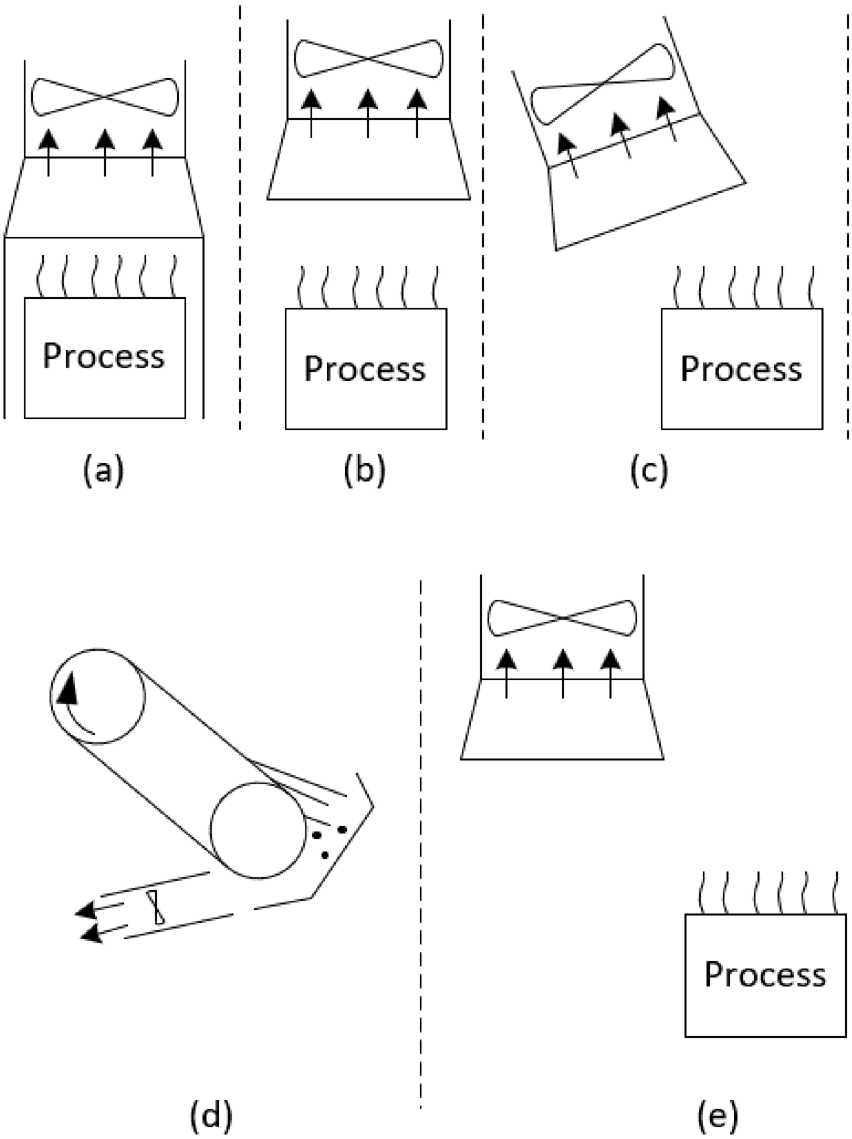


Figure 14 Illustration of different ventilation principles for processes. (a) is enclosed ventilation, (b) is receiver principle, (c) is the catch principle, (d) is the mechanic principle and (e) is the simple exhaust principle.

2.1.1.1 Enclosure principle - Figure 14(a)

The process is enclosed or partly enclosed and the fan extracts the contaminated air. In this case the contaminated air can only leave the enclosure through the ventilation system, see Figure 14(a). This principle is used for processes like melting.

2.1.1.2 Receiver principle - Figure 14(b)

In this case the extraction is located above the process, see Figure 14(b), which typically exist in a heating process like moulding machines, melting ovens, welding processes etc. where the air is heated in the process. As the contaminated air is heated in the process it will move upwards to the extraction point.

2.1.1.3 Catch principle - Figure 14(c)

This principle is best suited for processes with no heating as too much energy is used to overthrow the thermodynamic forces. If the sources are heated, the receiver principle should be used instead. In this principle a strong air current is created for the contamination to be collected at the extraction point, see

Figure 14(c). This is typically used at welding processes or to remove wood- and metal dust, together with vapours from processes.
In this case it is important that point of extraction is located close and directed towards the source.

2.1.1.4 Mechanic principle - Figure 14(d)

The mechanic principle is best fitted for dynamic contamination sources like a grinding machine. It is suitable where the particles are rather large and are thrown or blown down to a spark arrester and then exhausted by a fan, see Figure 14(d).

2.1.1.5 Simple exhaust - Figure 14(e)

In this principle, the extraction point is far from the source, which is typically seen where roof fans are used to extract heat or contamination from different processes, as illustrated in Figure 14(e). This is the simplest but also most inefficient method to remove contamination from a process as large air flows are needed to remove the contamination compared to receiver or catch principle.

2.1.1.6 Comparison

Figure 15 compares the energy consumption for different sources with different ventilation principles. As illustrated, the enclosure principle is generally the most energy efficient method and should be used where possible.

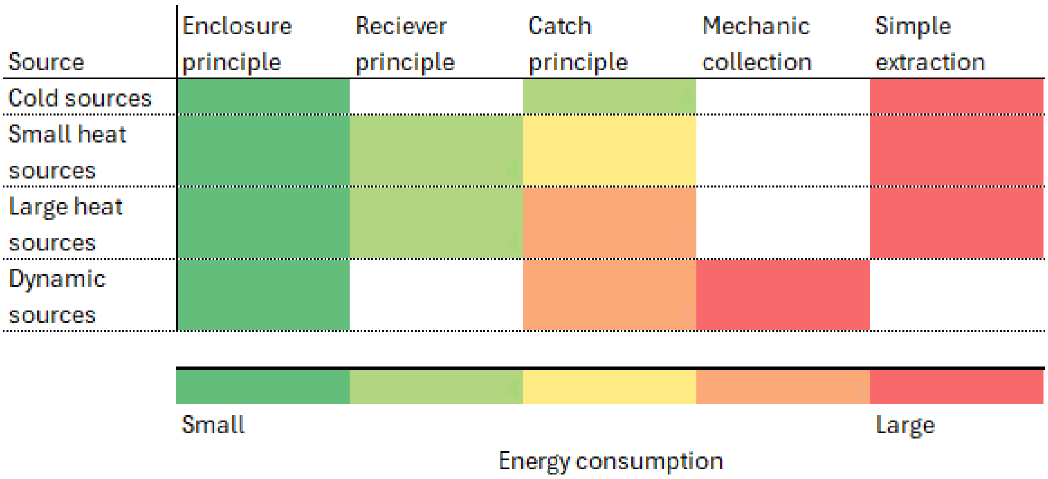


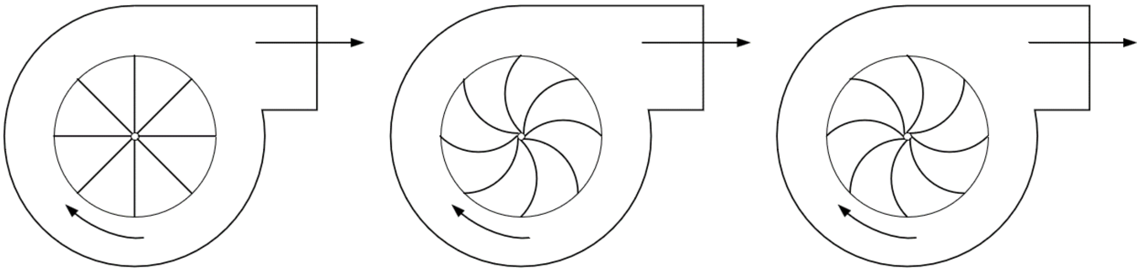
Figure 15 Rating of the energy consumption for process ventilation with different sources and principles. White cells mark that the principle is unfit to the source [3].

2.2 Technologies

2.2.1 Centrifugal fans

In centrifugal fans the air flow changes direction two times, once when entering and second when leaving. For centrifugal fans three major types exists:

- Radial fans
- Forward curved fans
- Backward curved fans



(a) Radial (b) Forward curved (c) Backward curved

Figure 16 Schematic of different centrifugal fans.

Radial fans, see Figure 16(a), are suitable where high static pressures are needed, and the air stream can be heavily contaminated. Due to simple design, these fans can work in high temperatures.

Forward curved fans, see Figure 16(b), are suitable in clean environments and operate at lower temperatures. This type is best suited for moving large volumes of air against relatively low pressures.

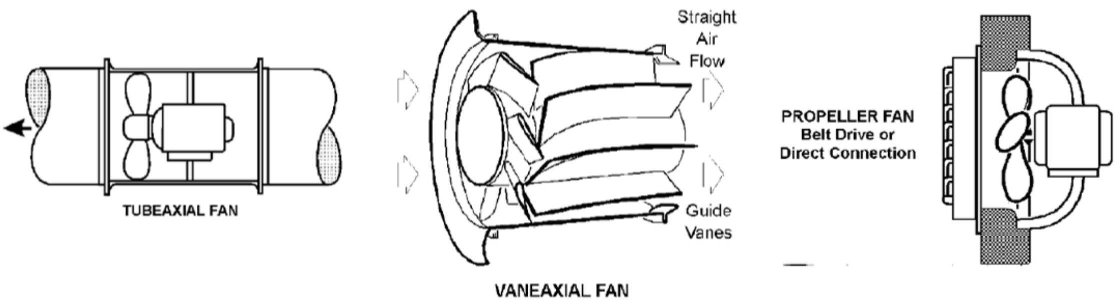
Backward curved fans, see Figure 16(c), are more efficient than forward curved fans, and can be suitable for cases where high pressure together with high medium flow apply. Due to the curved blades, this type is mostly suited for pure air or gasses as the dust and other particles can accumulate on the blades.

An advantage for the centrifugal fan is that the motor and drive is located outside the air stream meaning that they can be used for high temperature processes. The maximum allowed temperature is informed by the manufacturer.

2.2.2 Axial fans

With axial fans the air enters and leaves the fan with no directional change. For axial fans the major types are:

- Tube axial.
- Vane axial.
- Propeller.



(a) (b) (c)

Figure 17 Schematic of different axial fans [1].

As shown in Figure 17(a) for the tube-axial fan, the fan is surrounded by a housing to improve the air flow efficiency. As the wheel turns faster than propeller fans it enables operation under high pressures up to 4 kPa with an efficiency up to 65%.

Vane-axial fans are like the tube-axial fans but are more efficient due to the guide vanes. These fans can be used for pressures up to 5 kPa. Vane-axial fans are in general the most efficient ones and should be used where possible.

Propeller fans, see Figure 17(c), are suitable for low speeds and moderate temperatures. Typically, they are suitable for application where large volumes of air should be delivered with low pressure or free delivery, such as wall-mounted fans in industrial buildings. These fans work with an efficiency of 50% or lower.

For the axial fans, the motor and drive are located in the air stream, which, depending on the supplier, sets restrictions on the maximum allowed temperature in the duct.

2.2.3 Blowers

Blowers are used where pressure up to 120 kPa is needed and the major types are centrifugal blowers and positive-displacement blowers.

Centrifugal blowers typically operate against pressure of 35 kPa to 70 kPa. This type is typically used in applications where the risk of clogging is low, as the airflow tends to drop drastically when system pressure increases.

Positive-displacement blowers provide a constant volume of air without being affected by a variation in system pressure. These blowers can be suitable for applications prone to clogging, as they can provide pressure enough to blow clogged material free.

2.2.4 Choice of type

The choice of fan type is highly depending on the application. Centrifugal fans are suitable for low to moderate flows at high pressures, while the axial fans are suitable for low to high flows at low pressures. Another important point is to investigate the ventilator curve, which illustrates the ventilator performance in different operating conditions. Figure 18 shows the ventilator curve for a specific centrifugal fan from a supplier. From this, fan efficiency can be calculated for different airflows, speeds, and pressures and the fan with highest efficiency based in the specific operation point can be selected. In section 1.6 it is described that it is important to dimension to the actual operation point, and Figure 18 shows why. A change in required airflow or pressure can significantly change the total efficiency of the fan and hence the energy consumption for the specific fan.

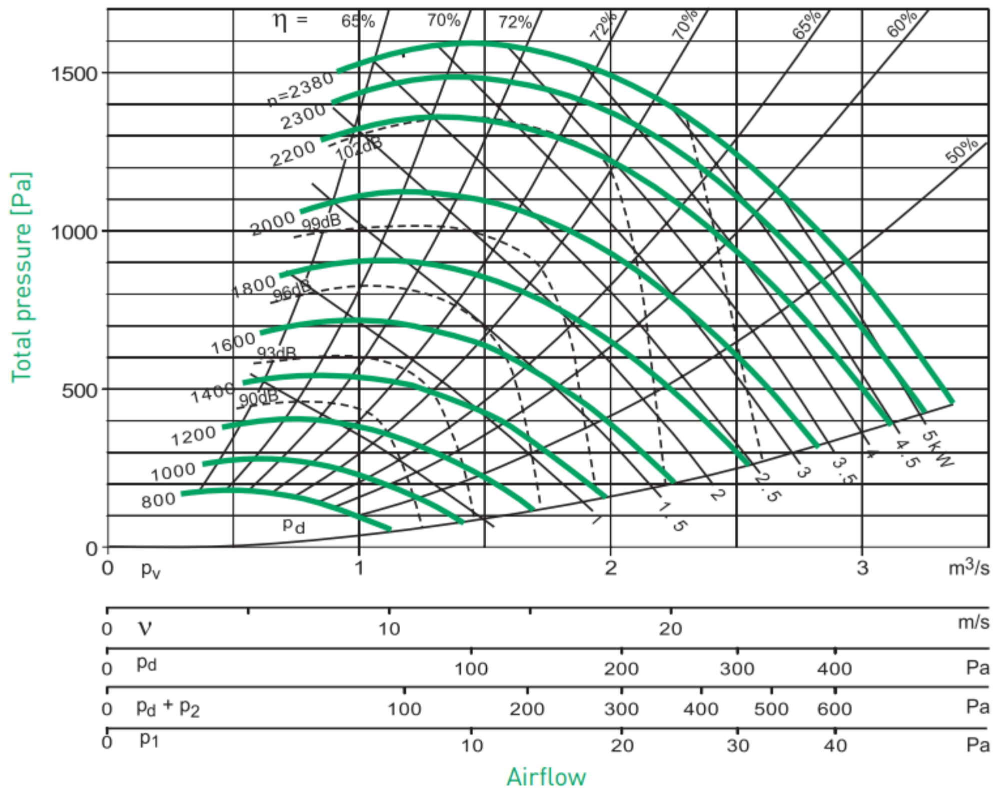


Figure 18 Ventilator curve. This is for a CNA-CNB centrifugal fan from Novenco [8].

2.2.5 Fan affinity laws

All fans operate under a set of laws concerning speed, power, and pressure. Changing the speed of a fan will change the pressure rise and power needed to operate with the new speed. Figure 19 illustrates what influence the fan speed has on flow, static pressure, and power consumption.

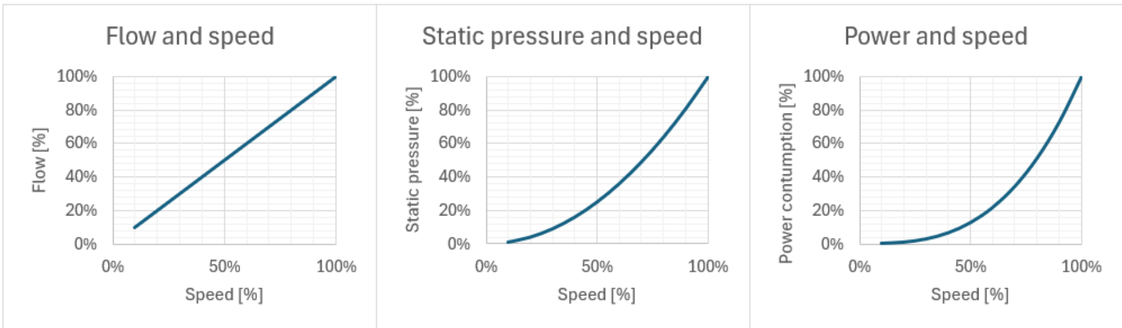


Figure 19 Fan speed influence on flow, static pressure, and power consumption [1].

Figure 19 are based on the laws shown below:

Flow and speed	Static pressure and speed	Power and speed
$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$	$\frac{SP_1}{SP_2} = \left(\frac{N_1}{N_2}\right)^2$	$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$

Where Q is the flow, N is speed, SP is static pressure, and P is power.

The shown laws demonstrate, before investing in new fans, the importance of performing an optimization study on how to reduce the airflow demand as a reduction in the airflow reduces the required speed. Reducing the speed can reduce fan power consumption to the power of 3 as shown. This gives a clear prioritisation when it comes to optimizing fan- and blower systems. This is also illustrated previously by Figure 11 and Figure 12.

2.2.6 Control systems

A well working control system (be it small and local or large and global) is essential for good system energy performance. The main issues in relation to control systems are:

- Check that the control system can control the fans as required, and that there is no mismatch between fan/motor/drive-sizes and the demand.
- The control system must be capable of using high- and low-setpoint values, as well as high- and low-alarm values. In addition, it should be possible to define hysteresis around high- and low-values as well as time constants.
- Work with as big an interval as possible between the high and low thresholds for any control value (especially temperature and humidity values if applied).
- Measuring the main airflow should be carried out by a permanently installed calibrated flowmeter with as little pressure drop as possible (e.g. vortex-, pitot- or hotwire-methods).
- Measuring the main pressure should be carried out by two permanently installed calibrated pressure transducers placed before and after the fan.
- Check that all measurements and signals from the system are displayed correctly on the automatic control system display. Typically, these include main airflow and pressure, differential pressures, motor power, signals from safety switches, differential pressure switches, and in some cases temperature and humidity values.
- Check that signals for controlling fan-motors, dampers, valves, pumps, and rotary motors result in the correct response at the components.
- Always use true signal feedback to the operators display. If calculated responses are used, it should be shown with a clear marking.

2.3 Duct design

The duct should be made with as few bends, elbows etc. to reduce the system resistance. Furthermore, designing the duct as round channels instead of square channels helps with reducing the system resistance. Regarding the velocity of air in the ducts the values in Table 6 can be used as guidance.

Table 6 Guidance for air velocity in ducts.

	Process	Material transport
Velocity of air	15 m/s	30 m/s

It is often seen that the inlet for a centrifugal fan consist of a bending as seen by Figure 1. This should be avoided as it adds pressure drop. If the duct is connected to the inlet of the fan, the duct must be straight.
The outlet for centrifugal fan is also often seen to add unnecessary pressure drop. It is important that the duct at the outlet follows the airs rotational direction to induce minimum losses. A bad design can reduce the fans efficiency with up to 10%.
If the air rotational direction is not followed at the outlet, it is important that a straight duct after the outlet is installed to minimize the losses. The length should be a least two times the hydraulic diameter.
Figure 20 shows different outlet designs for a centrifugal fan. Position A does not induce losses if the requirements to straight length between the ventilator outlet and bending inlet is followed. Position B does not induce losses. Position C and D induces a reduction of the fan efficiency of 10% and 5%, respectively.

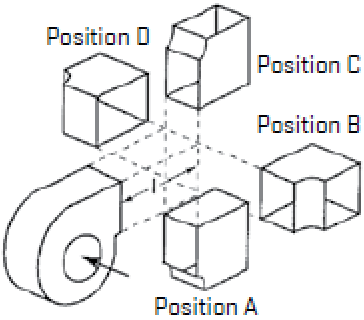


Figure 20 Outlet design for a centrifugal fan [3].

In general, the size of bending should follow the guidelines in Table 7.

Table 7 Guidelines for the size of bend radius in ducts [3].

	Guideline
Low pressure system	Bend radius ≥ duct diameter
Medium and high-pressure system	Bend radius / duct diameter ≥ 2

2.4 Other thing to consider

2.4.1 Fan housing

The fans performance also depends on the fan enclosure and duct design. Designing the housing with inducers/diffusers are more efficient as compared to square housings. Furthermore, the inlet and outlet conditions, e.g. whirl and turbulence created by grills, dampers etc., can significantly influence the fan performance curve from the manufacturer. Likewise, can bend and elbows in the inlet or outlet change the velocity of air and thereby change the fan characteristics. These factors should be evaluated during fan selection as they would influence the fan performance curve.

2.4.2 Air temperatures

The air inlet temperatures are also an important consideration, as the temperature affect the density of air, which affects the volume flow rate and the fans capacity to develop pressure. It is therefore important, if temperatures change significantly, that this information is provided to manufacturer to take into consideration during the fan design.

2.4.3 High temperature processes and gasses

It is important for the manufacturer to know the temperatures at which the air and gasses enter the fan or blower with, like it also is important to know the composition of the gas. These factors influence the choice of material that the fan should be constructed from to secure the lifetime for the fan.

2.4.4 Dust

If dust particles are expected in the ducts, the manufacturer should know the expected concentration of dust and the nature of dust as this has influence on the material choice for the fan or blower.

2.4.5 Grid connection

The available power connection should be provided to the manufacturer to secure that the fan can be connected to the grid. Furthermore, the voltage and type of motor should also be specified to eliminate problem of compatibility between the fan and the electric network.

2.5 How to proceed

Section 2.1 to 2.4 gives a brief overview of subjects to consider when ordering a new fan or blower.

The main points can be summarized as follows:

1. Firstly, optimize the need for airflow and reduce pressure drop.
2. Be as accurate as possible with regards to the air flow and pressure the fan or blower should deliver.
3. Prepare information with regards to air flow, pressure, dust, grid power, and air and process temperatures.
4. Go through the points in section 1 of this document to check if all the new equipment and solutions are the best available. It is when installing new equipment that energy efficient solutions are the cheapest and easiest to build in.

3 The procurement process for new fan and blower systems

The procurement process for new fan and blower systems is mostly related to the maintenance and replacement of worn-out equipment and the process is therefore rather simple. However, it should still be investigated whether a more optimized solution exist and if it is feasible under the present conditions. This section describes the process for investing in new equipment.

To do this, the procurement process should follow the steps below:

1. A pre-feasibility phase.
2. A feasibility phase.
3. A tendering phase
4. A tender evaluation phase.

Later steps when implementing, testing, and commissioning the fan or blower system are not described in this context.

3.1 Pre-feasibility phase

The aim of the pre-feasibility phase is to define the project to carry out and evaluate alternative overall solutions so as it can be concluded what the most attractive way forward will be.

The dilemma most industries must challenge in this phase is whether to select a cheap, low-efficient solution or a more expensive and more efficient solution with lower operating costs. It is recommended to assess these alternatives carefully and well documented for the management to make the right choice.

Another consideration to be made before the purchase process commences is whether the current set-up in the production will also be the right one in the future.

The easiest way forward will most often be to install new equipment without further consideration, but more careful investigations might uncover alternative solution strategies. As such, a pre-feasibility phase should carefully assess and document the design basis for the project and compare various elements in the solution strategy, by example:

1. **What is the purpose of the project?**
   It is important to be precise about for which reasons a new fan or blower installation is to be considered.

   As previously described, the most common reasons for initiating a project for new fans or blowers are due to high maintenance costs or that the equipment is worn-out.

   New fans or optimization of current system can however also offer a range of other benefits, such as:
   - Reduced operational costs (including energy, staff, and maintenance).
   - Airflow to match better with the demand.
   - Improved working environment.
   - Reduced carbon footprint
   - Compliance with current regulation
   - Increased market value of the product as a result of lower environmental impacts.

The combined value of these benefits could very well supersede the value of the energy cost savings. It is important, therefore, to consider these already in the pre-feasibility study and highlight those that are deemed most important.

But also, a strategy to become more energy- and cost efficient or to reduce carbon emissions can be the reason for starting a project.

2. **What is the scope of the project?**
   A fan-project might be simple replacement project, i.e. a replacement of a worn-out fans, dampers, ducts etc. However, it can also be due to a new system needs to be installed, e.g. a production site is expanding with a new spray dryer or existing process ventilation system is expanded, the control strategy is to be changed etc.

   During the early phases, the expected scope of the project shall be described.

3. **Which demand is to be covered?**
   A careful investigation of the demand shall take place to make sure that the new equipment is dimensioned properly and that the air demand or pressure demand have been reduced as much as possible.

   If a fan is worn-out, it is important to assess if a new fan should be designed like the old one or if it possible to optimize by firstly assess whether it is possible to reduce energy consumption by a different control strategy or different duct design as it is described in section 1. It should also be assessed whether the operation point has changed from the old fans design point, which is often the case.

4. **Which technology to use?**
   There are multiple technologies and ventilations principles to choose between when selecting a solution. These will greatly impact the overall environmental footprint of the project.

   Use the purpose to choose between fans, control strategy, duct design, etc. Figure 21 illustrates how the costs distribute over the years for new equipment, showing how the energy and operation cost will increase during the lifetime. It can therefore make sense to invest in the more efficient technology, even though it is more expensive, to reduce the energy and operation cost over the lifetime and improve the TCO of the investment.

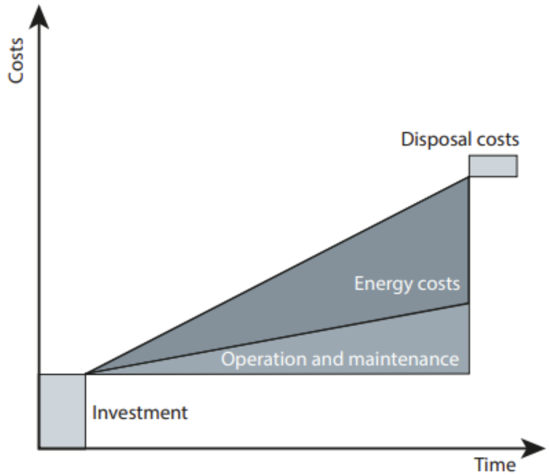


Figure 21 Illustration on how the costs distribute over a new equipment's lifetime.

When the above has been assessed, a fairly accurate investment budget (CAPEX and OPEX) should be made, so that the management can allocate funds for the project. Furthermore, documentation of the current energy performance should be gathered to be able to compare the energy performance after the installation and conclude whether the energy saving is realised.

A pre-feasibility report must describe the purpose of the project, the design basis for the project and expected investments (CAPEX) and expected operation costs (OPEX) should be assessed for each alternative solution identified.

As such, the pre-feasibility report shall describe the business case for the project including relevant alternative solutions. The business case shall include an assessment of Total Cost of Ownership (TCO) for alternative solutions calculated as NPV.

The report shall be presented for the management in the company to decide on further steps, and often it should also be recommended to initiate a dialogue with the bank regarding financing options for alternative solutions. Some banks will have attractive loan and financing options for sustainable solutions, which should be identified already in the early stages of the project development as this can have significant impact on financing costs etc.

Based on meetings with the management, the next steps should be decided. The scope of the project shall be described in a concluding memo and the feasibility phase initiated.

3.2 Feasibility phase

The aim of the feasibility phase is to carry out a pre-liminary solution design for the preferred solution and make a fairly accurate investment budget (CAPEX and OPEX) so as the management of the company can allocate funds for implementing the project.

The following is more crucial for large projects including new fans, ducts, filters, control etc. In a project where only the fan or a VSD has to be replaced, the investment is in a size where it typically can be covered by the maintenance budget.

Input and knowledge of suppliers are important and beneficial when carrying out the feasibility study and can also give new inspiration to the configuration of the fan or blower system and the preferred solutions. Further, vendors can assist with more accurate budget prices.

The feasibility study and the following feasibility report must include all elements necessary to achieve the most optimal solution and may include topics such as:

- Project scope
- Detailed description of the project
- Optimizing the demand to cover
- Optimization of total cost of ownership (TCO) over a ten-year period
- Financial analysis, i.e. investment and operation costs (CAPEX and OPEX)
- Financing options (E.g. subsidies)
- Assessment of impacts on the operations of the enterprise
- Assessment of other impacts
- Project risks
- Overview of approvals and legislative framework
- Time schedule for implementation
- Project organization incl. preferred suppliers
- Recommendations for next steps

The outcome of the feasibility study is a report to be used as basis for the management's decision on the investment.

Finally, the feasibility study shall be presented to the management to get approval of funds for the investments (CAPEX).

3.3 Tendering phase

Based on the feasibility study and approval of CAPEX from the management, the detailed project preparation will comprise a number of phases.

3.3.1 Final scope definition

The exact scope of the contract must be established, and the following items will usually be included:

- Complete fan-installation
- Electrical connection
- Control strategy and system (Interface to current control system)
- Delivery and assembly
- Insulation
- Commissioning (in close cooperation with the owner)
- Trial operation
- Noise measurement
- Documentation incl. energy performance and savings
- Hand-over and final project conclusion
- Spare parts and service contract (option)

The list above is highly dependent on the actual project being performed. For the trial operations it is important to adjust the operating parameters to develop the optimal working mode for the current system. This can help define results for flow rate, pressure, power consumption and efficiency and in addition provide information regarding the scalability of the proposed solution. This information can be used by the management to setup the correct and efficient operational strategies.

3.3.2 Technical specifications

The requirements to equipment must be described unambiguously. It is particularly important to describe the overall delivery performance:

Environmental:

- Noise requirements

Functionality
- Airflow and pressure provided.
- Total efficiency of the fan
- Max electrical consumption (at 100% load).
- Ducts should be free for leakages (If new ducts are installed)
- Control strategy.

Definition of how the performance test shall be conducted. It is important to be very specific to avoid discussion on methods, timing, sampling, calculation afterwards.

It shall also be described how deviations shall be handled and what shall be fulfilled before a handover can take place. This is more crucial for a large project where new systems are installed compared to only replacing the fan or switching from a damper to VSD.

3.3.3 Performance guarantees

Before setting the conditions for the performance guarantees it is important to evaluate the operation conditions to make sure that it is possible to make the test runs.

3.3.4 Service contract

Taking spare parts and service of the fan-installation into the contract will result in a fair price for the operation in the coming years.

3.4 Contracting phase

The quotation evaluation has two main purposes:

- Identifying deviations from the tender documents
- Making the tenders comparable enabling price negotiations

In the technical clarification, it is important to take a deep dive in the two most attractive quotations to ensure that there are not misunderstanding and deviations from the tender documents which are not immediately apparent.

After this clarification and final price negotiation, a contract can be completed.

3.5 Later project phases

It is important to follow the installation and commissioning phase closely to monitor whether important design decisions in the feasibility and tendering phase are followed through.

After the project have been installed and been operating it is important to conduct a general evaluation. To do so it is important to collect and document the new energy performance. This is both in relation to the performance guarantees but also whether the energy saving have been achieved as it may have been one of the main reasons for the project to initiated in the first place. The evaluation of the project could for example cover:
- Did it deliver the calculated energy reduction?
- Was it finished within the budget?
- Does the new system function as wanted?
- Does there exist further optimization potential, which can be investigated later?

References

[1] Energy Efficiency in Electrical Utilities, Guide book for National Certification Examination for Energy Managers and Energy Auditors, Bureau of Energy Efficiency.

[2] Eco-design requirements for fans driven by motors with an electric input power between 125 W and 500 kW.
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02011R0327-20170109
Accessed 24-06-2024.

[3] Den lille blå om ventilation. Dansk Energi
https://elforsk.dk/udgivelser
Accessed 24-06-2024.

[4] Eco-design requirements for electric motors and variable speed drives
https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02019R1781-20230124
Accessed 24-06-2024.

[5] IE5 Motors: The Importance, The Benefits and How We're Using Them
https://www.dutypoint.com/ie5-motors/
Accessed 24-06-2024.

[6] Workstream 1 Report, Danida & Low Carbon Transition Unit (LCTU)

[7] Best Available Techniques (BAT) Reference Document for the Food, Drink and Milk Industries
https://eippcb.jrc.ec.europa.eu/reference
Accessed 24-06-2024.

[8] CNA-CNB Centrifugal Fans Standard Temperatures and Ex
https://www.novenco-building.com/media/1333/cna-cnb-cat-gb-mu15544-0517.pdf
Accessed 25-06-2024.

Appendix. Available suppliers

No.	Company name	Address of factory	Website	Ventilation type
Domestic suppliers				
1	Chau Phu Company Limited	Lot A110, Road No. 2, Thai Hoa Industrial Park, Tan Hoa Hamlet, Duc Lap Ha Commune, Duc Hoa District, Long An Province, Vietnam	http://www.chauphu.com/	Industrial fans, ventilation system
2	Nam Tien Production Trading Industrial Equipment Company Limited	182/1G Tan Thoi 3 Hamlet, Tan Hiep Commune, Hoc Mon District, Ho Chi Minh City, Vietnam	https://hutbui.vn/	Exhaust fans, ventilation components & systems
3	Hai Yen Technology Engineering Joint Stock Company	103 Pham Van Chieu, Ward 14, Go Vap District, Ho Chi Minh city	www.hytech.vn	Central Air Conditioning, Ventilation, Industrial Refrigeration
4	Nghe Nang Industrial Co., Ltd	No. 77, Road DT 743, KP. Dong Tac, Tan Dong Hiep Ward, Di An city, Binh Duong Province.	https://nghenang.vn/	Exhaust fans, ventilation components & HVAC systems
5	Dai Phong Electromechanical Company Limited	No. 6/9 Do Van Day, Tan Hiep Ward, Hoc Mon District, Ho Chi Minh City (HCMC)	www.quatdaiphong.com	Industrial fans, cooling system
6	Phuong Linh Production, Trading and Electromechanical Company Limited	Southern Branch - Phuong Linh 4 Electronics Center: Address: No. 28/9 Truong Chinh, Tan Thoi Nhat Ward, District 12, HCMC	https://phuonglinh.vn/	Industrial fans, ventilation, cooling system
7	Global Industrial Equipment Joint Stock Company	No. 134 Hang Bac, Hang Bac Ward, Hoan Kiem District, Hanoi City, Vietnam	https://quattoancau.vn/	Industrial fans, ventilation, cooling system
8	Duc Phong Technology & Automation Corporation (Dpta)	161 Ngo Quyen Str., Hiep Phu Ward, Thu Duc City, Ho Chi Minh city, Vietnam	www.dpta.com	Ventilation, cooling system
9	Viet Sun Trading and Service Engineering Company Limited	Highway 51, Tan Hanh Quarter, Phu My Ward, Phu My Town, Ba Ria Vung Tau Province	https://bangtaivietsun.com.vn/	Ventilation, cooling system
Internaional suppliers				

10	Nederman Vietnam Company	16 Dang Tat, Tan Dinh Ward, District 1, Ho Chi Minh City (HCMC)	https://www.nederman.com/	Fans, industrial dust extraction systems
11	Duy Anh Equipment Import and Export Company Limited- Official Representative of Donaldson in Vietnam	No. 86, Le Trong Tan Street, Khuong Mai Ward, Thanh Xuan District, Hanoi City, Vietnam	https://donaldson-vietnam.vn/	Components of ventilation systems
12	Venti Oelde Ventilatorenfabrik Oelde GmbH	Robert-Schuman-Ring 21, D-59302 Oelde, Germany	https://www.venti-oelde.com/products	Industrial fans
13	HOWDEN SOLYVENT VENTEC	69330, Auvergne-Rhône-Alpes, Meyzieu, France, No. 1E Nguyen Van Thu, Dist. 1, HCMC, Vietnam	https://www.howden.com/	Industrial fans HVAC
14	EuroVent Fan	TN Metal Works Company Limited 92/1 Moo.7 Petchkasem Rd., Omnoi, Krathumban, Samut sakorn 74130	http://www.euroventblower.com/	Industrial fans HVAC
15	Reitz fans (Reitz Holding GmbH & Co.)	Konrad-Reitz-Straße 1, D-37671 Höxter-Albaxen, Germany	www.reitzgroup.com	Industrial fans