KAESER COMPRESSORS

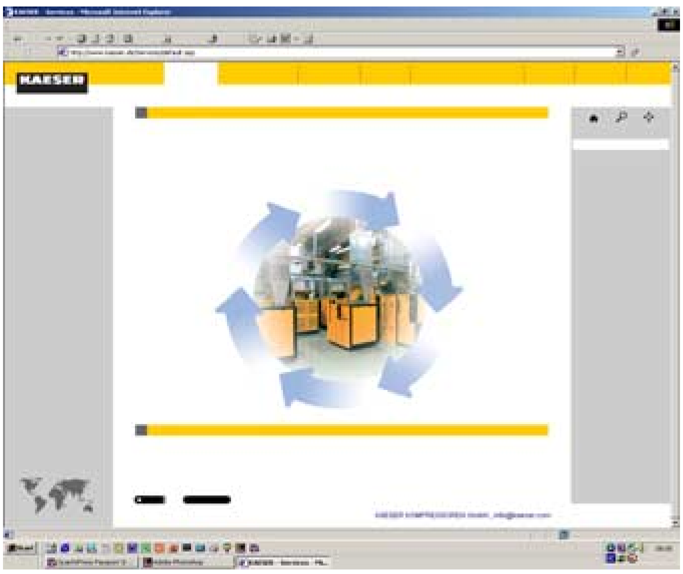
Compressed Air Engineering

Fundamentals,
tips and
suggestions

Are you aware of your air costs?

If you really want to know, ask Kaeser for an analysis of your compressed air demand (ADA).

You'll find more information in chapters 11 to 13 or in our "Advice and Analysis" brochure.



Further information and tools for correctly planning your compressed air supply system can be found in Internet at:

www.kaeser.com

Contents

It's the same with compressed air as with many other things in life; a minor cause can have an overwhelming effect - both in the positive and in the negative sense. On closer inspection things are often different to

1. What is compressed air?

what they at first appear. Under unfavourable conditions, compressed air can be expensive but, in the right circumstances, highly economical. It's possible that in the end, our tips will save you more money than the clever advice of your investment consultant. In this first chapter we will explain the terms used in compressor engineering and the things you should watch for in connection with them.

1. Free air delivery

The delivery of a compressor (known also as the free air delivery or FAD) is the expanded volume of air it forces into the air main (network) over a given period of time. The correct method of measuring this volume is given in Standard ISO 1217, annex C. In addition, the former CAGI-Pneurop PN 2 CPTC 2 recommendation can be used.

Proceed as follows to measure FAD: first the temperature, atmospheric pressure and humidity are measured at the air inlet of the complete packaged compressor. Then, the maximum working pressure, temperature and volume of compressed air discharged from the compressor are measured. Finally, the volume V_2 measured at the compressor outlet is referred back to the inlet conditions using the gas equation (*see also illustration below right*).

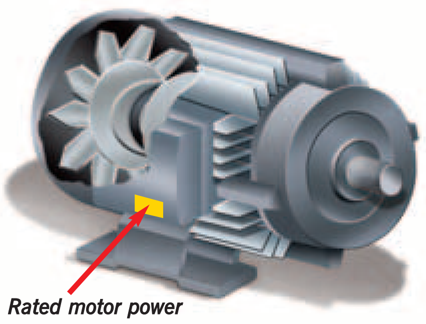
$$V_1 = \frac{V_2 \times P_2 \times T_1}{T_2 \times P_1}$$

The result is the free air delivery (FAD) of the **packaged** compressor. It must not be confused with the delivery of the **airend** (airend delivery).

Note:
ISO 1217 on its own only defines the delivery of the airend. The same applies to the old CAGI-Pneurop PN 2 CPTC recommendation.

2. Motor shaft power

The motor shaft power is the power that the motor delivers mechanically to its



output shaft. The optimum motor shaft power that can be achieved with optimum use of electric efficiency and the power factor cos φ without overloading the motor is within the range of the rated motor power. It is shown on the motor's nameplate.

Note: **If the motor shaft power deviates too far from the rated motor power, the compressor will run inefficiently and/or is subject to increased wear.**

3. Specific power

The specific power of a compressor is the relationship between the electric power consumed and the compressed air delivered at a given working pressure. The electrical power consumption is the sum of the power consumed by all consumers in a compressor, for example, drive motor, fan, oil pump, auxiliary heating, etc.; if the specific power is needed for an economic appraisal, it should refer to the whole of the packaged compressor and the maximum working pressure. The overall electrical power consumption at maximum pressure is then divided by the FAD at maximum pressure.

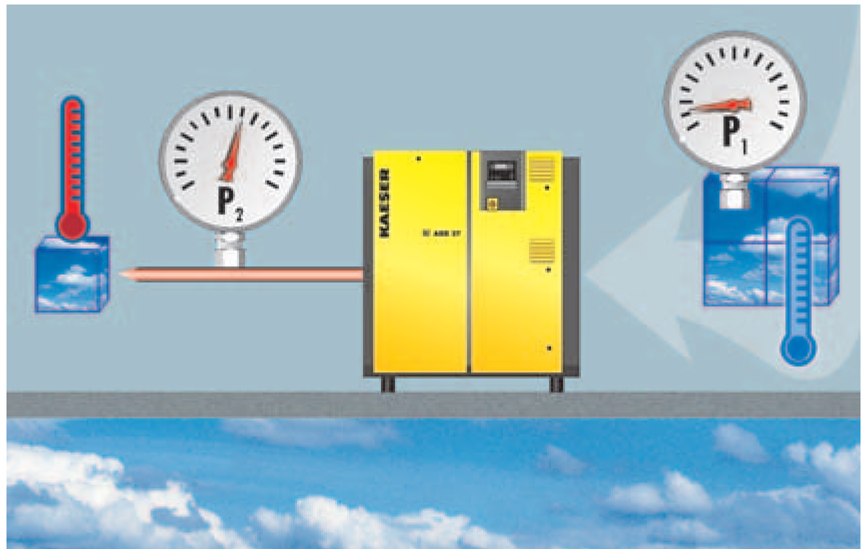
4. Electric power consumption

The electric power consumption is that power that the drive motor draws from the mains power supply with a defined mechanical load on its shaft (motor shaft power). It exceeds the motor shaft power by the value of the motor losses; these losses include both electrical and mechanical losses from bearings, fan, etc.

The ideal electric power consumption **P** can be calculated using the formula:

$$P = U \times I \times \sqrt{3} \times \cos\varphi$$

U, I, and **cos phi** are quoted on the motor nameplate.



5. EPACT – the new formula for energy-saving drive

Efforts in the USA to reduce the energy requirements of three-phase asynchronous motors resulted in the Energy Policy Act (EPACT) becoming law in 1997.

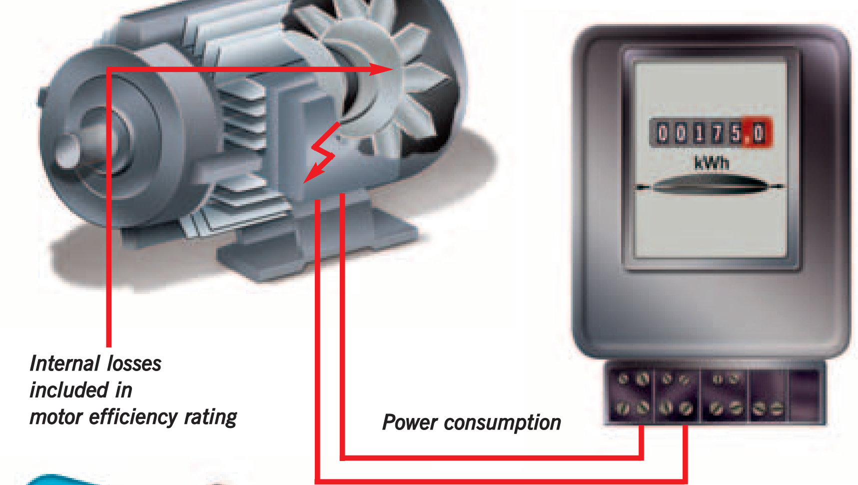
Since 1998 KAESER has been selling rotary screw air compressors in Europe that conform to this strict standard. The EPACT motors provide important advantages.

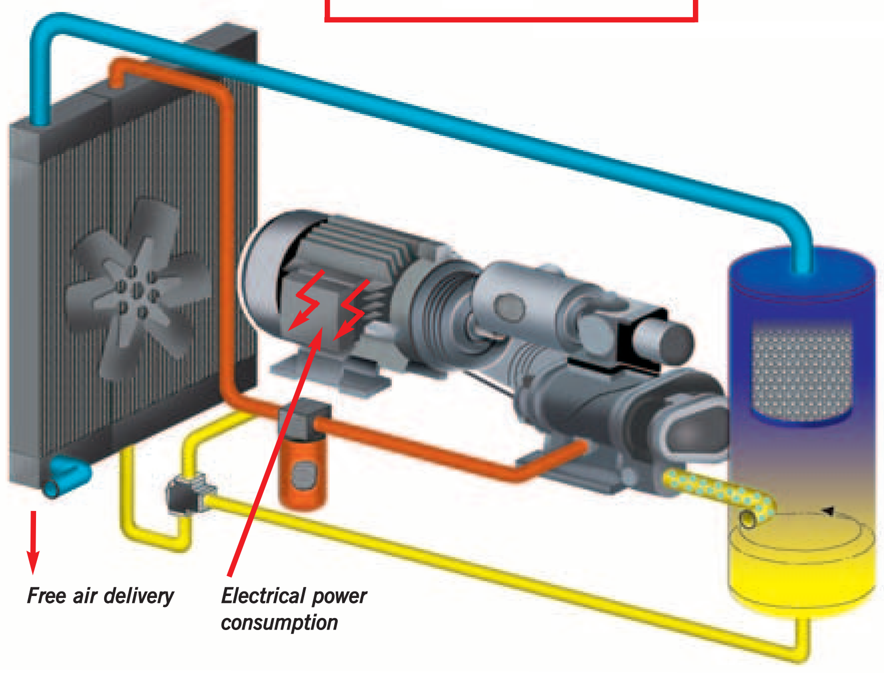
a) Lower operating temperatures

Internal efficiency losses caused by heat generation and friction can be as high as 20 percent of power consumption in small motors and 4-5 percent in motors upward of 160 kW. In EPACT motors, however, this heat loss is significantly less. Whereas the increase in working temperature on a conventional motor under normal load is approximately 80 K with a temperature reserve of 20 K compared with insulation class F, the temperature increase of an EPACT motor is only 65 K with a temperature reserve of 40 K under the same conditions.

b) Longer life

Lower working temperatures mean less thermal stress on the motor and the motor bearings. This results in a second advantage, extended motor life.





c) 6 percent more air for less power consumption

Less heat loss leads to an increase in efficiency. Thus, with precise matching of the airend to the possibilities offered by EPACT motors, KAESER is able to achieve up to six percent increase in air delivery and a five percent improvement in specific power. This means improved performance, shorter compressor running time and less power consumed per cubic metre of compressed air delivered.

Experts have been arguing for years on the subject of the most efficient method of treating compressed air. The main question is, which is the most cost-effective compressor system to produce oil-free compressed air? Leaving aside the claims of individual manufacturers, there is no doubt that today high grade, oil-free compressed air quality can be achieved with both dry-running and fluid-cooled compressors. This means that the only criterion deciding system choice is its cost-effectiveness.

2. Compressed air
efficiently treated

1. What is "oil-free" compressed air?
According to ISO 8573-1, compressed air can be described as oil-free if its oil content (including oil vapour) is less than 0.01 mg/m³. That is approximately four-hundredths of that contained in atmospheric air. This is so minute as to be barely measurable. But what about the quality of the compressor's intake air?

It is obviously highly dependent on local conditions. Even in normally contaminated zones the hydrocarbons in the air caused by industry and traffic emissions can lie between 4 and 14 mg/m³. In industrial areas, where oil is used as a lubricating, cooling and processing medium, the mineral oil content can be far above 10 mg/m³. Other impurities such as sulphur dioxide, soot, metals and dust are also present.

2. Why treat air?
Every compressor, regardless of type, sucks in contaminated air, concentrates the contamination by compression and, if no measures are taken to remove it, passes it on to the air network.

a) Air quality in"oil free" compressors
This applies especially to compressors with so-called oil free compression. Because of the pollution mentioned above it is impossible to produce oil-free compressed air with a compressor that is only equipped with a three-micron dust filter. Other than these dust filters, so-called oil free compressors have no further treatment components.

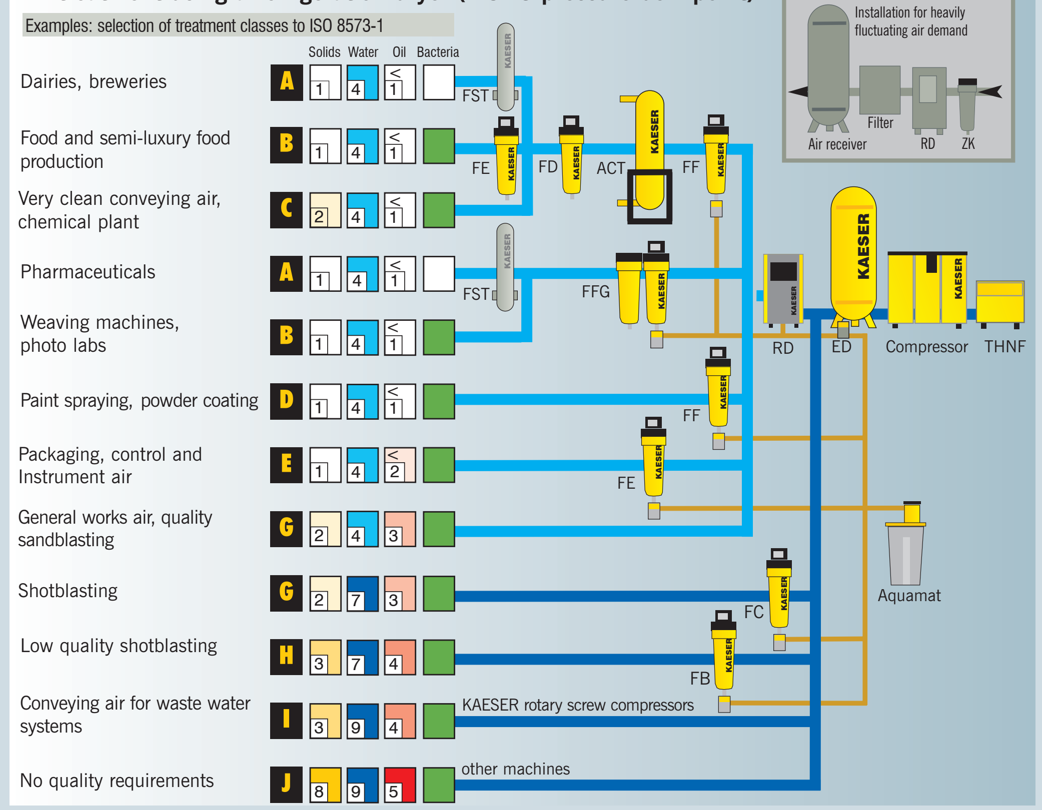
b) Air quality from oil-cooled rotary compressors
In contrast, aggressive matter is neutralised and solid particles are partly washed out of the air by the cooling oil in oil-cooled rotary compressors. Despite the high degree of purity of the compressed air produced, it is still not possible to get oil free air from this type of compressor without some form of air treatment. Neither oil-free nor oil-cooled compressors alone can provide air that is classified as oil-free to ISO 8573-1.

c) Compressed air drying
Before the compressed air is supplied to the user it must be sufficiently dried to suit the application. In most cases, refrigeration drying is used as this is the most efficient (see "Why do we need to dry compressed air", page 9).

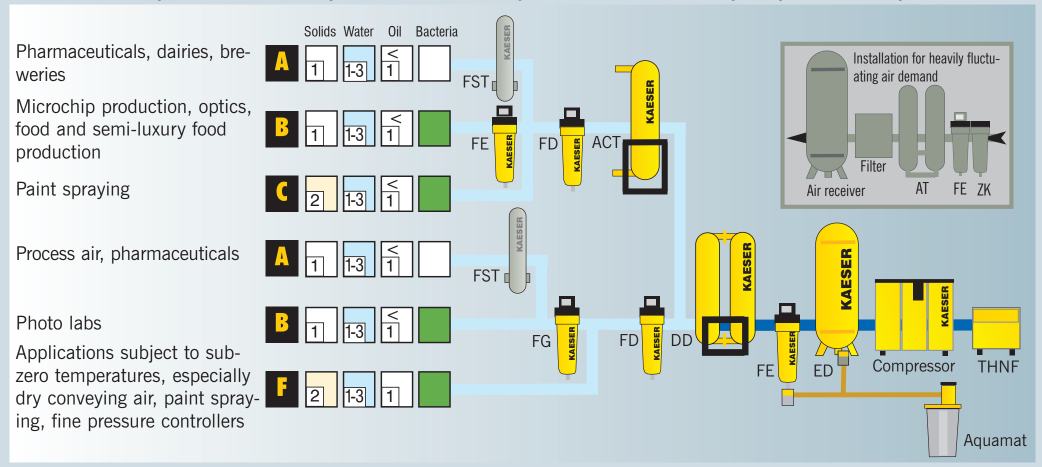
3. Choosing the right compressor system
The choice of an oil-free compressor system for one particular application or an oil-cooled compressor system for another should not depend on the quality of the air from the compressor alone but on the overall cost of both the compressor and the treatment equipment needed to achieve the desired quality. These are determined by power, maintenance and servicing costs, which can be up to 90 percent of the overall cost of air production. The lion's share of 75 to 85 percent is power costs. In the lower pressure range of 500 mbar to around 3 bar, oil-free systems such as rotary blowers [up to 2 bar] are highly energy-efficient. In contrast, oil-cooled screw compressors are significantly superior to the so-called "oil-free" types between 4 bar and 16 bar, as far as energy-efficiency is concerned. Above 5 bar "oil-free" compressors have to be designed with two compression stages to achieve a reasonable relationship between power consumption and air delivery. The large number of coolers needed, the high speeds, enormous control difficulties, watercooling and high procurement costs make the use of oil-free compression in this pressure range questionable. An added disadvantage is that the air from "oil-free" compressors is aggressive because of precipitating condensate and sulphur components drawn in with atmospheric air; the pH value is between 3 and 6.

Choose the required grade of treatment according to your field of application:

Air treatment using a refrigeration dryer (+3 °C pressure dew point)



For air mains subject to sub-zero temperatures: treatment systems with desiccant dryers (pressure dew point to -70 °C)



Explanation:
THNF=bag filter
Cleans dusty intake air
ZK=centrifugal separator
separates accumulating condensate
ED=ECO Drain
electronic level-controlled condensate drain
FB=prefilter 3 µm
separates liquid droplets and solid particles > 3µm, oil content ≤ 5 mg/m³
FC=prefilter 1 µm
separates oil droplets and solid particles > 1µm, oil content ≤ 1 mg/m³
FD=particulate filter 1 µm
separates dust particles (attrition) > 1µm
FE=microfilter 0.01 µm
separates oil aerosols and solid particles > 0.01µm,
aerosol content ≤ 0.01 mg/m³
FF=microfilter 0.001 ppm
separates aerosols and solid particles > 0.01µm,
aerosol content ≤ 0.001 mg/m³
FG=activated carbon filter
for adsorption of oil vapours,
oil vapour content ≤ 0.003 mg/m³
FFG=combination filter
comprising FF and FG
RD=refrigeration dryer
pressure dew point to +3 °C
DD=desiccant dryer
DC series: heatless regeneration, pressure dew point to -70 °C,
DW, DN, DTL, DTW series: heat regeneration, pressure dew point to -40 °C
ACT=activated carbon adsorber
for adsorption of oil vapours,
oil vapour content ≤ 0.003 mg/m³
FST=sterile filter
provides bacteria-free compressed air
Aquamat=condensate treatment system

Contaminants:
\+ solids -
\+ water -
\+ oil -
\+ bacteria -

Degree of filtration:

ISO 8573-1 Class	Solid particles: Max. no. of particles per m³ with size d (µm) ≤0.1	0.1<d≤0.5	0.5<d≤1.0	1.0<d≤5.0	µm	mg/m³	Humidity: Pressure dew point (x=liquid water in mg/m³)	Overall oil content mg/m³
0	as specified by user							
1	–	100	1	0	–	–	≤-70 °C	≤0.01
2	–	100000	1000	10	–	–	≤-40 °C	≤0.1
3	–	–	10000	500	–	–	≤-20 °C	≤1.0
4	–	–	–	1000	–	–	≤+3 °C	≤5.0
5	–	–	–	20000	–	–	≤+7 °C	–
6			–		≤ 5	≤ 5	≤+10 °C	–
7			–		≤ 40	≤ 10	x≤0.5	–
8			–		–	–	0.5<x≤ 5.0	–
9			–		–	–	5.0<x≤10.0	–

- **A** Oil vapour content ≤ 0.003 mg/m³, particle retention > 0.01 µm, sterile, odourless and tasteless
- **B** Oil vapour content ≤ 0.003 mg/m³, particle retention > 0.01 µm
- **C** Oil vapour content ≤ 0.003 mg/m³, particle retention > 1 µm
- **D** Aerosol oil ≤ 0.001 mg/m³, particle retention > 0.01 µm
- **E** Aerosol oil ≤ 0.01 mg/m³, particle retention > 0.01 µm
- **F** Aerosol oil ≤ 0.01 mg/m³, particle retention > 1 µm
- **G** Aerosol oil ≤ 1 mg/m³, particle retention > 1 µm
- **H** Aerosol oil ≤ 5 mg/m³, particle retention > 3 µm
- **I** Aerosol oil ≤ 5 mg/m³, particle retention > 1 µm
- **J** Untreated

4. Treatment with the KAESER Pure Air System
Modern oil-cooled rotary compressors have a 10 percent higher degree of efficiency than those using oil-free compression. The Pure Air System, developed by KAESER for oil-cooled rotary screw compressors, provides further cost-savings of up to 30 percent. The residual compressed air oil content achieved by this system is less than 0.003 mg/m³, far below the permissible limit given in the ISO standard. The system includes all the treatment components needed for achieving the required air quality. Depending on the application, either refrigeration or desiccant dryers are used (see "Why do we need compressed air drying", page 9) together with various filter combinations. Air qualities from simply dry air through particle-free up to oil-free and sterile air are reliably and cost-effectively achieved according to the quality classes laid down in the ISO standard.

5. Treatment flow chart
An air treatment flow chart as depicted above is now included in every KAESER screw compressor brochure. The correct combination of treatment equipment for any application can be determined at a glance.

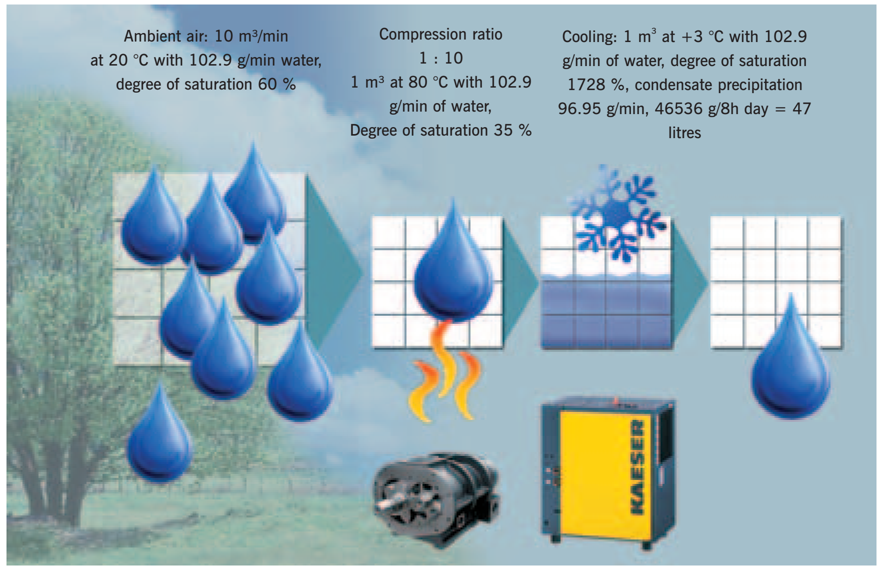
The problem lies in the air - in the true sense of the word; when atmospheric air cools down, such as is the case after compression in a compressor, water vapour precipitates as condensate. Under average conditions, a 30 kW compressor with a capacity of 5 m³/min at 7.5 bar will “produce” approximately 20 litres of water per shift. This water has to be removed from the air system to avoid damage and problems on the production line. Compressed air drying is, therefore, an important part of the air treatment process. In this chapter you will find valuable information on the topic of economical and environmentally friendly compressed air drying.

3. Why do we need to dry compressed air?

1. A practical example

If an oil-cooled rotary screw air compressor draws in air at atmospheric pressure with a relative humidity of 60 percent and an ambient temperature of 20 °C at a rate of 10 m³ per minute then this air contains approximately 100 g of water vapour. If this air is compressed to an absolute pressure of 10 bar at a compression ratio of 1:10, then one so-called working cubic metre is obtained. However, at a temperature of 80 °C after compression, the air can absorb up to 290 g of water per cubic meter. As only about 100 g is available, the air is very dry with a relative humidity of approximately 35 %, so that no condensate can form. The temperature of the air is then reduced from 80 to around 30 °C in the compressor's aftercooler. At this temperature, a cubic metre of air can only absorb about 30 g of water, so that an excess of around 70 g/min results, condenses and is separated. This means that approximately 35 litres of condensate accumulate during an eight hour working shift.

A further 6 litres per shift are separated by a refrigeration dryer if located downstream. The air is initially cooled down to +3 °C in these dryers and then heated up again later to the ambient temperature. This leads to a water vapour saturation deficit of around 20 percent and therefore to a better, relatively dry air quality.



2. The cause of humidity

Our ambient air always contains a component of water, i.e. it is always humid. This humidity is dependent on the actual temperature of the air. For example, air saturated to 100 percent with water vapour at a temperature of +25 °C holds almost 23 g of water per cubic metre.

3. Precipitation of condensate

Condensate forms if the volume of the air is reduced and the temperature of the air is reduced at the same time. Therefore, the capacity of the air to absorb water is reduced. This is precisely what happens in the airend and in the aftercooler of a compressor.

4. Important terms briefly explained

a) Absolute air humidity

Absolute humidity is the water content of the air, given in g/m³.

b) Relative humidity (Hrel)

Relative humidity is the ratio of the actual absolute humidity to the highest possible absolute humidity (100 % Hrel). This is variable according to temperature; warm air can hold more water vapour than cold.

c) Atmospheric dew point

The atmospheric dew point is that temperature at which the air reaches a degree of humidity saturation (Hrel) of 100 percent at atmospheric pressure (ambient conditions).

Some examples:

Dew point in °C	Max. water content in g/m³
+40	50.7
+30	30.1
+20	17.1
+10	9.4
0	4.9
-10	2.2
-20	0.9
-25	0.5

d) Pressure dew point

The pressure dew point (PDP) is the temperature at which compressed air reaches its humidity saturation point (100 % Hrel) under its absolute pressure. This means, in the above case, that air subjected to a pressure of 10 bar with a pressure dew point of +3 °C has an absolute humidity of 6 g per working cubic metre.

To put it more clearly - if the cubic metre mentioned is expanded from 10 bar to atmospheric pressure then its volume multiplies 10 times. The water vapour component of 6 g remains unchanged, but is now distributed over 10 times the volume. This means that every cubic metre of free air now contains only 0.6 g of water vapour, which corresponds to an atmospheric dew point of –24 °C.

5. Economical and ecological compressed air drying

a) Refrigeration or desiccant drying?

New environmental legislation concerning refrigerants cannot change the fact that desiccant dryers do not provide an alternative to refrigeration dryers, neither from an economical nor from an environmental point of view. Refrigeration dryers consume only 3 % of the power that the compressor needs to produce the compressed air; desiccant dryers, on the other hand, 10 to 25 percent or more. Which is why refrigeration dryers should always be used wherever possible.

The use of a desiccant dryer only makes sense if an extremely dry air quality with a pressure dew point down to –20, –40 or –70 °C is required.

b) What refrigerant?

CFCs such as R 12 and R 22 are no longer allowed in refrigerating systems. The table below shows the influence of refrigerants on the environment. Up until the year 2000 most manufacturers used R 22, a partly halogenated CFC. In comparison with R 12 it had an ozone depletion potential of only 5 percent, and the global warming potential of 12 percent was far less. Today, however, HFC R 134a refrigerant is preferred and recommended by the authorities as an alternative to R 12 and R 22 because of its 0% ozone layer depletion potential. The advantage of R 134a is that old equipment previously using R 12 can be easily and cheaply converted to the new refrigerant.

Other refrigerants with zero ozone depletion potential such as R 404A and R 407C are now available. These are so-called “blends”, mixtures of various refrigerants, that each suffer from different temperature "glides", i.e. deviations in the temperature at which their component parts evaporate and condense and also have a higher global warming potential as shown in the table below. For this reason, R 407C would only be considered for special applications. Because of its lower temperature glide, R 404A, on the other hand, is only of interest where high flow rates of 24 m³/min and above are involved.

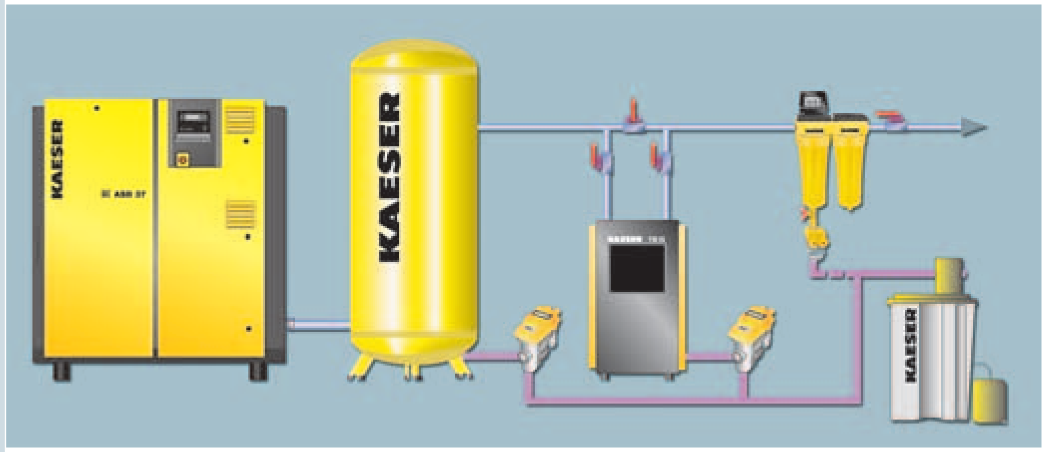
	Refrigerant	Composition formula	Ozone depletion potential ODP [R 12 = 100%]	Global warming potential GWP [R 12 = 100%]	Temperature glide. Possible variation in in evaporation and condensation temperature [K]
	HCFC R 22	$CHClF_2$	5%	12%	0
	HFC	$CH_2F\text{-}CF_3$	0%	8%	0
Blends	R 404A	R 143a/125/134a	0%	26%	0.7
Blends	R 407C	R 32/125/134a	0%	11%	7.4

Condensate is an unavoidable by-product of compressed air production. We have already discussed how it is formed in the chapter “Why do we need to dry compressed air”. We explained how, under average

4. Condensate

Its correct drainage

conditions, a 30 kW compressor with an FAD of 5 m³/min produces 20 litres of condensate per shift. This liquid must be removed from the air system to avoid malfunctions, production downtime and corrosion. In this chapter we explain how you can drain condensate correctly and save significant costs at the same time.



1. Condensate drainage

Condensate, contaminated by diverse pollutants, collects at certain points in every air system **(see illustration above)**. This means that reliable drainage of this condensate is vital. It has a significant influence on air quality, reliability and the efficiency of a compressed air system.

a) Collection and drainage points

Initially, mechanical elements of the air system collect and drain condensate. 70 to 80 percent of all the condensate is collected at these points - provided the compressors are fitted with good aftercooling.

Centrifugal separator:

This is a mechanical separator that separates condensate from the air by centrifugal force (see illustration right). To function optimally, each compressor should have its own centrifugal separator.

Intercoolers:

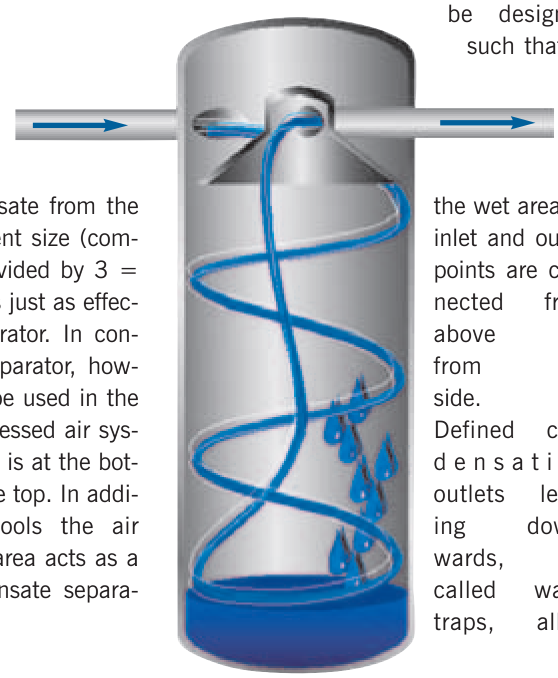
On two-stage compressors with intercoolers condensate collects at the separator in the intercooler.

Air receivers:

As well as its main function as a storage or buffer tank, the air receiver separates condensate from the air by gravity. If of sufficient size (compressor FAD in m³/min divided by 3 = air receiver size in m³) it is just as effective as a centrifugal separator. In contrast to the centrifugal separator, however, the air receiver can be used in the main air line of the compressed air system, providing the air inlet is at the bottom and the outlet is at the top. In addition, the air receiver cools the air because its large surface area acts as a radiator, improving condensate separation even more.

Water traps in the air line:

To avoid undefined condensate flow, the air line should be designed such that in the wet area all inlet and outlet points are connected from above or from the side. Defined condensation outlets leading downwards, so-called water traps, allow



condensate to be removed from the main air line.

With correct design and an airflow of 2 to 3 m/s a water trap in the wet area of the air system separates condensate just as effectively as an air receiver **(Illustration 1)**.

b) Air dryers

As well as those already mentioned, there are other collecting and drainage points to be found on air dryers.

Refrigeration Dryer:

Further condensate is separated in the refrigeration dryers because of the drying effect of cooling the compressed air.

Desiccant dryers:

Because of the considerable cooling effect of the air line, condensate collects at the prefilter in the inlet to the desiccant dryer. In the desiccant dryer itself, water only exists as vapour because of the partial pressure conditions prevailing in the dryer.

c) Local separators

If no central drying system exists, large quantities of condensate collect at the local separators fitted just upstream of air consumers. However, their servicing needs are very high.

2. Commonly used drainage systems

At present, three systems are mainly used:

a) Float drains (Illustration 2)

The float drain is one of the oldest drainage systems and replaced absolutely inefficient and unreliable manual drainage. However, even condensate drainage using the float principle proved to be extremely susceptible to malfunction because of dirt and pollution in the compressed air.

b) Solenoid valves

Time controlled solenoid valves are more reliable than float drains but they have to be checked regularly for clogging and contamination. Wrongly adjusted opening periods can cause air losses and increased consumption of energy.

c) Condensate drains with level control (ECO DRAIN, illustration 3)

Nowadays, drains using intelligent level control are preferred. They have the advantage that the float, which is highly susceptible to faults, is replaced by an electronic sensor. This means that in contrast to float drains, faults caused by dirt or mechanical wear are eliminated. Also, air losses (such as occur with float valves) are prevented by the automatically controlled opening periods of the valve.

Further benefits are automatic self-monitoring and the possibility of passing on signals to a central control system.

d) Correct installation

A short length of pipe containing a shut-off valve should be fitted between the condensate separating system and the condensate drain **(Illustration 3)**. This allows the drain to be isolated during maintenance and the compressed air system can remain in operation.

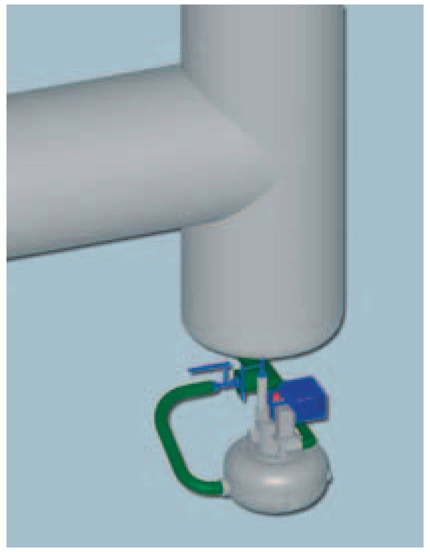


Illustration 1: Water trap with condensate drain

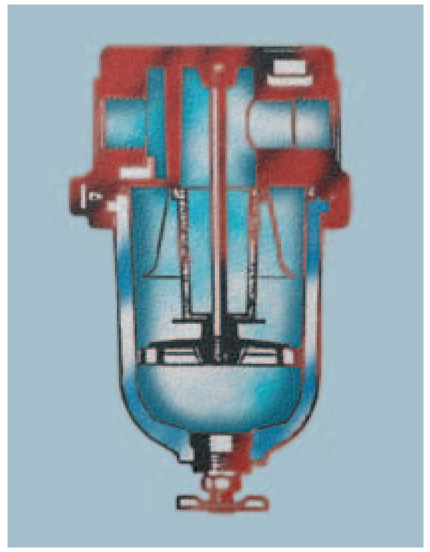


Illustration 2: Float drain

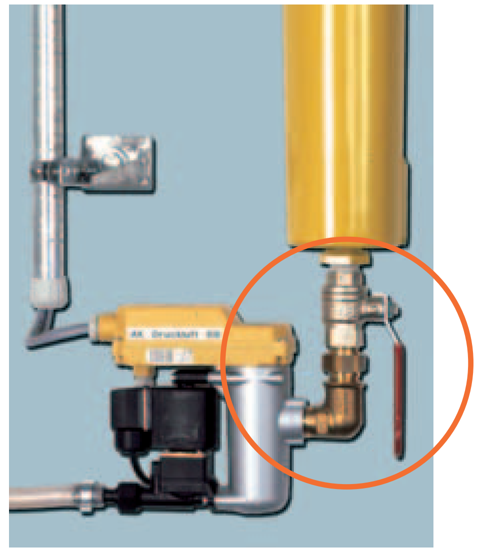


Illustration 3: ECO DRAIN with ball valve

5. Condensate

Its safe, economical treatment

Condensate is an undesirable and unavoidable by-product of compressed air production. (see chapters 3 and 4). The term ‘condensate’ is misleading because it could be misunderstood to mean only condensed water vapours. Be careful! Every compressor works like an oversized vacuum cleaner; it sucks in polluted air from the surroundings and passes it on in a concentrated form in the untreated compressed air to the condensate.

1. Why do we need condensate treatment?

Users who dispose of condensate by simply pouring it down the drain are risking heavy fines. This is because condensate accumulating during the production of compressed air is a highly dangerous mixture. As well as solid particles, it contains increasing amounts of hydrocarbons, sulphur dioxide, copper, lead, iron and other substances caused by growing environmental pollution. In Germany, the directive for condensate disposal is the Water Management Act. This act stipulates that polluted water must be treated according to “generally approved engineering regulations”. This affects all types of condensate – including condensate from “oil-free” compressors.

There are legal limits for all pollutants and for pH-values. These vary according to federal state and branch of engineering.

The maximum permissible limit for hydrocarbons, for example, is 20 mg/l and the pH limit for disposable condensate ranges from 6 to 9.

2. Composition of condensate

a) Dispersion

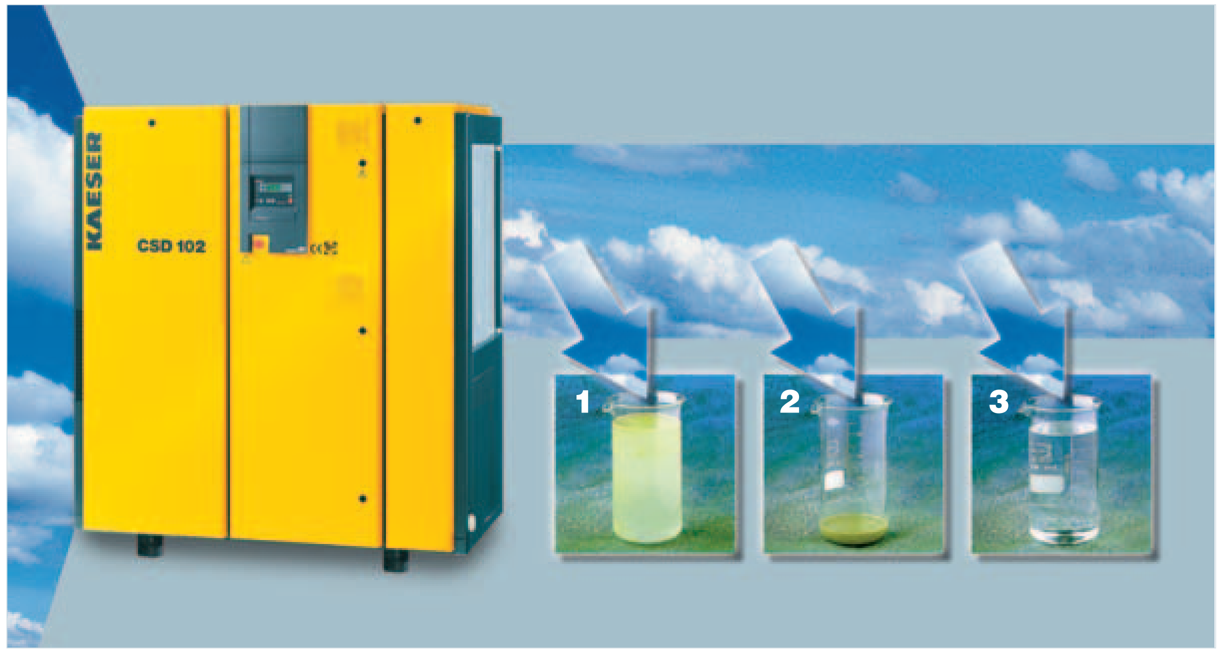
Condensate can be of various compositions. Generally, dispersion occurs in oil-cooled rotary screw compressors that are run with synthetic coolants such as Kaeser Sigma Fluid Plus. This condensate normally has a pH value between 6 and 9 and can be regarded as pH neutral. With this condensate, pollutants drawn in from the atmosphere are captured in a floating layer of oil that is easily separated from the water.

b) Emulsion

A visible sign of emulsion is a milky fluid that does not separate even after several days **(see 1 in illustration on the right)**. This composition often occurs in reciprocating, rotary screw and sliding vane compressors that are run with conventional oils. Pollutants in such a composition are also captured by the oil. Because of the thick, stable mixture, oil, water and pollutants such as dust and heavy metals cannot be separated by gravity. If the oils contain ester compounds, the condensate could be aggressive and must be neutralized. Treatment of such condensate is only possible with emulsion splitting units.

c) Condensate from oil-free compressors

Because of increasing atmospheric pollution, condensate from oil-free compressors still contains a considerable proportion of oily components. Such condensate often exhibits high proportions of sulphur dioxide, heavy metals and/or other solid particles. This condensate is generally aggressive, having a pH value between 3 and 6. Condensate of this quality cannot be disposed of as wastewater, even though this is often claimed.



All compressors suck in water vapour and pollutants with the atmospheric air. The resulting condensate must be freed of oil and other contaminants (2), before it can be disposed of as clean water (3)

3. External disposal

Of course, it is possible to collect the condensate and have it disposed of by a specialised company. However, these costs are between □40 and □150/m³. In view of the amount of condensate accumulating, treatment would be the more economical method. It has the advantage that only about 0.025 percent of the original volume is left to be disposed of according to environmental regulations.

4. Treatment process

a) Dispersions

A triple chamber separator comprising two initial separating chambers and an activated carbon filter chamber is used to treat this kind of condensate. The actual separation takes place under the force of gravity. The oil layer floating on the surface of the fluid in the separating chamber is skimmed off into a canister and disposed of as waste oil. The remaining water is then filtered in two stages and can be disposed of as waste water. This process saves up to 95 percent of the costs involved if a specialised company disposes of the condensate. Such separators can be supplied to cope with a compressor FAD of 160 m³/min. If needed, several separators can be connected in parallel.

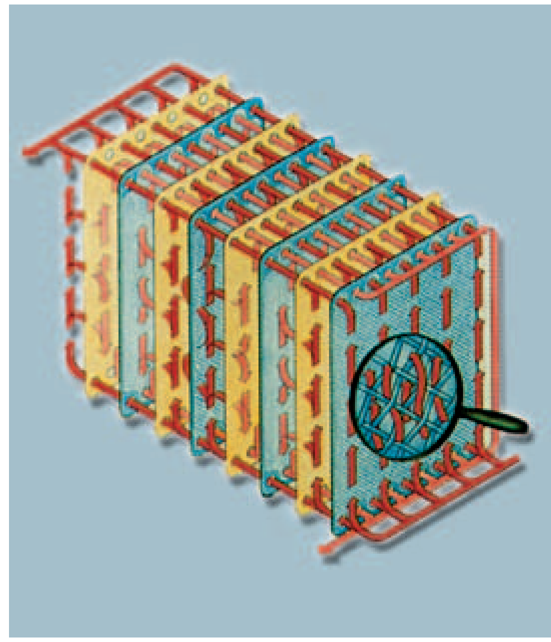
Gravitational separators such as this Aquamat treat condensate dispersions reliably and economically

b) Emulsions

In general, two types of separator are used for the treatment of stable emulsions; membrane separating systems work on the principle of ultra-filtration using the so-called cross-flow process. During this process, pre-filtered condensate flows across the membrane. A part of the condensate permeates the membrane and leaves the separator as clean water that can be disposed of as wastewater, the process repeating itself. The second type uses a powdered splitting agent. This encapsulates oil particles, forming easily filtered macro flocs. Filters of a defined pore size reliably retain these flocs. The drained water can be disposed of as wastewater.

c) Condensate from oil-free compressors

Condensate from oil-free compressors must be treated with a chemical separating process. This includes pH neutralization through addition of alkaline and the binding and concentration of heavy metal components in a filter cake which has to be disposed of as hazardous waste. This process is by far the most complex. Special disposal approval must be obtained that covers not just possible oil components in the condensate but also concentrated pollutants drawn in from the ambient air. The latter can contaminate the condensate considerably.



Membrane separators are mostly used for stable condensate emulsions

Despite all its benefits, compressed air is a relatively expensive energy medium. This means that costs should be saved wherever possible. In many applications one of the main causes of increased costs

6. Efficient

compressor control

is a mismatch of compressor air delivery to fluctuating air demand. Often, the duty cycle of the compressors is only 50 percent. A lot of users are not even conscious of this fact because their compressors have an indicator showing only the hours in operation but not the hours under load. Well matched control systems can help by increasing the load factor to over 90 percent, achieving power savings of up to 20 percent and more.

1. Internal control

a) Loaded/unloaded control

Most compressors are fitted with three-phase asynchronous drive motors. The permissible starting frequency of these drive motors is lower the higher the drive power. It does not correspond to the starting frequency necessary to cut in and cut out compressors with narrower starting differentials that meet the actual air demand. These switching cycles would only unload the pressurised end of the compressor. The drive motor, on the other hand, must carry on running for a certain period to avoid exceeding its starting frequency. The power needed to turn the motor during this off-load period must be regarded as a loss. The power consumption of a compressor switched to off-load running is still 20 percent of full load drive power.

b) Variable frequency drive

The efficiency of compressors that are speed-controlled by a frequency converter is not constant over their whole range of control. In the control range between 30 and 100 percent it reduces from 94 to 86 percent for a 90 kW motor, for example. Added to this are the losses in the frequency converter and the non-linear power characteristic of the compressors.
If variable speed compressors are wrongly used, they can turn into power eaters without the user being aware of the fact. This means that variable frequency drive is not a universal remedy in the search for maximum efficiency and energy-saving operation.

2. Classification of air demand

Generally, compressors can be classified according to function into base load, medium load, peak load or standby units.

a) Base load air demand

The base load air demand is the volume of air constantly needed by a production facility.

b) Peak load air demand

In contrast, the peak load is the volume of air demanded at certain peak load times. It varies because of the differing demand from various consumers.

To meet the diverse functions of load as well as possible, each compressor must be controlled differently by an internal controller. These slave controllers must be capable of upholding compressor operation, and, therefore, the supply of compressed air should a defect occur on the master controller.

3. Master controllers

Master controllers coordinate the operation of the compressors in a compressed air system and cut the compressors in or out according to the air demand.

a) System splitting

Splitting is the division of compressors of equal or differing capacities and type of control according to base load and peak load air demand of a production facility.

b) The tasks of a master controller

Coordination of compressor operation is a demanding and comprehensive task. Modern master controllers must not only be able to put compressors of differing make and size into operation at the same time. They must also be capable of monitoring the system for maintenance purposes, balancing the operating hours of the machines and recording malfunctions to bring down servicing costs and increase reliability.

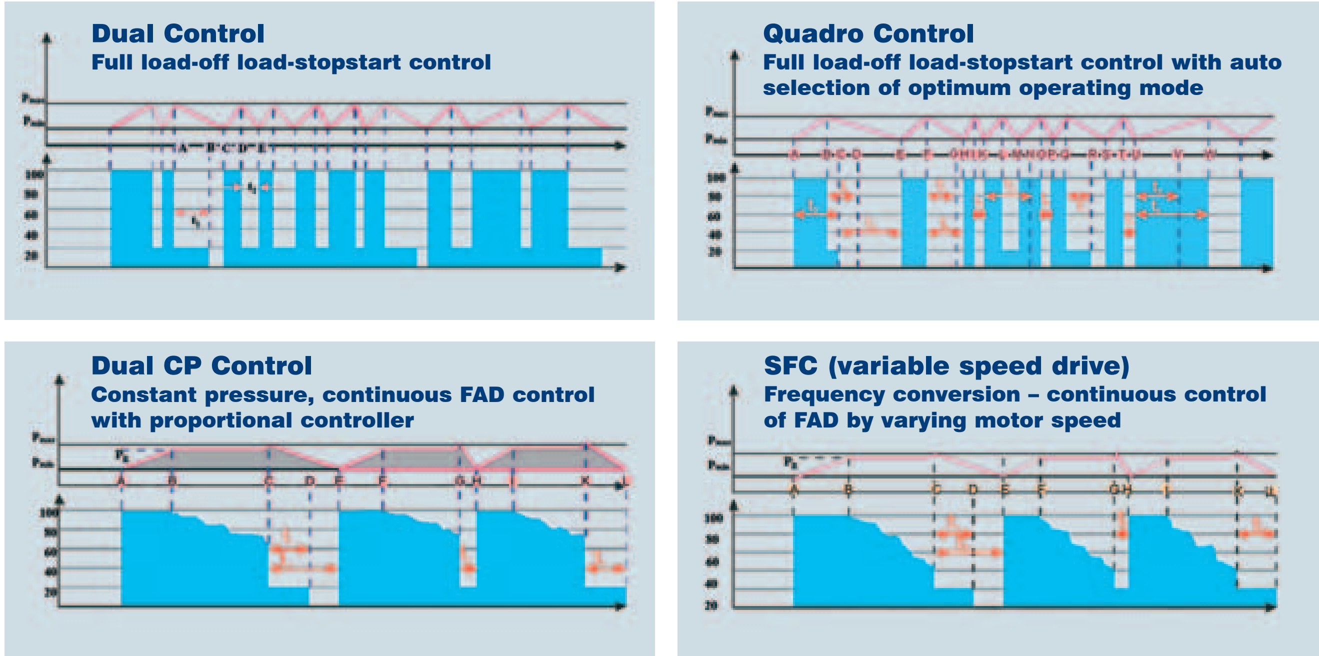
c) Correct grading

An important condition for an efficient - that is power-saving - master controller is perfect grading of the compressors. The sum of the air capacities of the peak load machines must therefore be larger than that of the next base load machine to be cut in. If a peak load machine with variable frequency drive is used, the control range must be larger than the capacity of the next compressor to be cut in, otherwise the efficiency of the compressed air supply cannot be guaranteed.

d) Safe data transfer

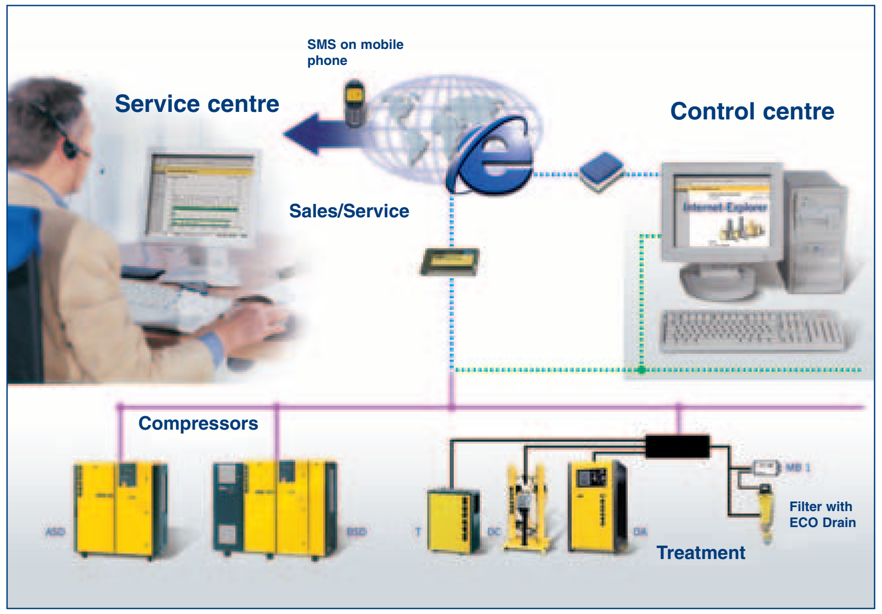
Another important requirement for perfect function and efficiency of a master controller is safe data transfer. It must be ensured that messages are transferable between each compressor and between the compressors and the master controller. In addition, the signal paths must be monitored so that faults such as loss of continuity in a connecting cable are immediately recognised.

Normal transfer methods:
1. Volt-free contacts
2. Analog signals of 4 – 20 mA
3. Electronic interfaces, e.g. RS 232, RS 485 or Profibus DP
The most modern method of transfer is the Profibus. This bus can pass large volumes of data over long distances in a very short time **(illustration below)**. This means that master controllers do not have to be located in the compressed air installation itself.



Four control concepts for configuration are integrated in the internal controller "KAESER Sigma Control"

Profibus provides a fast data link from the compressed air system to the master controller and the control centre



Compressed air systems are typically comprised of multiple compressors of similar or various sizes. As proper control is essential to efficient system operation, a master controller is needed to coordinate the operation of individual machines. In the past, this task was quite simple as it usually involved sequencing compressors of the same size to handle the base load in such a way that their running time was about the same. Today's requirement is somewhat more sophisticated, as it is now necessary to closely match the air supply to the changing demand in order to achieve maximum energy efficiency. Basically, there are two different master compressor control systems; cascade and pressure band control.

7. Pressure band control

Optimum demand-related matching of compressors

1. Cascade control

The classical method of controlling a group of compressors is cascade control. Each individual compressor is assigned lower and upper pressure set points that either add or subtract compressor capacity to meet system demand. If several compressors are to be coordinated, the additive nature of this strategy results in a cascaded, or stepped control system. When air demand is low only one compressor is cut in and pressure rises and fluctuates in the upper range between minimal (p_{min}) and maximal pressure (p_{max}) of this compressor, pressure falls when air demand is higher and several compressors cut in to satisfy it **(Illustration 1)**. This results in a relatively large overall pressure swing with maximum values well above nominal working pressure, increasing the significance of leaks and their subsequent energy losses. On the other hand, if consumption is high, pressure falls well below nominal working pressure and there is a reduced reserve of pressure in the system.

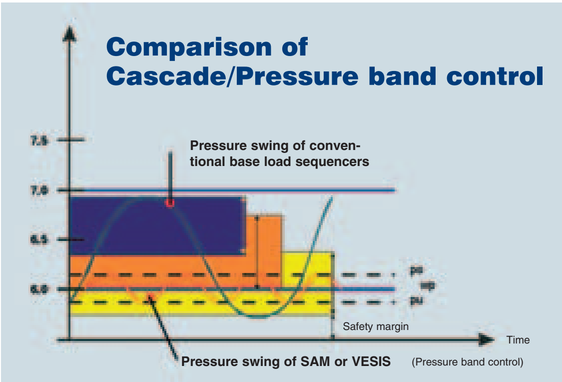


Illustration 1: Comparison of fluctuations and savings in pressure using cascade control (base load sequencing) and pressure band control

a) Cascade control using conventional pressure switching

If pressure switches or pressure gauge switches are used for cascade control then generally the minimum pressure differential between cut-in and cut-out should be set to 0.5 bar for each individual compressor, whereas the individual switching points should be staggered by at least 0.3 bar. The maximum number of compressors that should be controlled in this way is four, which generally results in a cumulative pressure swing of 1.4 bar for the group.

b) Cascade control using electronic pressure switching

The use of electronic pressure transducers reduces the pressure-switching differential on individual compressors to 0.2 bar and also allows the stagger between switching points to be reduced. This can bring the cumulative pressure swing of the group down to 0.7 bar.

As already mentioned, no more than four compressors should be switched with cascade control, otherwise there is a danger that power and air leak losses will be extremely high because of the huge pressure swing.

2. Pressure band control

Without doubt, the more up-to-date and energy-efficient method of multiple compressor coordination is pressure band control. The operation of any number of compressors can be coordinated to hold system pressure within a single, so-called pressure band **(Illustration 1)**. A vital condition, however, is the use of a microprocessor controlled sequencer or better, an industrial computer with controller intelligence. There are several methods of pressure band control, as explained below.

a) Vector control

In vector control the rate of rise or fall in system pressure between the fixed minimum and maximum pressure is interpreted as the differential between supply and consumption. Based on the calculation of past consumption, the controller then selects appropriate compressors **(Illustration 2).** Under certain circumstances, this can lead to system pressure oscillations on air systems with fluctuating air consumption, which makes corrective damping necessary. A vital point in this regard is the matching of the compressors. Generally, with this method of control, the pressure-swing cannot be reduced to less than 0.5 bar, as sensing is done within minimum and maximum pressure range.

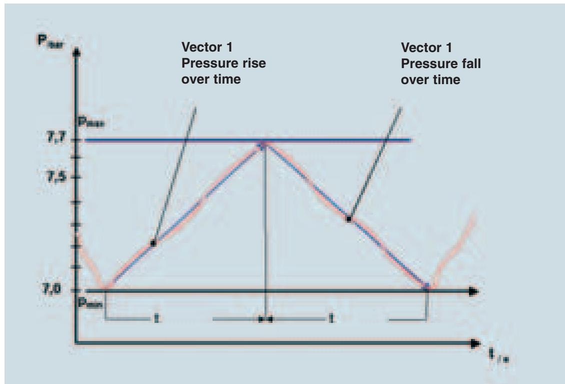


Illustration 2: Vector control

b) Pressure band control with trend recognition

Pressure band control with trend recognition is more efficient than vector control because pressure-switching differentials of 0.2 bar can be achieved. This is the narrowest pressure band known in compressed air engineering at the present time. Trend recognition is not based on the short term pressure rise and fall over a defined period. It observes the profile of consumption in the system after a compressor is put online and then draws corresponding conclusions for the next compressor selection **(Illustration 3)**. Trend recognition, which works to an accuracy of between 0.01 to 0.03 bar, is continually updated, enabling the controller to coordinate the compressors within minimal pressure switching differentials, even with heavily fluctuating demand. Today, it is technically possible to control up to 16 compressors online within a pressure band of only 0.2 bar. In cases of extremely high demand, an emergency pressure band can protect the operative pressure band, ensuring a safe, reliable air supply. These controllers can contribute to significant energy savings in air supply systems. A reduction of only 0.1 bar saves one percent of the energy consumed.

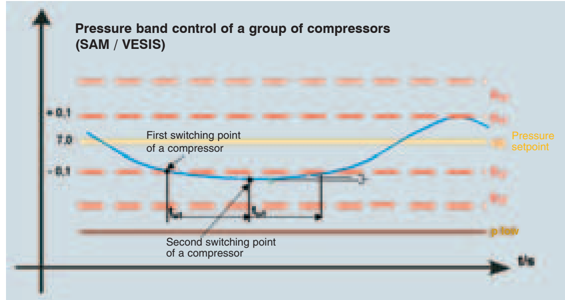


Illustration 3: Pressure range control using trend recognition (above)

c) Peak load related control

Pressure band controllers using trend recognition group the compressors according to their capacities. This means that they are not only in the position of evenly loading the compressors according to their operating hours and hours on load but also of selecting the right compressor at exactly the right point in time **(Illustration 4)**. An important requirement, however, is optimised splitting. Splitting is the grouping of compressors of the same or different capacities according to base load and peak load demand (see also chapter 6 "Efficient compressor control").
However, this method of controlling compressors, the most efficient at the present time, requires the transfer and processing of high volumes of data. Only intelligent industrial computers such as Sigma Air Manager (SAM) from KAESER are capable of processing these large volumes of data. Such industrial computers are easily interfaced to central control systems and, as well as being a highly efficient air system controller, can carry out the function of a web server with programmed HTML pages.
This makes it possible, without the need for special software, to record the operational data of the compressors together with the utilisation and efficiency of the complete compressed air system, to visualise the data in an understandable way, to evaluate them and to react accordingly (see also "Sigma Air Manager", page 27).

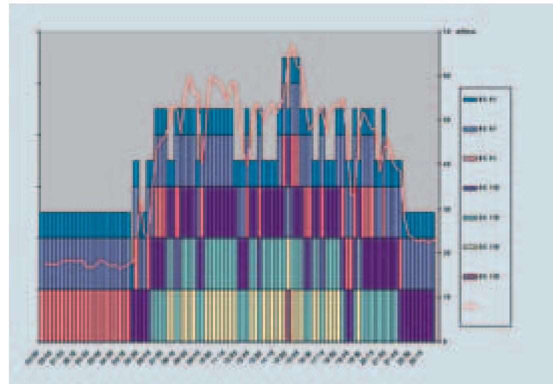


Illustration 4: Better utilisation of compressors with the help of optimised splitting and efficient compressor coordination

In view of the increasing cost of energy, thrifty use of it is not just a sound economic measure but an ecological necessity as well.

8. Energy savings
With heat recovery

Compressor manufacturers offer many possibilities, but one potential that is still largely ignored is the recovery of the heat produced by compression.

1. Compressors primarily generate heat
Although this statement may seem unbelievable, the truth is that 100 percent of the electrical energy input to a compressor is turned into heat. The action of compression charges the air in the compressor with potential energy. This energy is given up at the point of use by the compressed air expanding and drawing heat from the surroundings.

2. Up to 94 percent useable energy
The major proportion of the energy recoverable as heat, about 72%, is found in the compressor cooling oil, about 13 percent is in the compressed air itself and up to 9 percent is given up by the drive motor to the cooling air. In a fully encapsulated oil-cooled rotary screw compressor package even the losses from the electric motor can be recovered as hot air. This brings the total proportion of input energy available as heat up to a startling 94 percent. Of the remaining energy, 2 percent radiates away from the compressor package and 4 percent remains in the compressed air **(see heat flow diagram on page 19)**.

3. Possibilities of heat recovery
Users wanting to improve the economy of their compressed air plant can choose from a number of heat recovery methods.

a) Air heating
The simplest and most direct method of recovering the heat generated in an oil cooled rotary screw compressor is by direct utilisation of the cooling air carrying away the heat from the airend, oil cooler, motor, etc. This heated air is ducted away for use as space heating in warehouses and workshops **(Illustration 1)**. The hot air can also be used for other applications such as drying, heat curtains and pre-heating combustion air. When the heated air is not needed a manual or automatic flap or louver discharges it to the open. The flap can be thermostatically regulated to maintain a constant, set temperature. The space heating method allows 94 percent of the electrical energy consumption of a screw compressor to be recovered. And it is well worth it, even in small units, as an 18.5 kW compressor can easily make enough energy available to heat a normal family home.

b) Hot water
Hot water can be recovered for various purposes either from an air-cooled or water-cooled compressor package with a heat exchanger **(Illustration 2)** installed in the airend cooling oil circuit. Plate or fail-safe heat exchangers are employed, depending on whether the water is used for heating, laundry or showering, production or commercial cleaning purposes. Water temperatures of up to a maximum of 70°C can be achieved with these heat exchangers. Experience shows that for compressor packages upward of 18.5 kW capacity the additional costs for these heat recovery systems amortise within two years. Conditional, of course, on correct design.

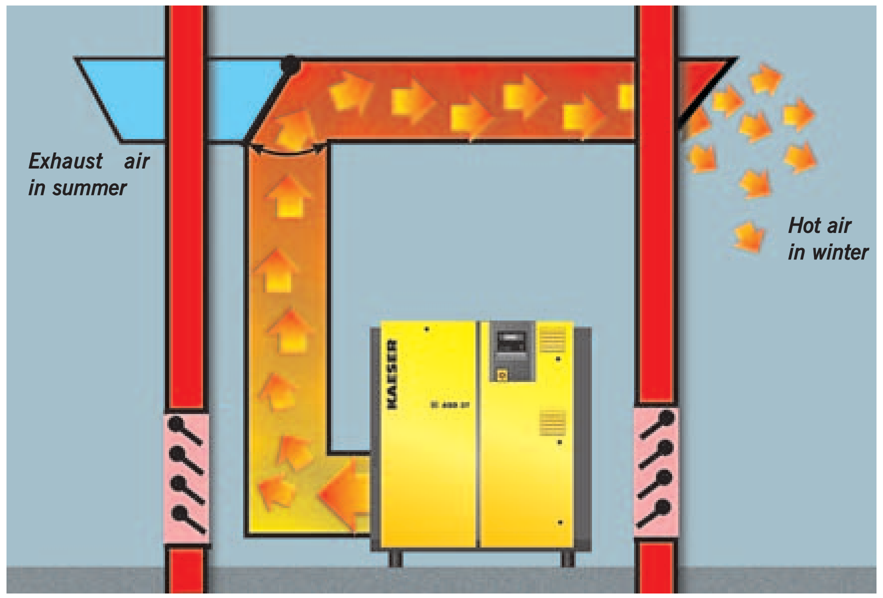


Illustration 1: Heat recovery system with ducting and control flap to direct the flow of hot air from the compressor

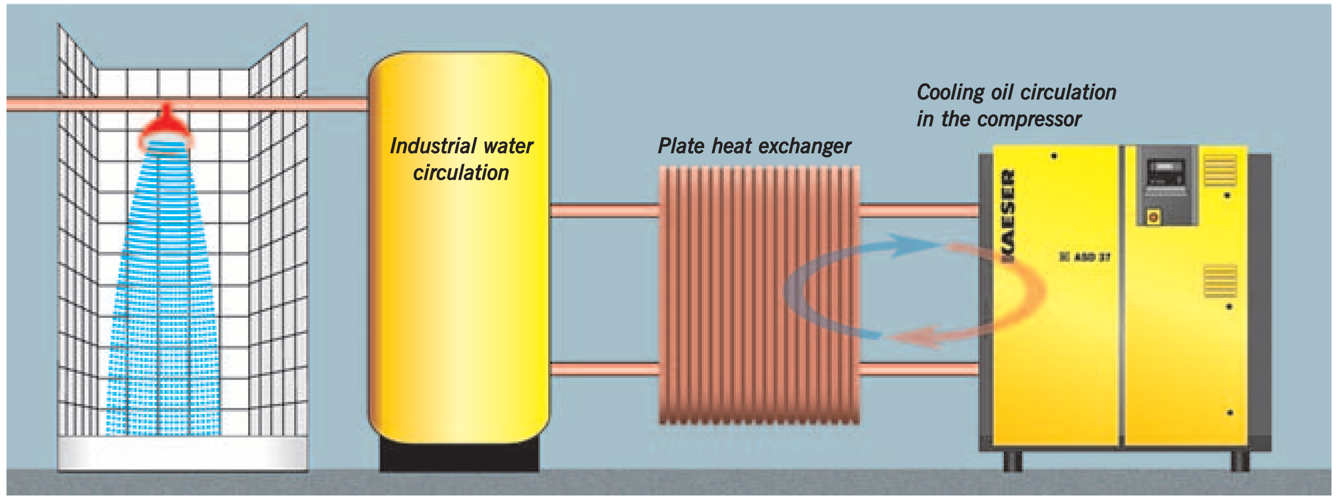
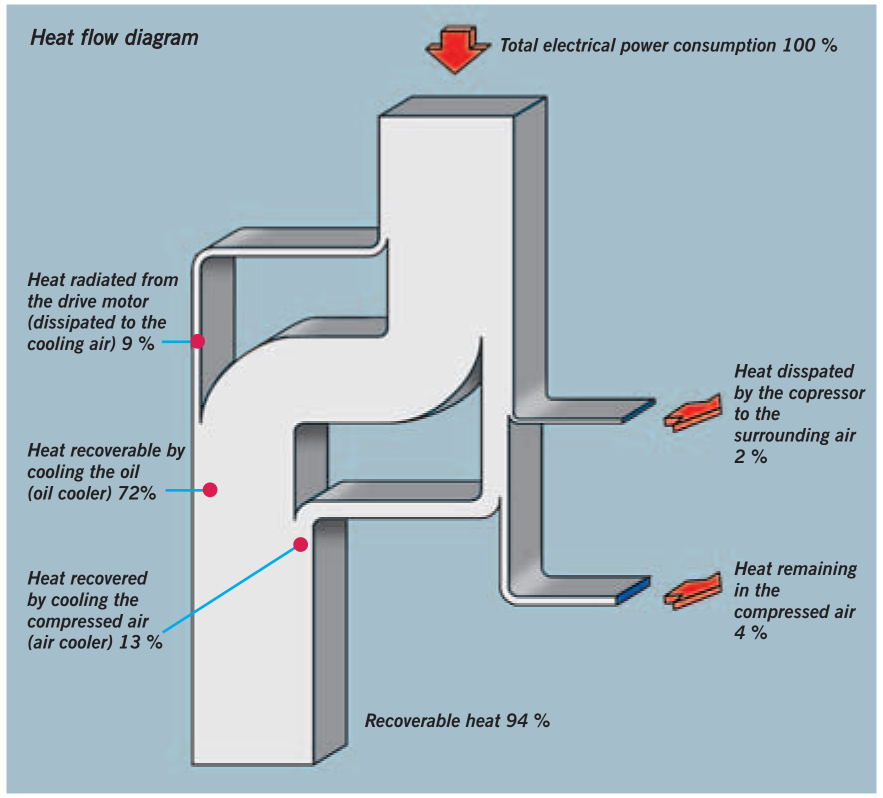


Illustration 2: Heat recovery system using a plate heat exchanger to heat water to 70 °C

4. Considerations of reliability
Normally, the compressor's primary cooling system should never be used both for cooling and as a heat recovery system. The reason; should the heat recovery system fail then compressor cooling and therefore the production of compressed air would be endangered. The safest method is to fit an additional heat exchanger in the compressor purely for heat recovery. Then, in the event of it failing, or if no hot water is needed, the compressor can revert to its primary air or water cooling system and so continue operation. The supply of compressed air is ensured.

5. Conclusion
Recovering the heat of compression for a useful purpose is an intelligent way of improving the economics of compressed air production and relieving the environment at the same time. The effort involved is relatively small. The investment is quickly recovered depending on local circumstances, the purpose to which the heat is put and the method of recovery chosen.



Compressed air, as an energy medium, is extremely flexible but not exactly cheap. It is only worth using if its production, preparation, and distribution are matched to each other as harmoniously as possible. This involves both correct design of the air system, and the right sizing and installation of the system's air distribution.

9. Avoiding energy losses (1)

Designing and installing a compressed air main

1. Economical compressed air production

When the cost of energy, cooling medium, maintenance and equipment depreciation is taken into account, the cost of each cubic metre of air produced, depending on the compressor size, utilisation, condition and model, is between 0.5 and 2.5 cents. Many production facilities place great importance on really economical compressed air production. That is also the reason for the fast advancement of oil-cooled screw compressors. They can save as much as 20 percent of the costs of producing compressed air compared with other types of compressor.

2. The influence of air treatment on the air main

In contrast, far less consideration is given to air treatment for the application at hand. This is regrettable, as only properly treated air can lower the maintenance costs of air consumers, pipework, etc.

a) Refrigeration dryers reduce maintenance

A refrigeration dryer provides an air quality sufficient to meet 80 percent of all applications. They often save the losses in pressure introduced by filters in the air network and consume only about three percent of the energy that the compressor would otherwise use to make up for these pressure losses. In addition, the saving in costs for maintenance and repair of air consumers and pipework can be easily ten times the average cost of refrigeration drying.

b) Space-saving combinations

Space-saving combinations of rotary screw air compressor, refrigeration dryer and air receiver **(illustration right)**, or combinations of rotary screw air compressor and dryer in tower layout are available for smaller or local applications.

3. Designing and installing an air main

First, it must be decided whether or not the air supplies are to be installed locally or centrally. A centralised system is generally sufficient for small and medium-sized production facilities as this does not give rise to problems encountered in a greatly extended air main, such as high installation costs, danger of frost in non-insulated outside lines and high pressure losses due to long pipe runs.

a) Correctly sizing the network

A calculation is always needed to correctly size an air main. This should be based on a maximum acceptable pressure drop of 1 bar between the compressor and the air consumer, including the pressure swing of the compressors and a normal treatment system (refrigeration drying).

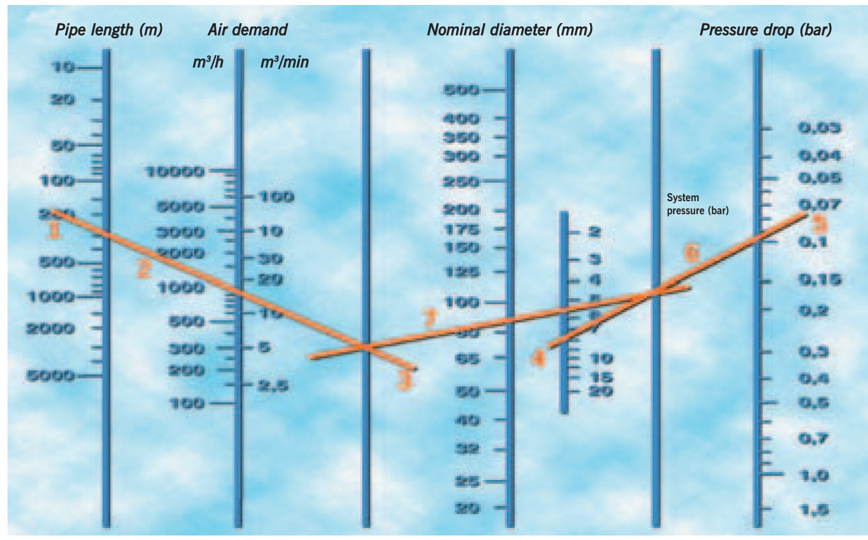
Individual pressure losses can be assumed as follows **(Illustration right)**:

Main line	0.03 bar	①
Distribution lines	0.03 bar	②
Branch lines	0.04 bar	③
Dryer	0.20 bar	④
PRL unit and hose	0.50 bar	⑤
Total	**0.80 bar**	

This list shows how important it is to calculate the pressure drops in the individual line sections. Moulded fittings and shutoff valves must also be taken into account. It is not sufficient to consider only the total length of pipework in a formula or table. It is far more important that the technical flow length of the pipework is determined. Normally, an accurate count of all fittings and valves is not possible during the early stages of design. For this reason, the technical flow length of the pipes is estimated by multiplying the total straight line length by a factor of 1.6. The pipeline diameters are then determined by means of the straight-line graph **(see illustration below right)**.

b) Energy-saving pipe runs

In order to save energy the pipe layout should be as straight and direct as possible. For instance, one can avoid bends when laying pipework around an obstacle by repositioning the run in a straight line alongside it. Sharp, 90° corners cause high pressure drops and should be replaced with large-radius elbows. Instead of commonly-used water taps, ball or butterfly valves with full through flow bores should be used. In wet areas, e.g. the compressor room in the case of modern air systems, connections to and from the main line should be made from above or at least from the side. The main line should have a drop of 2 in 1000. The possibility of connecting a condensate drain should be provided at the lowest point in this line. In dry areas the pipeline can be horizontal with branch lines connected directly downwards.



c) Which pipe material is correct?

No specific recommendation can be made with regard to material properties. The price alone provides little help in making a decision; galvanised steel, copper and plastic pipes are all about the same price if installation costs are added. Stainless steel piping is about 20 percent more expensive. However, more efficient processing methods have caused prices to drop lately.

Most manufacturers offer tables in which the optimal conditions for every pipe material are given. It is wise to study such tables before making a decision, to take into account the loads placed on the air main during future normal operation and then to make up a specification for the pipework. This is the only way to ensure a really good air main system.

d) Important - correct jointing

The pipes should be jointed either by welding, with adhesive or threaded with adhesive. Of major importance is that the jointing is done correctly to ensure a mechanically sound and leak-proof joint, even if it is difficult to take them apart again.

Every year, thousands of euros are blown away. The reason - aging or poorly maintained air main distribution systems allowing valuable energy to escape unused. Resolving these deficiencies requires a lot of thought and involves a lot of hard work. Here are some useful tips on refurbishing an air main network.

10. Avoiding energy losses (2)

Refurbishing an existing compressed air main

1. The basic requirement - dry compressed air

When planning a new air main, mistakes leading to problems in the future can be avoided. Often, refurbishing an existing air main is fraught with difficulty. Above all, it is a pointless exercise if the air fed into the distribution network contains moisture. Before beginning to refurbish, the first essential action is to make sure the air is dried at source.

2. What if there is an excessive pressure drop in the main?

If the pressure drop in the main is excessive, even after a satisfactory treatment system has been installed, then the cause is probably deposits in the pipes. Dirt carried in the compressed air is deposited on the pipe walls, reducing their effective diameter and narrowing the passage through which air flows.

a) Replacement or blow out

If the deposits are firmly encrusted there may be no alternative but to replace sections of pipe. However, it is possible to blow out the pipes if the inside diameter is only slightly narrowed by deposits, followed by thorough drying before bringing them back into service.

b) Installing supplementary lines

A good way of increasing the effective diameter of a spur line is to connect a second pipe in parallel with it. A supplementary ring main can also be laid if the inside diameter of the original ring is to narrow **(Illustration 1)**. If correctly sized, a supplementary spur line or double ring not only relieves the pressure drop problem but also increases the reliability of the distribution network in general. A fur-ther possibility of improving the airflow in a ring main is by using cross-connected lines as shown in **illustration 2**.

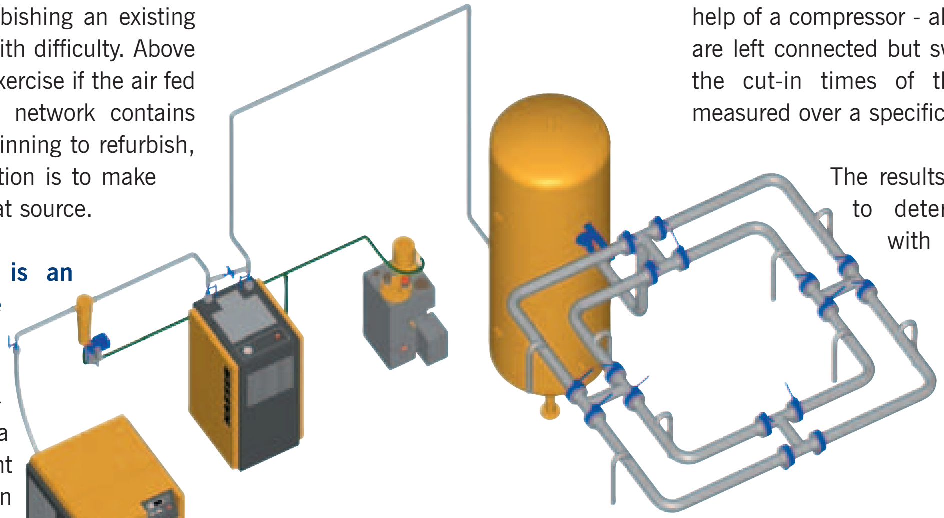


Illustration 1: Refurbishing an air main by laying a supplementary ring main

3. Tracing and stopping leaks

A prime objective of any refurbishment concept must be to stop, as far as is possible, leakage of air in the air main network.

a) Determining total leakage from an air main

Before searching for individual leaks in the network, however, the overall magnitude of leakage has to be established. This is done relatively simply with the help of a compressor - all air consumers are left connected but switched off and the cut-in times of the compressor measured over a specific period **(Illustration 3)**. The results are then used to determine leakage with the following formula:

Where:

VL = leakage (m³/min)

VC = free air delivery of the compressor (m³/min)

$\Sigma x = t_1 + t_2 + t_3 + t_4 + t_5$ = time the compressor ran on load (min)

T = total time (min)

$$VL = \frac{VC \times \Sigma t_x}{T}$$

b) Measuring consumer leakage

First, measurement 3. a) is made **(Illustration 4)** to calculate total leakage. Then, the shut off valves upstream of all consumers are closed and the measurement made again to determine the leaks in the air main **(Illustration 5)**. The difference between the total and network leakage is the leakage caused by the consumers and their fittings.

4. Where are most leaks to be found?

Experience shows that 70% of leaks from an air main occur in the last few metres of the network, i.e. at or near the takeoff point. These leaks can usually be pinpointed with the help of soap suds or special sprays.

The main pipework is only a source of significant leakage if old hemp seals in an originally wet network that have been kept damp by the moist air then dry out when the network is fed by dry air. Leaks in main pipework are best detected with the aid of ultrasonic instruments. When the last leak has been located, removed and the effective diameter of the pipeline is sufficient for the flow rate required then the old air main has (once more) become an efficient air distribution system.

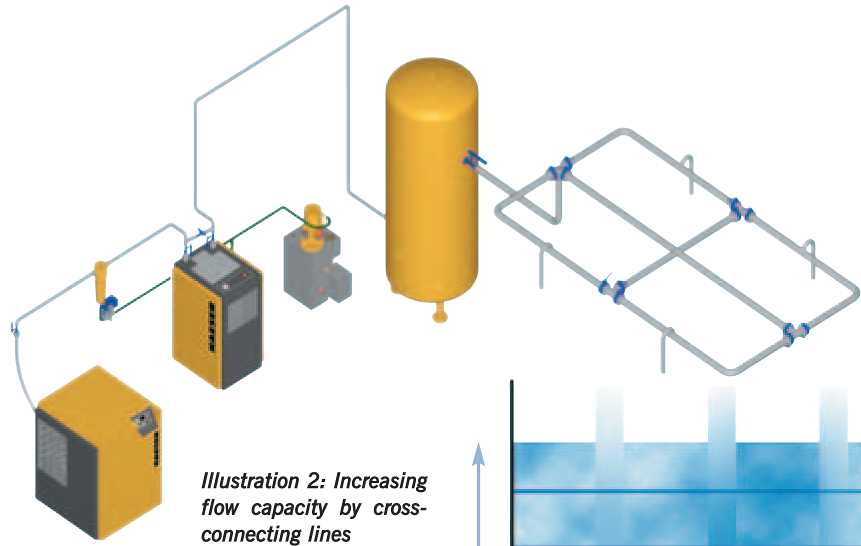


Illustration 2: Increasing flow capacity by cross-connecting lines

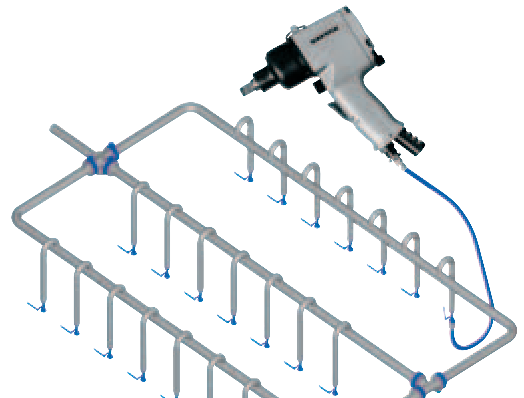


Illustration 4

Measuring consumer leakage

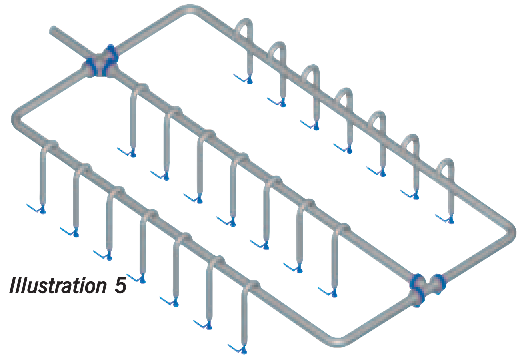


Illustration 5

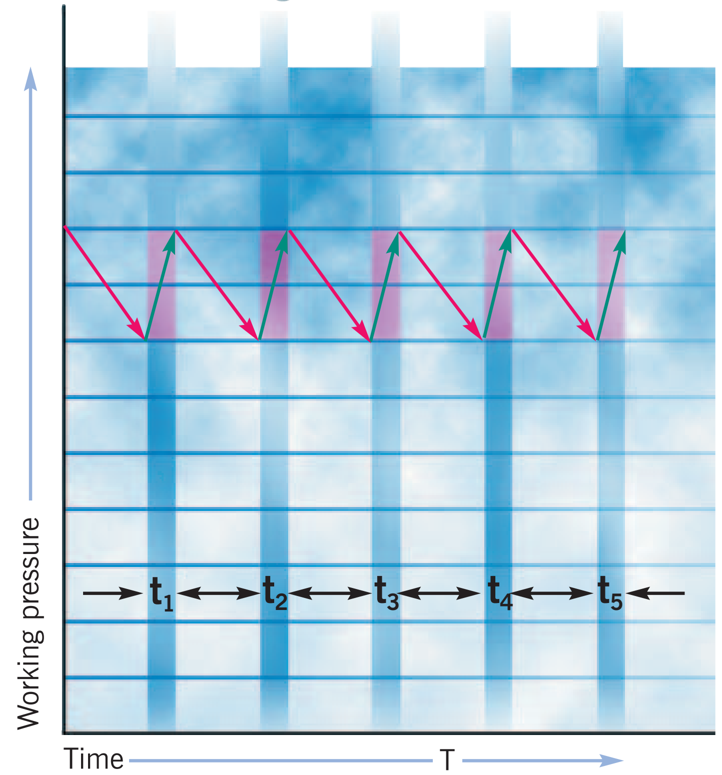


Illustration 3: Determining total leakage by measuring compressor cut-in times with all consumers switched off

Compressed air installations are generally complex systems. They can only be operated at their best and most economically if this is taken into account during planning, extension and modernisation. Kaeser has developed a tool to aid these processes. The tool takes the form of a comprehensive service that combines proven elements such as compressed air components, customer consultation and service with the modern possibilities offered by information technology in compressed air engineering.

11. Correctly designing air systems (1)

Air Demand Analysis (ADA)

The spectrum of compressed air applications is extremely broad, from A for automobile manufacturer to Z for zinc coating plant. But, the common prerequisite for efficient use of compressed air is the reliable production and treatment of the air itself. The air system must be able to deliver the air in the specified quantity and quality at an economic price.

1. Consultation influences economics

An air system is cost effective only if it suits the application for which it is intended and fits the location and the conditions under which it operates. In other words: the component parts of compressors, treatment plant and pipework must be correctly chosen, sized and be under some efficient means of control; there must be adequate ventilation and a means of dealing with accumulating condensate and, if possible, there should be a means of recovering the waste heat generated by the compressors. This is all taken into account in the KESS (Kaeser Energy Saving System) service. It comprises air demand analysis, planning **(Illustration 1)**, realisation, further training and customer service. Of decisive importance is the quality of the consultation and the choice of the right technology; the greatest potential for cost savings lie in power consumption and maintenance rather than in the purchase price itself.

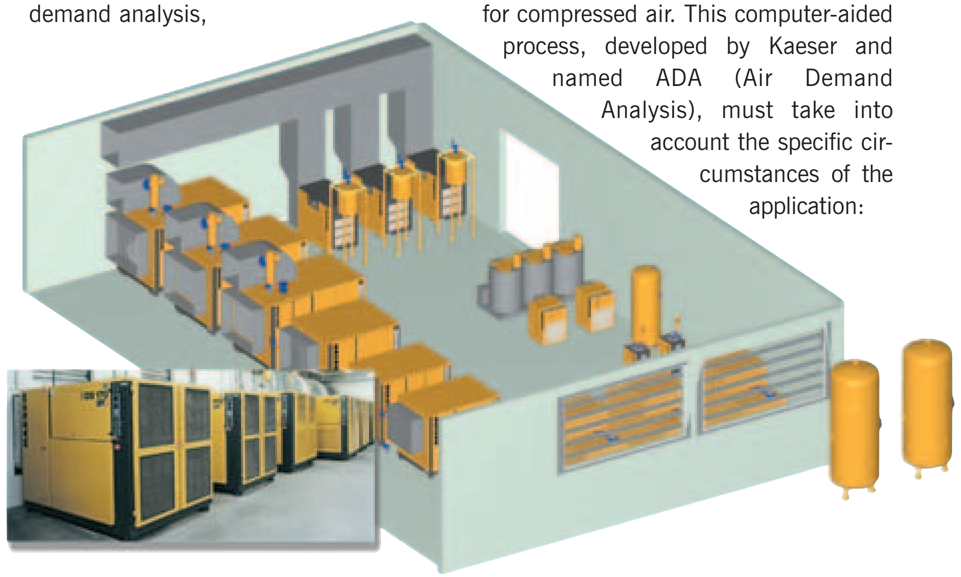


Illustration 1: The facilities of a modern 3-dimensional CAD system allow the air system to be designed down to the last detail and laid out to suit the user's needs

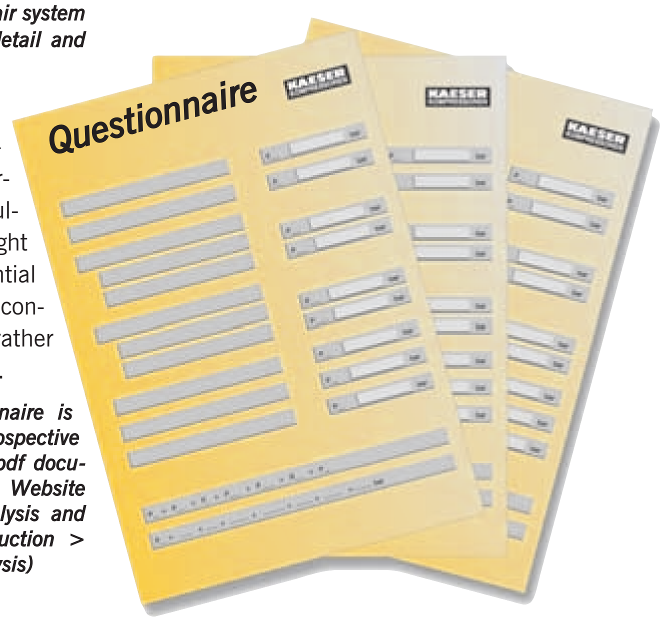


Illustration 2: A special questionnaire is available as a planning guide to prospective users. It can be downloaded as a pdf document directly from the KAESER Website www.kaeser.com, (Services > Analysis and Advice > Point-by-point cost reduction > Questionnaire for Air Demand Analysis)

2. Air Demand Analysis

The basis of every KESS exercise is an intensive investigation into the users current and possible future requirements for compressed air. This computer-aided process, developed by Kaeser and named ADA (Air Demand Analysis), must take into account the specific circumstances of the application:

a) Designing a new air supply system

The future customer is presented with a comprehensive questionnaire that provides information for the new design **(Illustration 2)**.
A Kaeser consultant can then interpret this guide to determine the system equipment needed to cope most efficiently with the expected air demand. The questions cover all aspects of an economical and environmentally friendly compressed air supply system.

b) Expanding and modernising

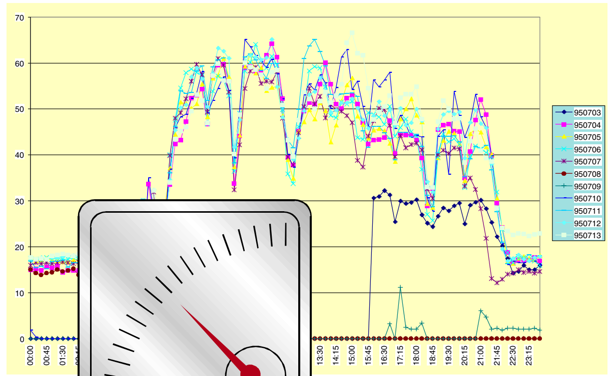
In contrast to new projects, expansion or modernisation of existing plant usually provides a sufficient basis for a design that suits requirements. Kaeser provides measuring instruments and data loggers with which the air demand is precisely determined in various locations and at different times. It is very important to determine maximum and minimum as well as average values **(Illustration 3)**.

c) Testing the efficiency of an existing air system

It is recommended that the efficiency of an existing air system is checked from time to time with the help of a computer-aided analysis method that determines whether the compressors are (still) correctly loaded, whether the control systems are (still) correctly programmed and whether leakage rates are still within an acceptable tolerance. ADA should also be used if compressors are to be replaced by new machines. This will avoid possible errors in capacity selection that may lead to inefficient duty cycles and assist in the selection of a suitable master control system **(Illustration 4)**.

d) Changes in operating conditions

It is well worth consulting a specialist when the conditions change under which an air system operates. Often simple changes to air treatment methods or pressure matching can be made to suit the new circumstances, achieving significant cost savings.



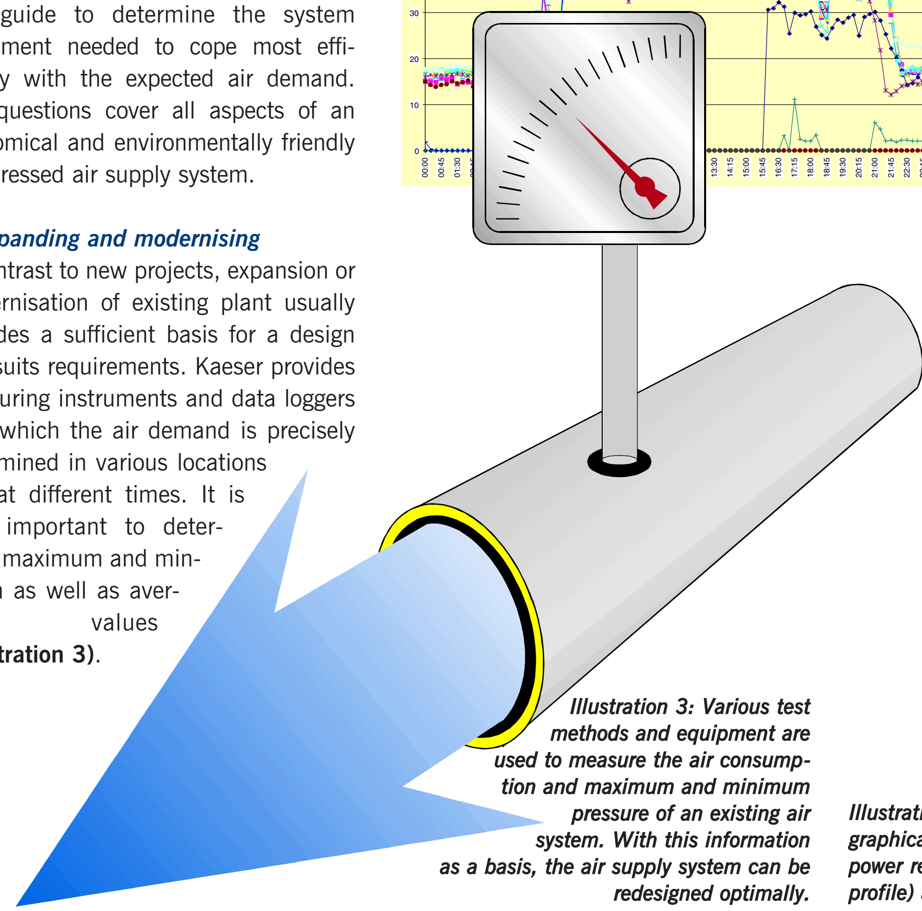


Illustration 3: Various test methods and equipment are used to measure the air consumption and maximum and minimum pressure of an existing air system. With this information as a basis, the air supply system can be redesigned optimally.

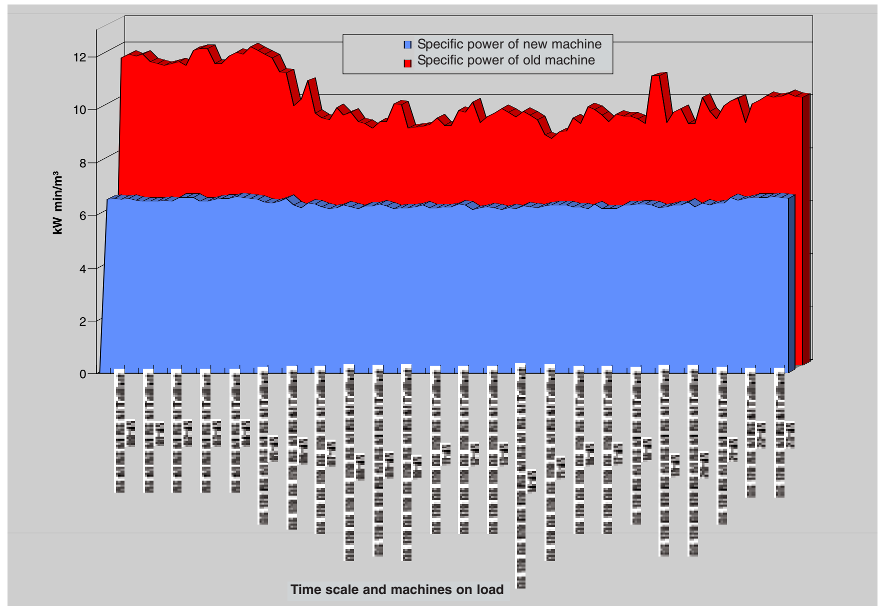


Illustration 4: ADA-acquired data can be graphically presented to show the specific power requirement of the old air system (top profile) and the new (lower profile).

12. Correctly designing air systems (2)

Determining the most efficient concept

A bottomless pit, or a money-saver? A compressed air system can be one or the other. The magic formula is "System Optimisation". If system optimisation were to be universally applied, over 30 percent of the average overall compressed air costs incurred in European industrial facilities could be saved. Around 70 to 80 percent of these savings would come from reduction in power consumption. Diminishing fossil fuel resources mean that energy will almost certainly become more expensive as time goes by. Finding the most efficient compressed air concept is vital to the user.

KAESER's Energy Saving System (KESS) includes a computer-aided calculation of system optimisation. This makes it easy to choose an air supply system most suited to the user's particular application from several possible alternatives. A design questionnaire, carefully filled out with the help of a KAESER consultant, serves as a basis for the new system and takes into account all factors, including anticipated overall air consumption and daily fluctuations. For existing air systems the calculation is based on the characteristic daily profile determined by an analysis of the air demand (ADA).

1. Computer-aided findings

Before an existing air supply system can be optimised, all the technical data relating to it and any possible new alternatives are entered into the KESS software. KESS then selects the optimum version from the possible alternatives and calculates the cost savings compared with the others. At the same time, the momentary power consumption at a defined air demand, including all losses, is calculated. It is also possible to get a precise picture of the specific power profile of the air system during the whole of the running period **(Illustration 1)**. This means that any weak points in partial load operation can be detected in advance and remedied. The overall result is a clear statement of potential cost savings and amortisation.

2. It's the mix that counts

In most cases a precisely coordinated configuration of compressors of different capacity has been shown to be the right answer. Generally it consists of large capacity base load and standby compressors combined with smaller peak load machines. The master controller's task is to ensure the best possible balanced specific power requirement. To do this it must be able to automatically select the most appropriate combination of base load and peak load machines from up to 16 compressors working within a pressure band of only 0.2 bar. Intelligent master control systems such as KAESER'S Vesis and Sigma Air Manager fulfil these high demands. These controllers can be linked with compressors and other components such as condensate drains, dryers, etc., for exchange of data via a bus system. They can also route all operating data to a control centre via an interface.

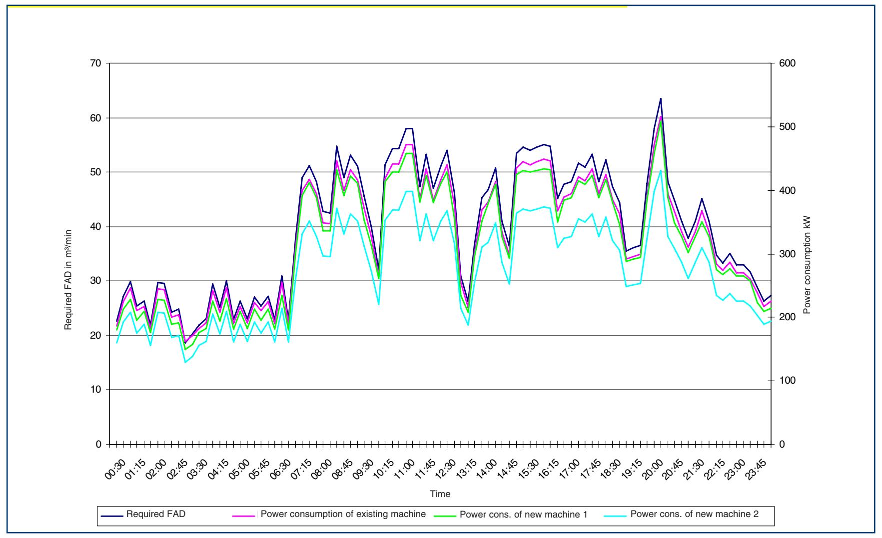


Illustration 1: Comparison of the power consumption of an existing air supply system with new alternative systems over a one-day period related to air demand

3. Structural optimisation

A newly designed or modernised air supply system should make optimum use of the space in which it is to be installed. Modern design systems such as those used by KAESER provide worthwhile support in this regard. During the design process they not only use floor plans and P & I flow charts but computer-generated and animated 3-D illustrations as well. This means that it is often possible to take advantage of economical air-cooling despite cramped conditions in the compressor room. Compared with considerably more complicated water-cooled systems, costs of around 30 to 40 percent can be saved with air cooling. A further advantage is that possible weak points and sources of faults can be identified and 'designed out', allowing the installation to be structurally optimised **(Illustrations 2 a - c)**.

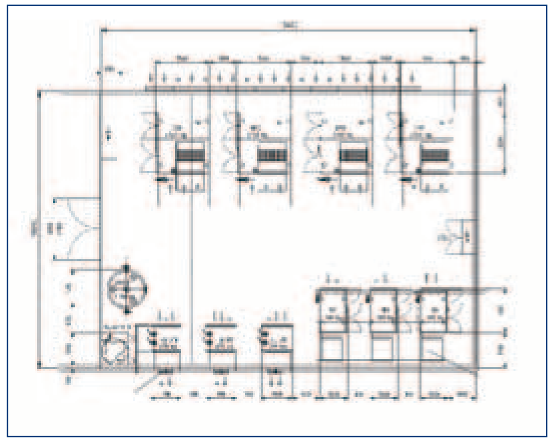


Illustration 2 a: Floor plan of an air supply system in a car manufacturing plant

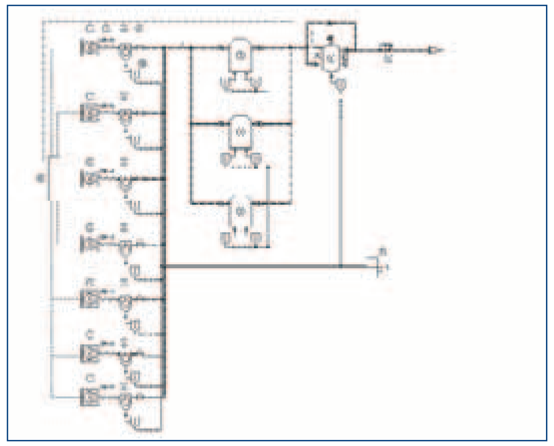


Illustration 2 b: P & I flow chart of the same air system

4. Operational optimisation and controlling

To ensure economical air supplies over the long term, an optimised cost-benefit relationship and the transparency necessary for effective controlling is an absolute must. The basis for such transparency is Sigma Control, an industrial computer integrated into the compressor with five pre-programmed control modes and the ability to collect data and transfer it to a data network. At the master control level a further industrial computer is used, the Sigma Air Manager already mentioned **(Illustration 3)**. Its task, as well as appropriate control and monitoring of the air supply system, is to collect all relevant data and pass it on to a computer network (Ethernet). This can take place via Internet or via the "Sigma Control Centre" software. Together with the visualisation system "Sigma Air Control", this PC-installed software can display a list of all the air compressors and their most important data. This shows at a glance whether the system is functioning correctly, whether maintenance or alarm messages are activated, and how high system pressure is. The depth of information can be freely selected. For example, operational events can be traced, graphs of power consumption, air demand and pressure can be called up, and preventive maintenance scheduled. This modern controlling tool plays a vital part in ensuring an uninterrupted supply of compressed air of the required volume and quality – at minimum cost.

Illustration 3: As well as optimal interplay of all system components, the new Sigma Air Manager master controller ensures significantly increased availability and effective controlling of the compressed air supplies

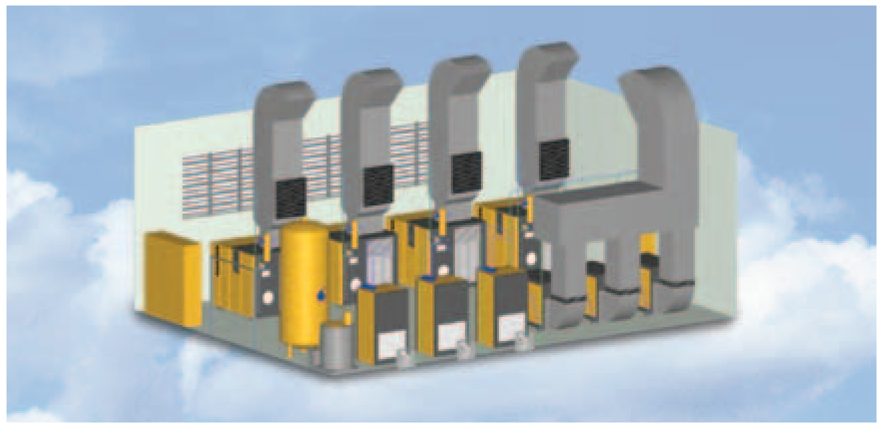


Illustration 2 c: Computer generated 3-D animation allows a virtual stroll through the installation and a view of the equipment from almost every perspective

13. Correctly designing air systems (3)

Determining actual system state and Air Demand Analysis (ADA)

Few of the compressed air systems in use today have an optimised cost structure. A system optimisation is highly recommended for all the rest. The basic requirement for such a system optimisation is a detailed analysis of air demand (ADA), as already outlined in chapter 11, page 24. In this chapter, we will describe step-by-step how the actual state of an air system can be determined in practice.

The prerequisite for analysis and subsequent optimisation is trustworthy cooperation between the user and the compressed air specialist. This includes the provision by the user of all the needed information in advance.

1. Information from the user

a) Layout plan

A layout of the production facility should be available for general orientation **(Illustration 1)**. It should detail the system's air main pipework, interconnecting lines and air inlet points. Details of pipe diameters and materials, the main air take-off points and any take-off points for air at special pressures and qualities must be shown.

b) Applications

Compressed air is a highly versatile medium and the user must make its specific applications clear. Such information should state, for example, whether the air is to be used as control air, for surface treatment, for rotating tools, for cleaning or as process air, etc.

c) Installed compressors

As well as the model and type, the technical data of the compressors such as working pressure, free air delivery, power consumption, type of cooling and use of heat recovery should be mentioned.

d) Air treatment

As far as air treatment is concerned, it is important to know whether the air is treated centrally or locally and what classes of quality are required. Obviously, the technical specifications of the components should be listed, and a flow chart will provide the necessary clarity **(Illustration 2)**.

e) Compressor control and monitoring

As not only the properties of the individual compressors but also their coordination influences the economics of an air system to a high degree, a description of the control and monitoring techniques used should be included.

2. Discussions between user and specialist

When the above information is available, the specialist should be familiarised with the relevant documents and then any problems with the air supply discussed. Such problems could be low or fluctuating pressure, poor air quality and inadequate utilisation of compressors or problems with cooling.

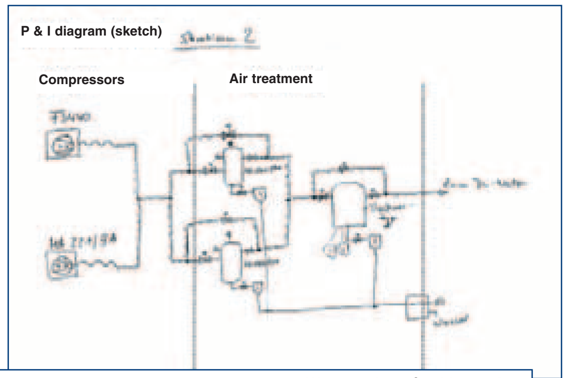


Illustration 2: Hand sketched P & I flow diagram of a proposed air system.

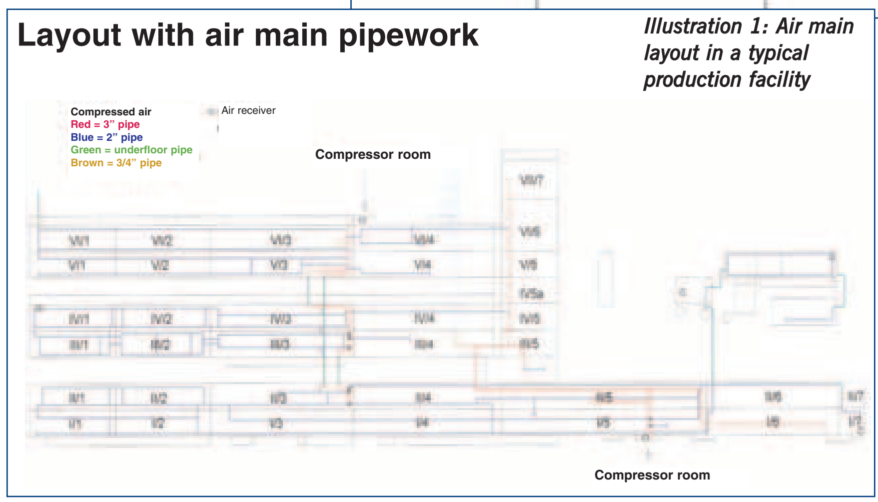


Illustration 1: Air main layout in a typical production facility

3. Inspection

The most revealing phase is an inspection of the compressed air system. This should always start in the most critical zone, i.e., where the greatest pressure drops **(Illustration 3)** or poor air quality are to be expected. Experience shows that these are often the final take-off points. It is recommended that special attention is given to the following points:

a) Connecting hoses, pressure regulators, condensate drains

It is mostly the hose connections to the air consumers that are leaky. These should be thoroughly checked. If a pressure regulator/lubricator (PRL) is installed then its pressure settings (inlet and outlet pressure) should be checked under load **(Illustration 4)**. Condensate drains fitted upstream of the pressure regulators should be checked for fluid level and clogging. The same applies to pipes taken off in a downward direction **(Illustration 5)**.

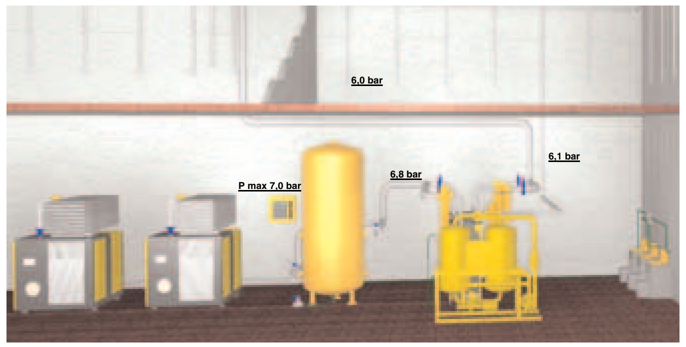


Illustration 3: Pressure drop in an air system

Illustration 4: Energy-wasting local pressure regulator with water separator

b) Shut-off valves

Distribution lines and their fittings leading away from the main line have a vital influence on system efficiency. Shut-off valves and the like belong to the neuralgic points of the system. They should be adequately sized, full-flow ball or butterfly types, not inefficient water taps or angle valves.

c) Main ring

The most important point is detecting causes of pressure drops such as narrowed sections.

d) Air treatment systems

The most important inspection criteria here are the pressure dew point achieved (degree of dryness) and the pressure drop across each component part. Further quality checks may be required depending on the application.

e) The air system

The air system itself can, of course, have considerable deficiencies. In particular, the location of the compressors, ventilation, cooling and pipework should be checked. Furthermore, the cumulative pressure swing of the compressors, the size of the air receiver and the location of the pressure measurement points from which the compressors are controlled must be checked.

f) Determining ADA measuring points

When the inspection is completed, the specialist and the user decide on the points at which ADA measurements are to be taken. The minimum requirements are measuring points upstream and downstream of the air treatment system and at the outlet of the air main.

4. Measurement of pressure and air consumption (ADA)

During measurement of pressure and air consumption the operation of the compressed air system is monitored over a period of at least 10 days with the help of modern data logger technology. The data logger collects the relevant data and transfers them to a PC that creates a diagram of compressed air consumption. The graph shows pressure drops, fluctuations in pressure and consumption, off-load profiles, on-load and standstill periods of the compressors and the relationship of the performance of each individual compressor to the respective air consumption. To complete the picture, the leaks have to be determined. This is done as described in chapter 10, page 22 and requires selective closure of defined sections of the air main over the weekend.

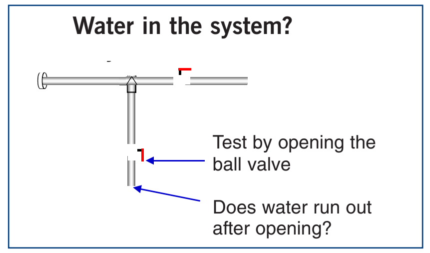


Illustration 5: Water in the system? (test)

Compressors convert almost 100 percent of the electrical power consumed into heat. Even a relatively small 18.5 kW compressor generates enough surplus thermal energy to easily heat a family home. Which is why efficient cooling is essential for reliable operation of a compressed air system.

14. Correctly designing air systems (4)

Cooling compressors efficiently - air cooling

The waste heat generated by compressors can be seen as a means of energy saving. With the help of appropriate heat recovery systems, up to 94 percent of the power consumed can be recovered as heat, and if this is put to good use it can significantly reduce the costs of compressed air production (see chapter 8, page 18). However, even where heat is recovered, the compressor still needs a complete, inherent cooling system. The costs for air cooling can fall below those for water-cooled systems by as much as 30 percent. Which is why air-cooled systems should be given preference wherever possible.

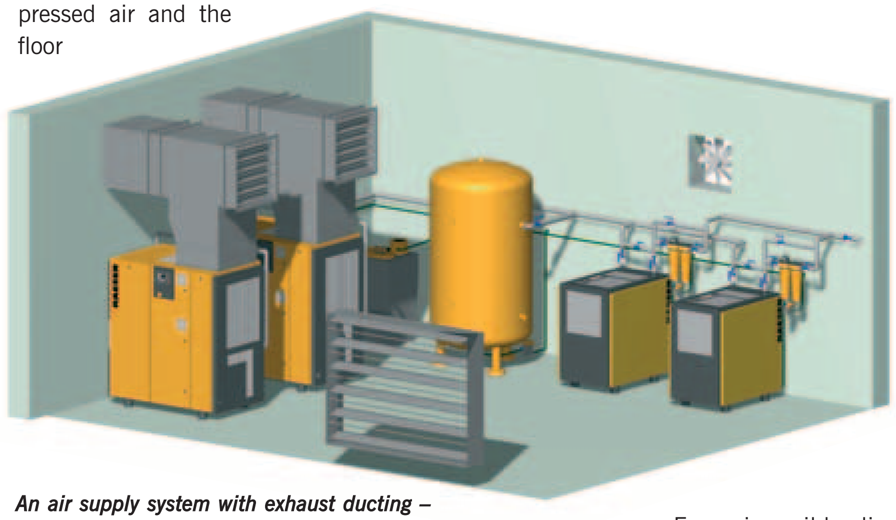
1. In and around the compressors

a) Clean and cool comes up trumps

One of the main requirements of accident prevention regulations is that compressors must be installed such that all round accessibility and sufficient cooling is assured. Regulations for the implementation of compressors require that ambient temperatures for the operation of air and oil-cooled compressors may not exceed +40 °C. Regulations also state that dangerous substances must never be released near intakes of compressors. These regulations no longer have to be regarded as minimal requirements. Their purpose is to keep the risk of accidents as low as possible. Economical operation and minimal compressor maintenance, however, demand a lot more.

b) The compressor room is not a garden shed

A compressor room is not a storage area. That is to say it should be kept free of dust and other contaminants, extraneous equipment that has nothing to do with the production of compressed air and the floor should be non-friable. Ideally, it should be washable. Under no circumstances may air be drawn in to the compressor room from a dusty or otherwise contaminated environment unless intensive filtration is used. But, even under normal operating conditions, intake und cooling air should be cleaned with appropriate filters.



An air supply system with exhaust ducting – an efficient means of ventilation

c) A well-tempered climate

Temperature has a considerable influence on the reliability and maintenance requirements of compressors; inlet and cooling air should be neither too cold (below +3 °C) nor too hot (over +40 °C) * This must be taken into account in the planning and installation phases. For example, summer sun shining on south or west-facing walls of a building can increase the room temperature considerably. Even in mild climates room temperatures of up to +40 or even +45 °C could occur. This is why apertures for cooling and inlet air should be located in shaded walls and not in direct sunlight. The size of the apertures is related to the capacity of the compressors installed and to the method of ventilation used.

*): The temperature limits mentioned refer to climatic conditions in Central Europe and standard equipment in a compressed air supply system.

2. Ventilating the compressor room

Adequate ventilation of the compressor room is essential - even for water-cooled compressors. Whatever the case, heat radiated within the packaged compressor from the airend and electric motor has to be extracted from the room. This corresponds to about 10 percent of the drive power of the compressor.

3. Various methods of ventilation

a) Natural ventilation (Illustration 1)

Cooling air is drawn into the room by the compressor fan, the air is heated as it passes over the compressor and rises upwards, leaving the compressor room through an aperture placed near the ceiling. This kind of ventilation (convection) can only be recommended, however, for use in exceptional cases and for compressor powers below 5.5 kW, as even sunshine or wind pressure on the exhaust aperture can cause it to break down.

b) Forced ventilation

This is the most commonly used method. Ventilation is thermostatically controlled to avoid the temperature in the compressor room from falling below +3 °C in the winter. Low temperatures are detrimental to the function of the compressors, the condensate drains and the air treatment equipment. Thermostatic control is necessary because with forced ventilation the compressor room is subjected to a certain vacuum that prevents backflow of hot air into the room. There are two methods of forced ventilation:

Ventilation with an extractor fan

A fan installed in the exhaust aperture of the compressor room and fitted with thermostatic control **(Illustration 2)** exhausts the heated air. An important requirement for this type of ventilation is that the cooling air inlet aperture is of sufficient size (see lower right in illustration 2); if it is too small, it could cause too high a vacuum resulting in increased noise from excessive airflow speeds. In addition, cooling of the compressed air plant would be endangered. The ventilation should be designed to restrict the temperature rise in the room caused by waste heat from the compressor to 7K above inlet temperature. Otherwise heat will build up and cause a compressor breakdown. A point to be considered is that extractor fans increase energy costs.

Ducted ventilation **(Illustration 3)**

Modern, fully encapsulated rotary screw compressors provide an almost ideal method of ventilation using exhaust ducting. The compressor fan draws in cooling air through an appropriately sized aperture and discharges it into a duct that takes it straight out of the compressor room. The principal advantage of this method is that the temperature of the cooling air may be allowed to rise significantly higher, to approximately 20 K above ambient. This reduces the volume of cooling air needed. Normally, the cooling fans fitted in the packaged compressors have sufficient residual thrust to drive the cooling air through the ducting and out of the room. This means that in contrast to ventilation with an external extractor fan no additional energy is needed. This applies only, however, if the residual thrust of the fans is sufficient for the ducting used. Ideally, the exhaust duct should be provided with a thermostatically controlled flap **(Illustration 4)** to direct hot air into the compressor room in winter to maintain proper operating temperatures. If air-cooled dryers are installed in the compressor room as well, the compressor(s) and dryer(s) should not influence each other's cooling air flows. At temperatures above +25 °C it is recommended to increase the cooling air flow rate by running a supplementary thermostatically controlled fan in the ducting.

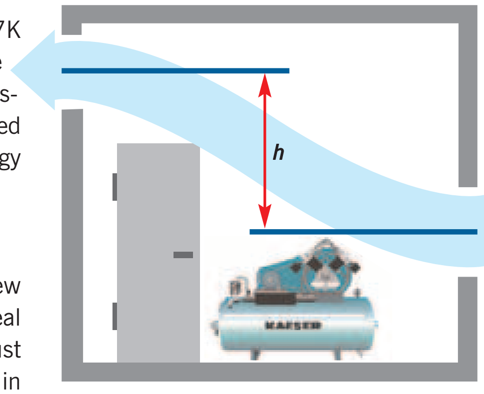


Illustration 1: Compressor room with natural ventilation for compressors below 5.5 kW

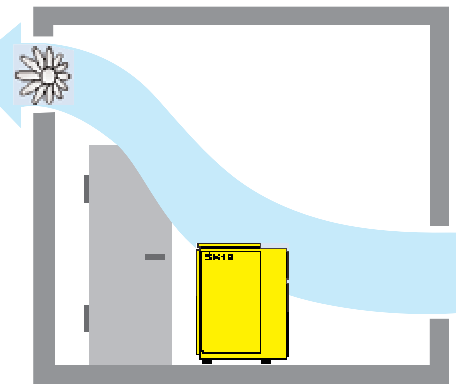


Illustration 2: Forced ventilation with extractor for compressors from 5.5 to 11 kW

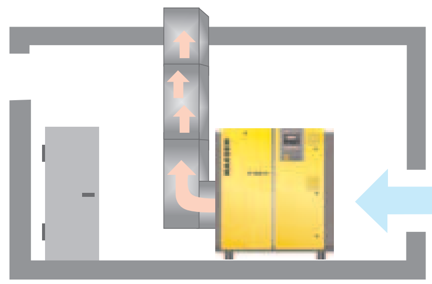


Illustration 3: Forced ventilation with exhaust ducting for machines above 11 kW

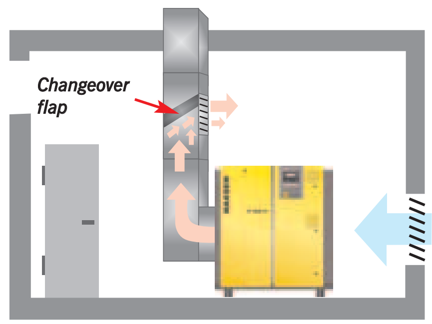


Illustration 4: A thermostatically-controlled flap directs hot air into the compressor room in winter

15. Using air systems correctly

Safeguarding reliability - cost-optimisation over the long term

On pages 20 to 31 we covered the things that had to be taken into account during installation and refurbishment of existing compressed air networks and how an efficient compressed air system should be planned and designed. Energy, cost-conscious planning and execution, however, are only half the battle. Over the long term, only efficient operation of the air system ensures the economical production of compressed air.

Striving for maximum system efficiency brings triple savings: the reliability of the air supplies increases, air costs and power consumption significantly decrease. The European “SAVE II” EU study indicates the potential to be high. Compressors in the EU consumed 80 milliard kWh in the year 2000. At least 30 percent of this energy could be saved.

1. What does optimum economy mean?

The economics of a compressed air system are reflected in its cost structure. The achievable optimum is never the same because it is related to a specific company and its production. Critical factors are compressor operating life, working pressure and other commercial parameters. The example illustrated **(Illustration 1)** is an optimised system with air-cooled compressors, operational life 5 years, power costs 8 cent/kWh, interest rate 6 percent, 7.5 bar working pressure, air quality to ISO 8573-1: class 1 oil content, class 1 dust content, class 1 water content (Illustration 1). The example shows that even under optimum conditions, power consumption with around 70 percent still takes the lion's share of overall compressed air costs.

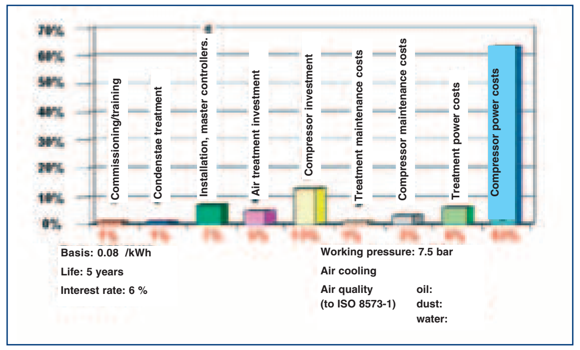


Illustration 1: Cost structure of an optimised air supply system

2. Maintaining economic efficiency

Anyone interested in air supplies that are economical over the long term should study the following points carefully:

a) Demand-oriented servicing

Modern internal compressor controllers such as “Sigma Control” and compressed air management systems such as “Sigma Air Manager” based on industrial computers provide accurate information on service intervals for the components of an air system. This has made it possible to carry out preventive maintenance and demand-oriented service work. The result is lower maintenance costs, more economical and reliable air supplies and increased production line reliability.

b) Matching air consumers

There is danger of making false savings both in the production of compressed air and in its consumption; for instance, by using a cheaply priced production machine that needs a higher working pressure. The cost of generating pressure higher than the standard 6 bar would quickly rise above the extra cost for a more efficient machine working with a lower pressure. When considering the specification of new air consuming production machines the pressure of the air needed is just as important as the electrical power supply, which is why guidelines of such production machines should be written for the purchase that cover both electrical power and compressed air supplies.

c) New production-related requirements

Changes in air consumption

i) Modification of production

In most manufacturing facilities the compressed air demand varies from shift to shift. This is often ignored and it can happen in that after a modification to production by the introduction of a new process, for example, the compressors in one shift are suddenly running far below capacity whereas in the other not even the reserve capacity is sufficient to cover the demand. The air supply should be adaptable to meet such changes.

Illustration 2: Measurement of air consumption. A sampling pipe in the air main uses the pressure differential to measure flow, from which consumption can be calculated

ii) Expansion in production

In this case not only the compressor capacity but also the pipework and the air treatment equipment may have to be adapted to meet the increased demand. It is advisable to precisely measure and document the air consumption of the existing compressor system **(Illustration 2)** in order to gather enough detailed information to economically modify or expand the air supply system to produce the higher capacity needed.

d) Continuity of supply and quality

It is quite normal to include a standby compressor in an air system to provide coverage when another is being serviced or replaced and to provide for occasional demand peaks. Such a reserve capacity, however, should be matched by reserve capacity in the air treatment equipment. If not, air quality will suffer when the standby compressor cuts in alongside those in continuous operation. The air treatment system should be designed to cope when all available compressors are running **(Illustration 3)**.

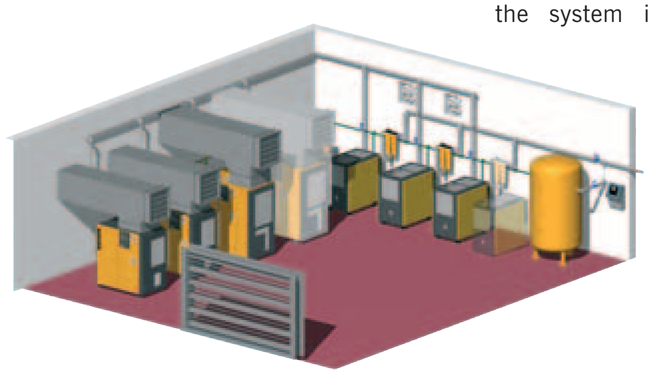


Illustration 3: Air treatment plant should have the capacity to handle the air delivery of all the compressors

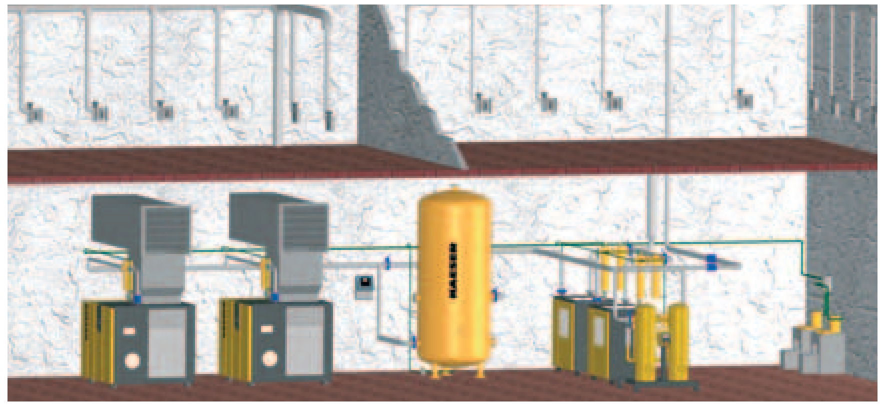


Illustration 4: A system supplying air at two different quality levels

e) Changing the air quality

If better air quality is needed the procedure differs depending on whether all the production is affected or only one section. In the former case, it is not enough to simply re-equip the central compressed air supply. The pipework that has transported air of lower quality will have to be cleaned or renewed. In the latter case, local air treatment that can supply the quality required is recommended **(Illustration 4)**. Airflow through local treatment devices should be limited. This ensures that an increase in demand above that for which the devices are intended does not result in degradation of air quality.

f) Monitoring leaks

Leakages occur in every air network whether they are well maintained or not, and they have the tendency to increase. This can lead to considerable losses of energy. The main cause is wear on hose connectors and machine components. Which is why it is vital to keep track of such problems and take prompt action whenever they occur. It is advisable to regularly measure overall leakage with the aid of modern control and monitoring systems such as Sigma Air Manager. If an increase is recorded, the leaks must be traced and cured.

3. Cost management backs up economics

Data acquired by analysis during the planning stage are interesting for later system operation. Once the system is installed and running, however, no special analysis is needed to acquire data at a later stage. These tasks are taken over by modern master controllers such as Sigma Air Manager. Thus a perfect basis for online compressed air audits and effective cost-management of the compressed air supplies is created **(Illustration 5)**.

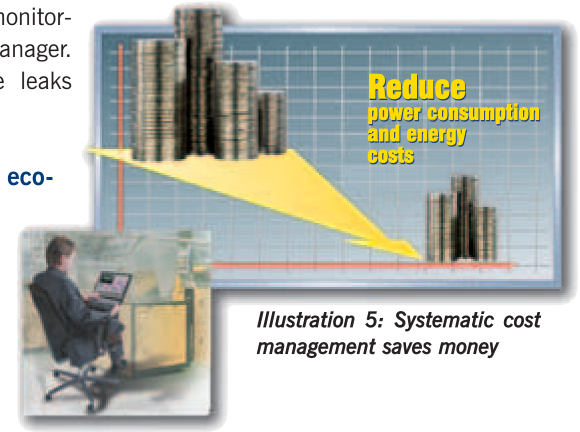


Illustration 5: Systematic cost management saves money

The more the users who introduce transparency into their air costs, sound out all the potential savings and give priority to energy efficiency rather than price when purchasing air supply equipment the nearer we will get to achieving the calculated 30 percent energy conservation potential, to the benefit of the balance sheet and the environment.

KAESER COMPRESSORS

More and more users choose KAESER COMPRESSORS

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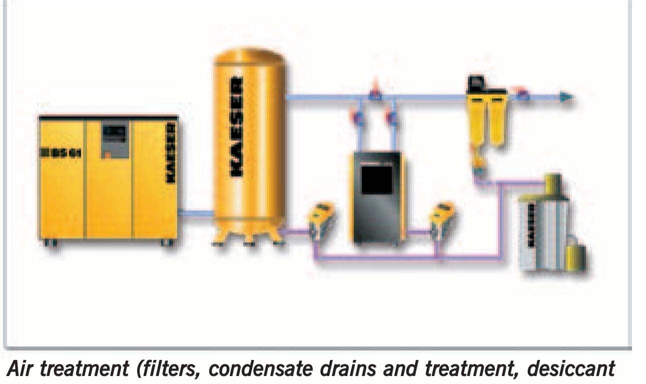
Our Product Range

Rotary screw compressors with SIGMA PROFILE

Refrigeration dryers with SECOTEC energy-saving control

Compressor controllers using Internet technology



Air treatment (filters, condensate drains and treatment, desiccant dryers, activated carbon adsorbers)

Rotary blowers with OMEGA PROFILE

Portable compressors with SIGMA PROFILE

Reciprocating compressors for trade and industry

Air tools and accessories

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