Fan System Energy Efficiency Optimization Management and Technical Guide

The five key points for energy-efficient air system:

- Less resistance: short, large, round and dense air ducts, no unnecessary resistance of chokes, shape and cross-sectional changes, etc.
- Less air: accurate estimation of the required air flow, cold/heat and humidity, demand-dependent operation (no demands, no operation).
- Variable volume flow and controllable drive for variable air demands
- All components operate in optimum efficiency range.
- Efficient motor with direct transmission (without belt and gearbox).

1. Introduction

1.1 Introduction and target audience

This guide deals with the mechanical ventilation of air with fans and aims to help reduce their electricity consumption. Fans are turbomachines which convey a gaseous media with impeller. It is driven by electric motor, often connected with a transmission (belt or gearbox) and sometimes installed frequency converter to regulate the speed.
The principles of this leaflet apply to all ventilation systems. However, the content is focused on medium-sized ventilation systems with volume flows above 1000 m3/h. The main application area is medium-sized facilities for large commercial service and residential buildings as well as industrial ventilation systems.
Comfort ventilation systems (for example for single-family homes), toilet exhaust and kitchen fans or very large installations (for example for tunnels) are not covered in this guide. The treatment of air for the air conditioning of rooms (heating, cooling, humidification and dehumidification) is not an explicit topic of this guide either.
The target audience are primarily ventilation system builders, planners, technicians and engineers.

1.2 Tasks of the fan system optimization participants

Ventilation technology experts play central role in achieving optimal mechanical air delivery. At the same time, it is important that everyone should be involved. At the client side, through the planning teams and entrepreneurs to the operators should be involved and carry out their tasks and contribute their competences. A key fact is that the right decisions should be taken early - earlier than usual in practices.

Orderer and builders (ordering competence)

- Clear commitment to energy efficiency
- Decisions based on life cycle costs rather than on the basis of pure investment costs.
- Declaration of general specifications and legal requirements, etc.
- Definition of specific requirements, e.g. limit or target values according to technical standards, etc.
- Good system assessment goal and methods: A good system can be assessed by the specific fan power combined with the need to optimize demand, control and operation. Electricity consumption can serve as a control for compliance with these requirements.
- Determination of responsibilities: identify the appropriate expertise in strategic planning and preliminary studies, if necessary involving a client advisor.

Architect(Purchaser and Planner Expertise)

- Clarify demands specifications of the client
- Ensure that the contracts contain clear targets
- Engage the engineers in determining the spatial building services concept (shaft concept, short lines, sufficient space)
- Ensure the communication between planner and entrepreneur: depending on the contract control of the objectives

Ventilation engineer (expertise)

- Clarify demands specifications of the client
- Design system components on the basis of a pressure loss calculation
- Clarify specifications in the tenders for energy efficiency
- Define concept for commissioning, acceptance, maintenance and operation, etc

Entrepreneur (component and system supplier)

- Clarify demands specifications of the client
- Commission measurements of energy efficiency
- Develop instruction and maintenance plan

Operator

- Take, read and understand the instructions and documents
- Maintain regularly
- Record energy consumption regularly
- Optimize operations
- Operate in demand-oriented way
- In case of changes: initiate the updating of the planning documents and the plant documentation

2. Components of fan system

2.1 Fans

Fans are flow machines which convey gaseous media by impeller. Pressure increase is generated between the inlet and outlet sides. Machines with a pressure increase (pressure ratio between 1.1 and 3) are referred as blowers, while machines with a very large pressure increase (pressure ratio of more than 3) as compressors.
The most important types are the centrifugal fan and the axial fan. The axial fan sucks the air axially and conveys it axially. The centrifugal fan sucks the air axially and delivers it radially.

2.2 Motor

The fans are usually driven by electric motors whose efficiency classes are differentiated according to IEC 60034. Depending on the required speed of the drive, asynchronous motors with the following number of poles can be used (nominal synchronous speed in revolutions per minute).

Table 1 Motor poles and nominal synchronous speed

Poles	nominal synchronous speed (RPM)
2	3000
4	1500
6	1000
8	750

The efficiency classes of motors with outputs between 0.12 kW and 1 000 kW comply with IEC standard 60034-30-1 (Figure 2). At low power levels up to 10 kW, the efficiency gains from IE4 to IE1 are very high in percentage terms. For larger outputs from 100 kW to 1 000 kW, the percentage improvements are small, but the reduction in losses in kW is very significant. The highest efficiencies can be achieved with electronically commutated permanent magnet and reluctance technologies.

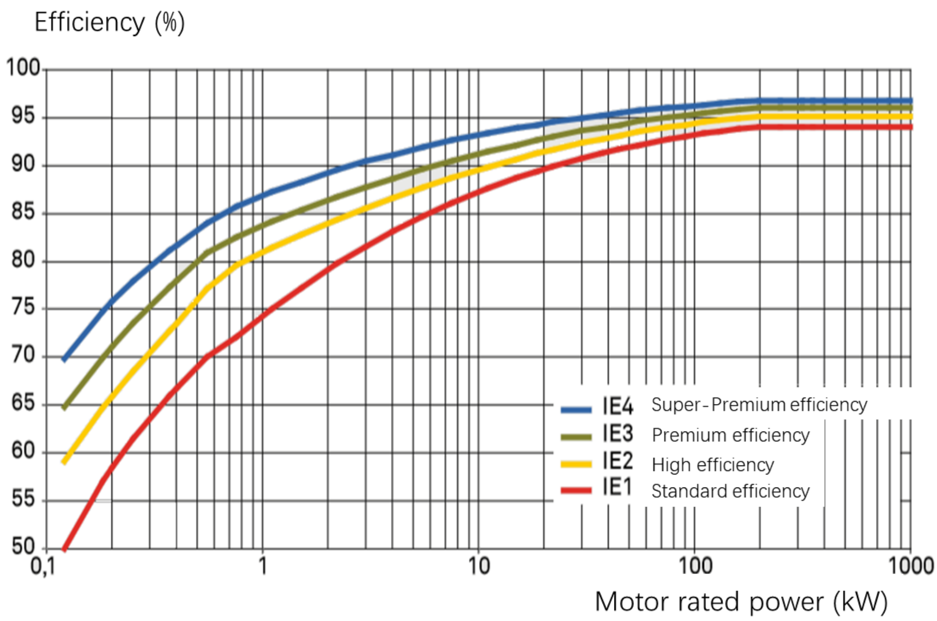

Figure 1 IEC IE Motor Energy Efficiency Classification

Note: More efficient motors (IE3) have less slip than old inefficient motors (IE1 or IE2), which means their speed is 1% to 5% higher. This can lead to the undesirable effect that a correspondingly higher volume flow is produced by the replacement of high efficient motor. With the same air network, the flow velocity increases. Since the electrical power requirement increases with the 3 times power of the air volume flow, the efficiency gain with the new motor can be lost again - without compensating for this effect. This negative effect can be easily avoided by better selection of the replacement fan or adaptation of the transmission ratio.

2.3 Transmission

The motor power is transmitted to the fan by direct drive, flat belts, toothed belts or V-belts

Direct drive

The direct coupling of motor and fan shaft is lossless and therefore has the best efficiency (100%). Other advantages are: maintenance-free and no pollution caused by belt abrasion. **Fan systems below 5 kW should choose this solution if possible.**

Figure 2 Flat belt transmission

The efficiency of flat belt is typically 2 to 5 percentage higher than V-belts. Other advantages include lower maintenance (less belt change) and lower abrasion. This may not require a second stage filter after the fan. Although flat belts need to be changed less often than V-belts, checking the belt tension is more demanded.

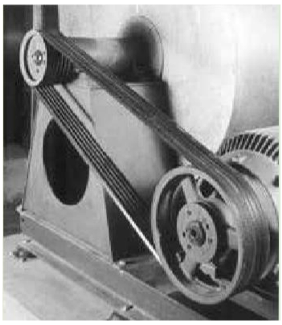

Figure 3 V-belt transmission

V-belt might have the most popular applications in fan systems. At low power and at partial load, its efficiency can fall below 80%. Another disadvantage is the frequent belt change. Because of the abrasion, a second stage filter after the fan might be needed to meet the requirements. Because of these disadvantages mentioned above, V-belts should be avoided. For small systems, direct drives are to be preferred. For larger capacities, flat belts should be chosen.

Figure 4 shows examples of transmission efficiencies of V-belts and flat belts at part load. With multiple belts, the efficiency per additional belt is reduced by about 1%.

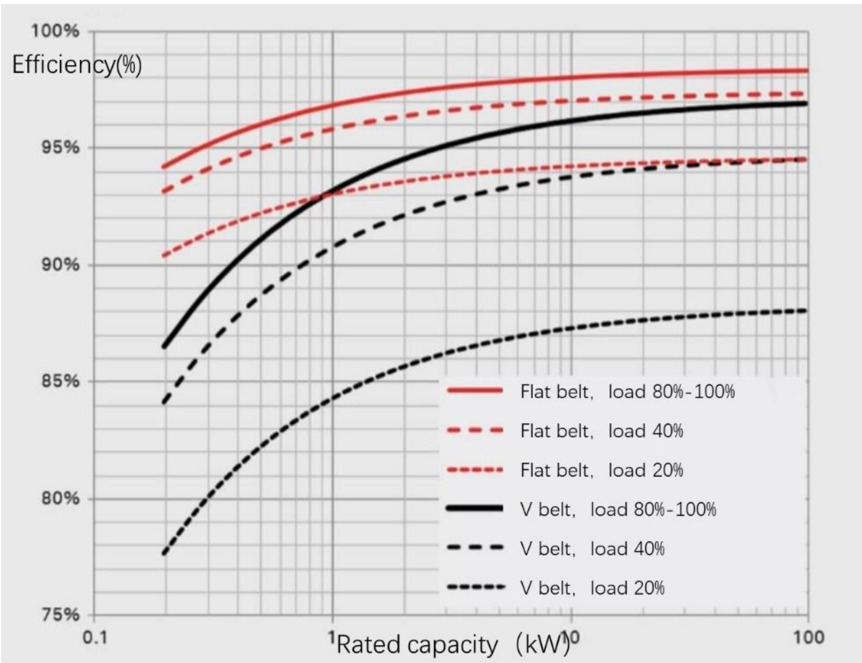

Figure 4 Efficiency of V-belt and flat belt at partial load

2.4 Variable Frequency Drive (VFD)

A VFD converts input power with a frequency of 50 Hz current (single-phase with low power) into a current with variable frequency. **This can be adapted to the application variable ratio of voltage and frequency are programmed. For media conveyance, the stress (decisive for the magnetization) is disproportionately reduced as the rotational speed decreases, because the load of a turbomachine decreases with the third power of the rotational speed (Figure 5).**

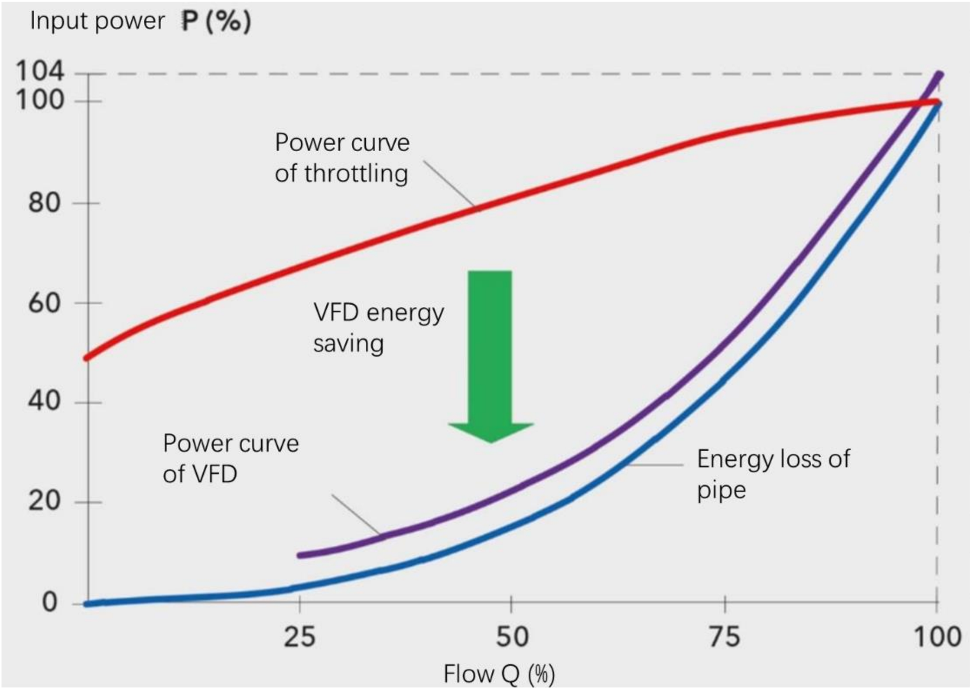

Figure 5 Energy Saving of VFD in fan system

Disadvantages of VFD

VFD is not always perfect (Figure 6):

- A VFD costs about the same as the motor working with it.
- VFD efficiency is 95% to 98% at nominal load.
- The harmonics from the VFD can reduce the efficiency of the motor by 1% to 2%.
- At partial load below 20%, the efficiency drops from 70% to 20%, depending on the size of the motor or VFD.

Because the output power of frequency converters is not quite sinusoidal (even with filters), the remaining harmonics cause additional losses in the motor. This effect must be taken into account in a profitability calculation.

Motor cooling: at low speeds, the internal cooling of the motor (impeller) may be insufficient, because losses in the motor can still be quite high due to the harmonics brought by the VFD. A motor that runs at below 50% speed for longer periods of time with VFD needs independent cooling of the motor (for example, forced air cooling or water cooling).

Motor operation via VFD only makes sense if actually variable outputs and speeds over a significant part of the operating time are required. If this is only necessary for the machine startup, you may find other solutions. In some cases, it may also make sense to bypass the drive at a predominantly constant speed (bypass) and only start the VFD for the motor if necessary.

Special consideration for speed control

Electromagnetic fields (EMF): VFD causes relatively high EMF. In order to avoid interference with other devices and to comply with the regulations, appropriate filters or shields are required. The closer the motor and the VFD are assembled, the easier to control the EMF. Therefore, VFDs are often assembled with the motor rather than being separately located in cabinets.

2.5 Tender Instructions of fan systems

Principles

- Demand professional planning with pressure loss calculation as the basis for the tender.
- Determine the efficiencies of the components at the best point or in the expected operating points.
- Determine how to assess efficiency differences in tenders.
- Determine control measurements and penalties for non-compliance.

For energy efficient operation, it is essential that the actual operating points of the fans are close to the best point. Therefore, the expected operating points must be determined and declared with a reliable pressure loss calculation. For variable speed operation applications, it is appropriate to indicate typical operating points with their frequency. On this basis, the different offers can be compared and evaluated.

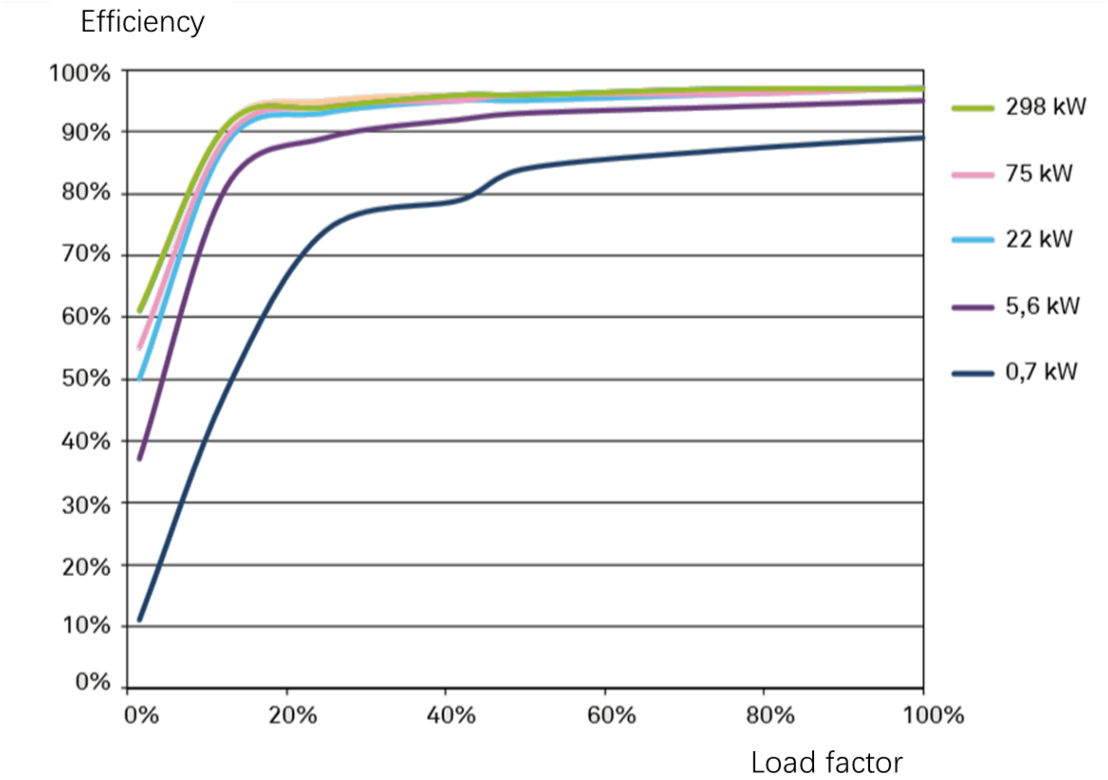

Figure 6 Motor load factor and efficiency

3. Energy requirement of air system

The energy requirement for air delivery with electrically driven fans is calculated according to the formula:

$$E = \frac{q_v \cdot \Delta p \cdot t}{\eta_v \cdot \eta_{Tr} \cdot \eta_M \cdot \eta_R}$$

E Electrical energy demand in Wh
q_v Volume flow in m3 / s
Δp Total pressure difference in Pa
t Operating time in h
η_v Efficiency of the fan
η_{Tr} Transmission efficiency (V-belt or flat belt)
η_M Motor efficiency
η_R Control efficiency (Frequency converter)
The result of the four components efficiencies is often summarized to the total efficiency η_{ges}. For multi-stage systems and for systems with variable volume flow, consideration must be taken separately for the various operating states. To achieve low energy consumption, the quantities q_v, Δp and t have to be minimized to maximize the efficiencies.

3.1 Appropriate air flow rate

Principles

- For human beings ventilation systems (living, working), calculate the air flow according to the outdoor air rate per person.
- Reduce heat, pollutant and moisture load in the room.
- Do not lose large heat loads through ventilation system, but check to the use of a water cooling system or a local recirculation cooling system. Ventilation systems for residential and office buildings are to be dimensioned for outdoor air rates per person.

The air volume flow required for heat removal of the ventilation system depends on the heat load and the temperature difference between room air and supply air.

3.2 Small pressure drops

Principles

- Short air network length

- Reduce air velocities to slower
- Apply streamlined network design (round air pipes, less fittings, streamlined fittings)

The arrangement of control panels, exhaust air inlets and shafts has a significant influence on the length of air network. The associated decisions must be made in very early planning phase. Additionally, decentralized solutions are limited by the maintenance requirements and hygienic requirements. To minimize the pressure losses, pay attention to low air velocities. The following reference values can be found in SIA 382/1 paragraphs 5.7.2.6 and 5.7.2.7: Under the utilization of the already existing pressure levels, higher air speeds are allowed. With a streamlined design, the pressure losses are significantly lower than unfavorable shapes.

- With the same area, same flow velocity and roughness, the lowest pressure losses are achieved with round air ducts. Rectangular channels become less favorable as the width-to-height ratio increases (Figure 8). At the same air speed and same cross-section area, a rectangular channel leads to about more than 50% higher pressure loss than round air channel. With the same air consumption (volume), the air cost is greater. Whenever possible, circular or square air ducts should be used. If rectangular air ducts have to be used, the air velocities should be reduced by a factor as shown in Figure 9 to reach the above benchmarks.
- Deflections should be carried out with the largest possible radius. If e.g. a 90° bend is made with a ratio of the mean radius R to the diameter D of 1.0 instead of 0.5 (no inner radius), the pressure loss will be reduced to about one-third. With R/D = 3 instead of 1, a further 50% pressure loss reduction is achieved. Pipe bends should be consisted of as many segments as possible and should have the largest possible ratio of R/D too. For rectangular air ducts, shallow channels are much less favorable than square or edged ones. Of the examples with 90° deflections shown in Figure 10, the worst solution with $\varsigma = 2.1$, has 14 times higher pressure loss than the best solution with $\varsigma = 0.15$.

The consideration of these connections requires professional and early planning of the air network with pressure loss calculation. In systems with air treatment units, the internal pressure losses often have the same order of magnitude as the external losses.

3.3 Operating time adapted to the requirements

Principles

- Adjust the air flow to the actual requirements.
- Adjust operating times to actual needs.

In many applications, e.g. for rooms with variable occupancy, the air requirement depends on the actual use. In these cases, energy consumption can be significantly reduced by adjusting the airflow to the actual demand. For variable occupancy, air flow regulation based on the concentration of CO_2 or mixed gas in the room is recommended. It is essential to note that the system zoning or volume flow control planning concept should take these requirements into consideration. In other applications, a control strategy based on the temperature, humidity or pollutant concentration or timer may be appropriate. The air systems should only be operated if the supplied rooms are actually used. It is therefore always necessary to provide appropriate control of the systems.

3.4 High efficiencies

Principles

- High efficiencies of fan, transmission, motor and frequency converter
- Consideration of efficiencies at actual operating points
- Consideration of the overall system efficiency.

For applications with a constant operating point, make sure that it is close to the best point of the fan. For multi-stage or variable-speed applications, the best solution should be determined by the available operating points and their frequencies.

4. Planning energy-efficient air transport

The implementation of the information given above is necessary for the construction and operation of lower power and energy requirements for ventilation with fans. Essential prerequisites are determined at very early stage. It is therefore important that these aspects are dealt with at very early stage of the project. It is also highly recommended that performance review and periodic review and optimization is performed after completion of the work.

The Four Most Common Obstacles to Energy Efficient Air Delivery

- Insufficient space, long and complicated air ducts
- Incorrect, missing or over dimensioning
- Insufficient adaptability to variable usage conditions
- Choice of low efficient components due to low awareness or the exclusive consideration of initial investment costs

4.1 Insufficient space

For air delivery with low pressure loss, the air speeds have to be small and the distances have to be short. Small air velocities mean large cross-sectional areas. Ensuring the space requirement has to be taken consideration at early planning. In addition, the space requirements for good accessibility of the apparatuses with the control panels must be taken into account. The first information on the space requirements for ventilation and air conditioning systems can be found in Annex E of SIA 382/1. The demand for short distances requires a well-considered arrangement of the central, outside air sockets and exhaust air openings and a coordinated shaft. This concern can only be met with an early planning.

4.2 Incorrect or missing dimensioning

Fans, motors, belt transmissions and frequency inverters reach their levels of effectiveness in a defined range. It is therefore important that these components are selected correctly. Incorrect or missing dimensioning can result in significant loss of efficiency.

4.3 Inadequate adaptation to variable usage conditions

Many applications have variable usage conditions. With on-demand operation, significant energy savings are possible. This presupposes that the conditions of use are clarified in good time and the systems including zoning and regulation are designed accordingly.

4.4 Choice of low-energy components

Depending on the type and quality of manufacturing, there are sometimes considerable differences in efficiency and part-load behavior in the components of air delivery. It is therefore recommended that a serious examination of variants. On pages 14 to 16, the concrete procedure for the detection and assessment of fans taking into account the life cycle costs under the intended conditions of use is shown.

5. Review and optimization of existing fan systems

5.1 Problems of existing fan system

For existing plants, the energy performance of air delivery can be determined and assessed with measurements. If differences between the existing system and the currently valid standards are confirmed, it must be checked in individual systems whether adjustments are possible and reasonable.

The five most important deficiencies of existing systems

- Too long operating time
- Too high volume flows
- Obsolete fan drives and controls
- Missing demand control
- Improper maintenance and no tracked installation plans

Too long operating time

Configured operating time plan does not match the current usage pattern. Adjustments of controller and timer settings can be implemented very quickly and cost practically nothing. Periodic checking of existing operating settings is highly recommended.

Excessive air flow

Many ventilation systems are oversized. The reasons lie in the original planning (fear of surcharges) and changed conditions of use. In ventilation systems that supply several rooms, the review and re-adjustment must be done on basis of room by room. New planning should usually be conducted by professionals. If the air flow is reduced by more than 20%, a replacement of the fan should be considered.

Outdated fan drives and controls

V-belts have poor efficiencies, especially for small and medium fans. In old systems, there are some speed control systems that are technically obsolete. In new designs, electronically commutated permanent magnet or reluctance motors are connected directly on the drive shaft of the fans. The mechanical transmission losses (friction) and the electrical losses are significantly lower than old solutions with asynchronous motors and transmissions. For small and medium sized fan systems, switching from old to new technology can save 30% to 50% electrical energy.

Lack of demand regulation

Variable air flow demand regulations (indoor air quality, room temperature, pressure) were significantly more expensive in ten years ago than today. For variable room occupancy and loads (heat, humidity, pollutants), variable load control retrofits should be checked for medium and large systems.

Improper Maintenance

Fans and other equipment operation requires proper maintenance. This includes periodic cleaning and maintenance work, filter and defective parts replacement, etc. Energy accounting is very helpful, with which energy consumption and energy efficiency can be detected quickly. Attention should also be paid to adjustments due to changes in use. This requires the tracking of the installation plans and plant documentation.

5.2 When should a system be checked?

It is recommended that a ventilation system should be checked about every 10 years in terms of energy efficiency. In this period, the conditions of use may change and the efficiency may deteriorate due to aging of components. Another reason is that within a decade, the technology significantly evolves and more efficient components and subsystems are available.

Figure 7 Dirty fan

The use of dirty fans reduces air flow and increases energy consumption

Another opportunity for checking the ventilation system is when an inexplicably high power consumption of the system or building is detected.

5.3 How to proceed in principle?

Existing plants are assessed in a multi-stage process:

- In first phase, the plant is roughly assessed by visual on-site inspection.
- If there is relevant potential for energy improvement, an energy analysis will be prepared in a second phase. This is essentially based on the plant documentation.
- In the event of missing or unclear data in the plant documentation, measurements

can be carried out in a third phase.

Visual inspection

Maintenance

Improper maintenance can cause high pressure drops or other unfavorable operating conditions due to soiling, aging and manual intervention (e.g. adjustment of dampers and regulators).

Before an energy analysis, the filters should always be changed. If it is observed that the filters are not or not often replaced, the operating service is to pay attention to it.

To ensure hygienically perfect air quality, a hygiene inspection is recommended at least every ten years. If it is determined that a hygiene inspection is planned, it should be finished prior to the energy analysis.

Observation during operation

The ventilators of an object (building, manufacturing plant, etc.) are assessed qualitatively. This is done by visiting with operators (e.g. electrician or home service). The five most important deficiencies serve as the criteria for the assessment.

Results of the visual inspection and further procedure

The visual inspection is documented in a protocol. The following steps are proposed for each system, for example the following assessments:

- No need for further action: the plant is energetically good and has no obvious defects.
- Immediate measures: check and adjust operating time and belt tension, etc.
- Further energy analysis: the plant will be further investigated. This can be done by an analysis of the plant documentation or existing measurements.
- Further non-energetic measures: due to obvious deficiencies, the energy analysis is continued and remedial measures are initiated.

5.4 Analysis of the system documentation

In the second phase, the selected systems are evaluated according to the system documentation:

- Air flow (per person, based on heat or pollutant loads)
- Demand control (air quality, room temperature, differential pressure). In addition, it checks whether obviously inefficient components are present.
- Fan efficiency (according to data sheet or empirical value)
- Transmission
- Motor (poor energy class, oversizing)
- Stage control and step control (throttling)

Obviously unfavorable conditions exist when:

- Volume flow 30% above the demand
- No demand control
- V-belt drives for fans with a shaft power of less than 2 kW

The analysis is documented in a log. The further steps are suggested per system. In general, the following factors come into question:

- No further action required
- Initiate measures, e.g. to reset air flow
- Initiate a remediation of the system

5.5 Measurements on site

Basic information on the measurements

Before starting the measurement, it is important to note the following:

- Decide settings (operating levels, load cases)
- The control or regulation must be set during the measurement in such a way that the airflow corresponds to the dimensioning value. For example, in a system with air quality control, the set point of the CO2 content must be set to the minimum value.
- Any circulating air admixture must be set so that the proportion of recirculated air corresponds to the dimensioning state.
- Are special components such as flow or constant pressure regulators available?
- For systems with supply and exhaust fans, it must be decided whether the electrical power consumption of each fan is measured separately or whether the power consumption of the entire air treatment unit is recorded.
- The informative value of measurements increases markedly when, in addition to the dimensioning case, measurements are also carried out under partial load operation. Do not forget: The measurements must comply with safety regulations (high current, danger of injury to fans).

Electrical energy consumption

In the operating state in which the air volume flow and the delivery pressure are measured, the electrical power consumption (active power) is also measured.
Measurements in power installations may only be carried out by authorized persons (licensed electricians).

Air volume flow and delivery pressure

In larger systems, the air volume flow is usually measured as straight as possible before or after the air treatment unit. The measuring point should not be located in the direction of flow immediately such as e.g. arcs or components located after fittings. An anemometer is used to record the airfoil (air velocity). Multiplication with the cross section results in the air volume flow. If the temperature at the measuring point deviates by more than 10 K from the reference value (often 20 ° C), the density influence must be taken into account during the evaluation.
For smaller and medium-sized systems, the air volume flow can also be measured at the air diffusers. To obtain sufficient accuracy, funnel measuring instruments should be used.
To assess the fans and the system, pressure measurements must be carried out in addition to the air volume flow. To determine the operating points of the fans, the pressures on the fan nozzle should be measured. To assess the air distribution, pressure measurements should be made on the nozzle of the air treatment unit.

If the cross sections of the two measuring points are not the same in a pressure difference measurement, the differences in the dynamic pressures must be taken into account.