Chapter 3

Dimensioning compressor installations

3.1 Dimensioning compressor installations

3.1.1 General

A number of decisions must be made when dimensioning a compressed air installation for it to suit the user's needs, give the best operating economy and be prepared for future expansion.

The foundation is the applications or process that will use the compressed air. Therefore, you must start by mapping out these to gain the correct basis for continued dimensioning.

The areas to be looked at are calculation or assessment of the air requirement and the reserve capacity and the space for future expansion. The working pressure is a critical factor, as this significantly affects the energy consumption. Sometimes it can be economical to use different compressors for different pressure ranges.

The quality of the compressed air is not just a question of the water content, but has also become increasingly directed towards environmental issues. Odour and the microorganism content are important factors that can affect the product quality, rejections, the working environment and the outdoor environment. The issue of whether the compressor installation should be centralised or decentralised affects the space requirement and perhaps future expansion plans. From economic and environmental standpoints it is becoming more important to investigate the possibilities of recovering energy at an early stage, this often gives very quick return on the investment.

It is important to analyse these types of issues with regard to current as well as future requirements. It is then possible, and only then, to design an installation offering sufficiently flexibility.

3.1.1.1 Calculating the working pressure

The compressed air equipment in an installation determines the requisite working pressure. The right working pressure does not just depend on the compressor but also on the design of the compressed air system with piping, valves, compressed air dryers, filters, etc.

Different types of equipment can demand a different pressure in the same system. Normally the highest pressure determines the requisite installation pres-

3:1

Connected equipment	Nominal air requirement	Utilisation factor max/min	Total air requirement max/min
Tools, total			
Production lines, total			
Process lines, total			

The air requirement for connected equipment is obtained from, e.g. tool catalogues and descriptions of production equipment. By analysing and assessing the utilisation factor you can easily attain upper and lower limits for the overall air requirement.

sure and other equipment is fitted with reducing valves at the point of consumption. In more extreme cases the method can be uneconomical and a separate compressor for special needs can be a solution.

Also bear in mind that the pressure drop increases quickly with an increasing flow. If a change in consumption can be expected, it is makes economic sense to adapt the installation to these conditions.

Filters, special dust filters, have a low initial pressure drop, but in time become blocked and are replaced at the recommended pressure drop, which here will be a factor in the calculation. The compressor's flow regulation also brings about pressure variations and shall be included in the assessment. It may be appropriate to systematise the calculations according to the following example:

Description	Pressure drop bar(e)
End user	6
Final filter	0.1–0.5
Pipe system	0.2
Dust filter	0.1–0.5
Dryer	0.1
Compressor's regulation range	0.5
Compressor's max working pressure	7.0–7.8

Primarily it is the end user together with the pressure drop between the compressor and the consumer that determines the pressure that the compressor needs to produce. By, as in this example, adding the pressure drop in the system the working pressure can be determined.

3.1.1.2 Calculating the air requirement

The nominal compressed air requirement is determined by the air consumers. This is calculated as a sum of the air consumption for all tools, machines and processes to be connected, bearing in mind the utilisation factor that experience tells us will be pertinent. Additions for leakage, wear and future changes in the air requirement must also be considered.

A simple method to estimate the present and future air requirement is to compile the air requirement for connected equipment and the utilisation factor.

This type of calculation requires a list of machines, supplemented with respective machine's air consumption and expected utilisation factor. If you do not have data for the air consumption or utilisation factor, standard values can be used. The utilisation factor for tools can be difficult to estimate, therefore calculation values should be compared with measured consumption in similar applications.

For example, when large power consumers such as grinders and sand-blasting machines are used, it is frequently for long periods (3–10 min) under continuous operation, despite the low overall utilisation factor. This does not really correspond to intermittent operation, which is why it is necessary to estimated how many machines will be used simultaneously to judge the total maximum air consumption.

The compressor capacity is essentially determined by the total nominal compressed air requirement. The compressor's free output flow rate should cover this rate of air consumption. The calculated reserve capacity is primarily determined by the cost of lost production with a possible compressed air failure.

The number of compressors and the mutual size is determined principally by the required degree of flexibility, control sys-

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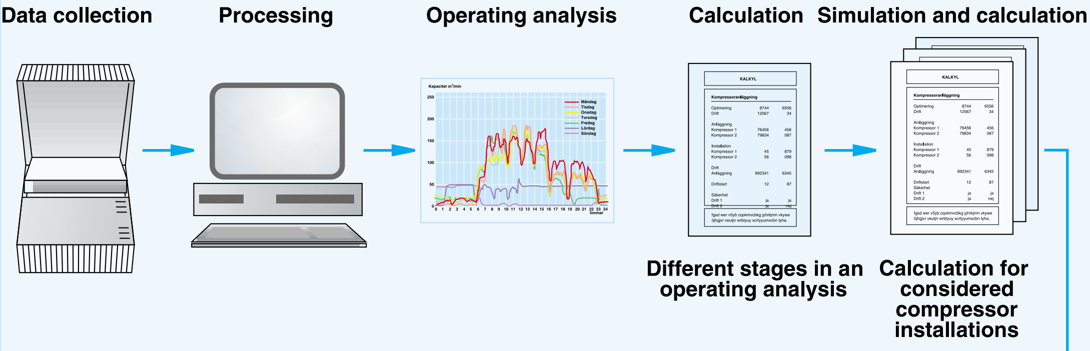

The principle for an operating analysis.

tem and energy efficiency. In an installation where, due to reasons of cost, only one compressor shall answer for the compressed air supply, the system can be prepared for the quick connection of a portable compressor in connection with servicing. An older compressor, used as a reserve source, can be used for inexpensive reserve power.

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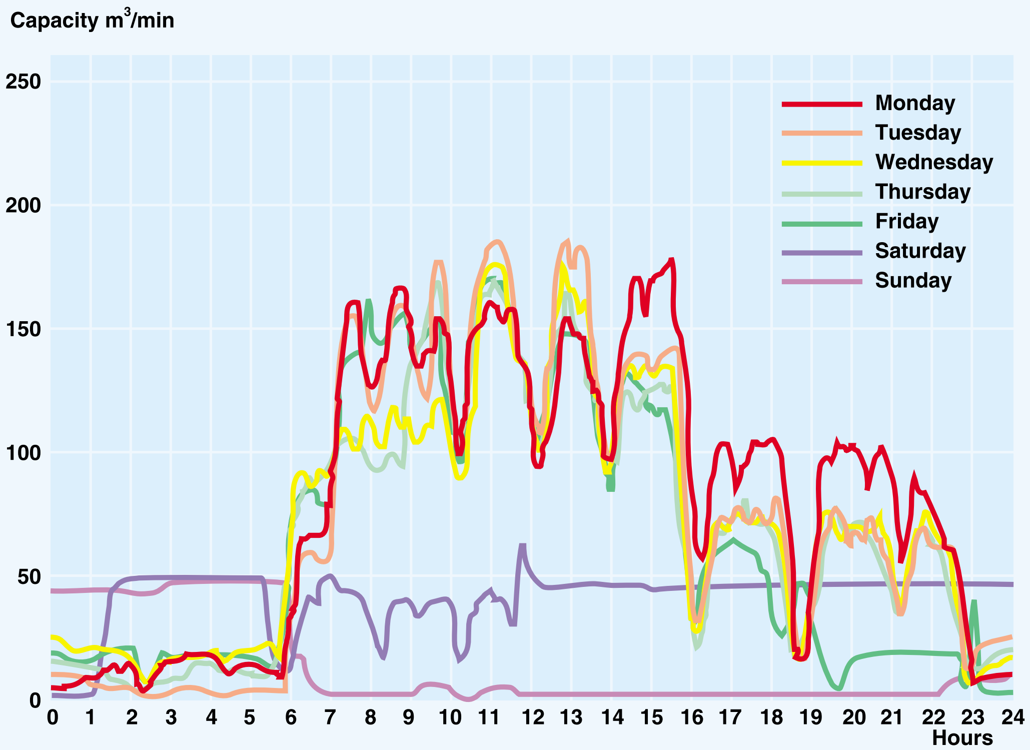

During an operating analysis the compressed air production is continuously measured, for example, during a week. This is the results in diagram form for a compressor with the capacity 260 m^3/min where the different curves represent the days of the week.

3.1.1.3 Measuring the air requirement

An operating analysis provides key factors about the compressed air requirement and forms the basis for assessing how much compressed air it is best to produce. Most industrial companies develop continuously, which means that the compressed air requirement also changes. It is therefore important that the compressed air supply is based on the current prevailing conditions, at the same time as an appropriate margin for expansion is built into the installation.

Operating analysis involves the measurement of operating data, possibly supplemented with the inspection of an existing compressed air installation during a suitable period of time. The analysis should comprise at least one week of operations and the measurement period should be selected with care in order to serve as a typical case to ensure that a relevant picture is obtained. The stored data also provides an opportunity to simulate different measures and changes in compressor operations and to analyse the significance for the installation's overall economy.

Factors such as the loading times and off-loading times also have a bearing on the total assessment of compressor operations. These provide the basis to assess the loading factor and the compressed air requirement, spread over a day or working week. Accordingly, the loading factor can not just be read off on the compressor's running hour meter.

An operating analysis also gives a basis for the potential energy recovery. Frequently more than 90% of the supplied energy can be recovered. Furthermore, the analysis can provide answers relating to dimensioning as well as the operating method for the installation. For example, the working pressure can often be reduced at certain times and the control system can be modified in order to improve compressor usage with changes in production. Another important factor is to check whether there is any leakage.

For the production of small quantities of air during the night and weekends, you must consider whether it is worthwhile installing a smaller compressor to cover this requirement.

3:4

Hole diameter: mm	**1**	**3**	**5**	**10**
Leakage, (l/s) at 6 bar	**1**	**10**	**27**	**105**
Power loss, kW at the compressor	**0,3**	**3,1**	**8,3**	**33**

Even small leakage can result in large costs and downtime.

3.1.2 Centralisation or decentralisation

3.1.2.1 General

There are several factors that affect the choice between one large or several smaller compressors to meet the same compressed air requirement. For example, the cost of a production stoppage, the availability of electricity, loading variations, costs for the compressed air system and the available floor space.

3.1.2.2 Centralised compressor installations

A centralised compressor installation is in most cases the solution of choice, as it is less expensive than several, locally situated compressors. Compressor plant can be efficiently interconnected, which result in lower energy consumption. A central installation also involves lower monitoring and maintenance costs as well as better conditions for recovering energy. The overall, requisite floor area for the compressor installation is less. Filters, coolers and other auxiliary equipment and the air intake can be optimally dimensioned and installed. Noise insulation will also be easier to fit.

A system comprising several, different sized compressors in a central installation can be sequence controlled to improve efficiency. One large compressor has difficulty in meeting large variations in the compressed air requirement, without efficiency dropping.

For example, systems with one large compressor are often supplemented with a smaller compressor, for use during periods such as a night shift or at weekends. Another factor worth considering is the effect the start of a large electric motor has on the mains supply.

3.1.2.3 Decentralised compressor installations

A system with several decentralised compressors involves a smaller, simpler compressed air system. The disadvantages of decentralised compressors is the difficulty in inter-regulating the compressed air supply, the expense and that maintenance work is more demanding as well as it is hard to maintain a reserve capacity. Decentralised compressors can be utilised to maintain the pressure in a system with a large pressure drop if the intermediate processes temporarily draw too much air. Otherwise an alternative with extremely short peaks is to solve the problem by positioning a buffer (air receivers) at strategic places.

A unit or building normally supplied from a compressed air central and which is the sole consumer of compressed air at specific periods can be sectioned off and supplied with its own compressor. The advantage of this is you avoid “feeding” any leakage in the remaining part of the system and that the localised compressor can be adapted to the smaller requirement.

3.1.3 Dimensioning at high altitude

3.1.3.1 General

The ambient pressure and temperature diminish at heights above sea level. This affects the pressure ratio, for compressors as well as the connected equipment, which in practice means an influence on the power and air consumption. At the same time the changes also affect the available rated power from electric motors and combustion engines.

You should also be aware of how the ambient conditions influence the end user. Is it a specific mass flow rate, e.g. in a process or is it volume flow rate you require? Is it the pressure ratio, absolute pressure or over pressure that was used for dimensioning? Is the compressed air temperature significant?

All these create different conditions for dimensioning a compressed air installation installed at a high altitude and can be fairly complex to calculate. If you feel unsure you should always contact the manufacturer of the equipment.

3:5

Atmospheric pressure

Height below/ above sea level	Pressure bar	Temperature °C
-1000	1.138	21.5
-800	1.109	20.2
-600	1.080	18.9
-400	1.062	17.6
-200	1.038	16.3
0	1.013	15.0
200	0.989	13.7
400	0.966	12.4
600	0.943	11.1
800	0.921	9.8
1000	0.899	8.5
1200	0.877	7.2
1400	0.856	5.9
1600	0.835	4.6
1800	0.815	3.3
2000	0.795	2.0
2200	0.775	0.7
2400	0.756	-0.6
2600	0.737	-1.9
2800	0.719	-3.2
3000	0.701	-4.5
3200	0.683	-5.8
3400	0.666	-7.1
3600	0.649	-8.4
3800	0.633	-9.7
4000	0.616	-11.0
5000	0.540	-17.5
6000	0.472	-24.0
7000	0.411	-30.5
8000	0.356	-37.0

The table shows the standardised pressure and temperature variations at different heights. The pressure is dependent on the weather and varies approx. ± 5%, while the local season dependent temperature variations can be considerable.

3.1.3.2 The effect on a compressor

To choose the right compressor where the ambient conditions differ from those stated on the data sheet, you should take the following factors into consideration:

- **Height above sea level or ambient ressure**
- **Ambient temperature**
- **Humidity**
- **Coolant temperature**
- **Type of compressor**
- **Power source**

These factors primarily affect the following:

- **Max. working pressure**
- **Capacity**
- **Power consumption**
- **Cooling requirement**

The most important factor is the intake pressure variations at altitude. For example, this means a compressor, with a pressure ratio of 8.0 at sea level, will have a pressure ratio of 11.1 at an altitude of 3000 metres (under the condition that the working pressure is constant). This affects the efficiency and thereby the power requirement. To what degree is dependent on the type of compressor and the design as set out in figure 3:6.

The ambient temperature, humidity and coolant temperature interact and

3:6

Compressor type	Reduction for each 1000 metres above sea level: Free output flow rate %	Mass flow or Normal flow %
Single stage oil-free screw compressor	0.3	11
Two stage oil-free screw compressor	0.2	11
Single stage oil injected screw compressor	0.5	12
Single stage piston compressor	5	17
Two stage piston compressor	2	13
Multi-stage centrifugal compressor	0.4	12

A rule of the thumb for the altitude's effect on the compressor at 7 bar(e) working pressure and constant ambient temperature. Bear in mind that each compressor has a top pressure ratio that can not be exceeded.

3:7

Height above sea level, metres	Ambient temperature, °C					
	<30	30-40	45	50	55	60
1000	107	100	96	92	87	82
1500	104	97	93	89	84	79
2000	100	94	90	86	82	77
2500	96	90	86	83	78	74
3000	92	86	82	79	75	70
3500	88	82	79	75	71	67
4000	82	77	74	71	67	63

The table shows the permitted load in % of the electric motor's rated power.

affect the compressor's performance to different degrees on single or multi-stage compressors, dynamic compressors and displacement compressors.

3.1.3.3 Power source

3.1.3.3.1 Electric motors

Cooling becomes impaired on electric motors by the thinner air at high altitude. It should be possible for standard motors to work up to 1000 m and with an ambient temperature of 40°C without the rated data deteriorating. With greater heights table 3:7 can be used as a guideline for standard motors. Notice that for some types of compressor the motor performance is impaired more than the compressor's requisite shaft power at high altitude.

3.1.3.3.2 Combustion engines

A reduction in the ambient pressure, a temperature increase or a reduction in humidity reduce the oxygen content in the intake air and thereby the extractable power from the engine. The degree of shaft power degradation depends on the type of engine and its breathing method as set out in figure 3:8. The humidity plays a lesser part (<1% / 1000 m) when the temperature falls below 30°C.

Notice that the engine power falls more rapidly than the compressor's requisite shaft power, which means that for each compressor/engine combination there is a maximum working height. Generally, you should let respective suppliers calculate and state the specific data that applies to the compressor, engine and air consumption equipment in question.

3:8

Engine type	Power reduction in % per 1000 m	Power reduction in % per 10°C temperature increase
Suction engine	12	3.6
Compressor fed	8	5.4

The table shows how combustion engines are affected by altitude and temperature.

3.2 Air treatment

3.2.1 General

It is a matter of vital importance to the user that the compressed air is of the right quality. If air that contains contamination comes into contact with the final product, rejection costs can quickly become unacceptably high and the cheapest solution can quickly become the most expensive. It is important that you select the compressed air quality in line with the company's quality policy and even attempt to judge future requirements.

The compressed air can contain unwanted substances, for example, water in drop or vapour form, oil in drop or aerosol form as well as dust. Depending on the compressed air's application area, these substances can impair the production result and even increase costs. The purpose of air treatment is to produce the compressed air quality specified by the consumer.

When the compressed air's part in the process is clearly defined, the answer to which system is the most profitable and efficient will be found. It is a question, among others, of establishing whether the compressed air will come into direct contact with the product or whether, e.g. oil mist can be accepted in the working environment. A systematic method is necessary to select the right equipment.

3.2.2 Water vapour in the compressed air

Air in the atmosphere always contains moisture in the form of water vapour. Some follows with the compressed air and can cause problems. Examples of which are: High maintenance costs, shortened service life and impaired tool performance, high rate of rejection with spray painting and plastic injection, increased leakage, disturbances in the control system and instruments, shorter service life for the

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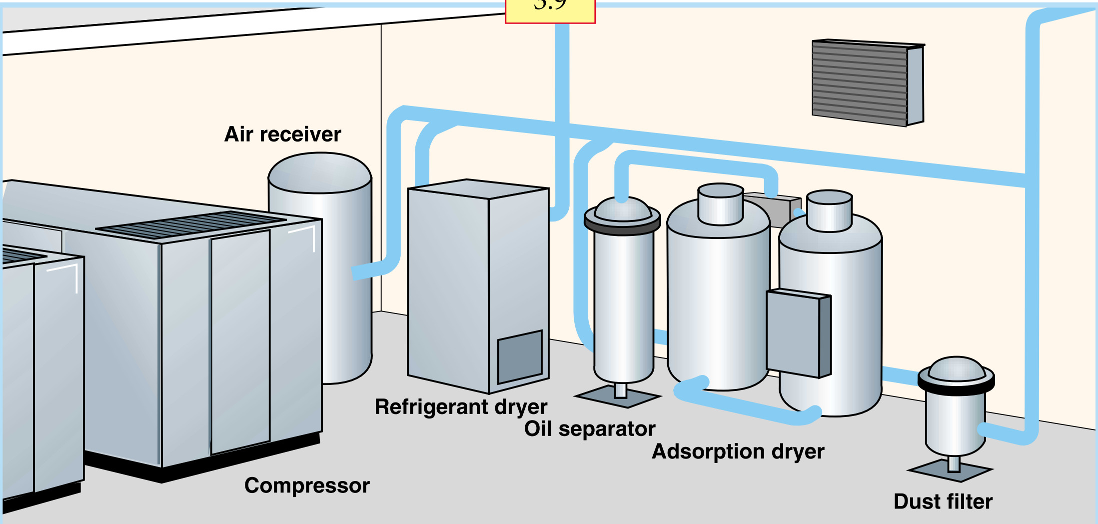

The main components in a compressed air system when set up and installed. The equipment for air treatment determines the quality of the compressed air, which has a great effect on the economy of the installation.

3:10

ISO 8573-1 quality classes

Quality class	Contamination		Water	Oil
	Particle size (µm)	Max. concentration (mg/m³)	Max pressure dew point (°C)	Max. concentration (mg/m³)
1	0.1	0.1	-70	0.01
2	1	1	-40	0.1
3	5	5	-20	1.0
4	15	8	+3	5.0
5	40	10	+7	25
6	-	-	+10	-

For example: compressed air of quality class 2.2.2. (Contamination: Particles 1 µm and 1 mg/m³, water: -40°C pdp (pressure dew point), oil: 0,1 mg/m³)

ISO has quality classified compressed air with regard to the degree of contamination.

pipe system due to corrosion and more expensive installation. The water can be separated by using accessories, e.g. after-coolers, condensation sepators, refrigerant dryers and adsorption dryers.

A compressor that works with 7 bar(e) overpressure, compresses air to 7/8 the volume. This also reduces the air's ability to hold water vapour by 7/8. The quantity of water that is released is considerable. For example, a 100 kW compressor that draws in air at 20°C and with 60% relative humidity will give off approx. 85 litres of water during an 8 hour shift. Consequently, the amount of water to be separated depends on the compressed air's application area. This in turn is decides which combination of coolers and dryers are suitable.

3.2.3 Oil in the compressed air

The quantity of oil in the compressed air is dependent on several factors, among others, the type of machine, design, age, condition, etc. There are two main types of compressor design in this respect, those working with lubricant in the compression chamber and those working without lubricant. In lubricated compressors the oil takes part in the compression process and also follows with the compressed air fully or partly. However, on modern, lubricated

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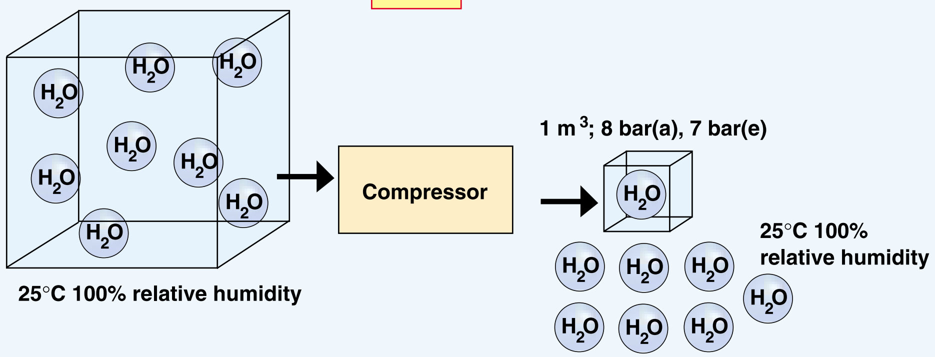

A compressor that works with 7 bar(e) overpressure, compresses air to 1/8 of the volume.

piston and screw compressors the oil quantity is only small. For example, in an oil injected, screw compressor the oil content in the air is less than 3 mg/m³ at 20°C. The oil content can be reduced by means of multi-stage filters. If such a solution is chosen it is important to consider the quality limitations, risks and energy costs this brings about.

3.2.4 Microorganisms in the compressed air

More than 80% of the particles that contaminate the compressed air are less than 2 μm and thereby easily pass through the compressor's intake filter. Thereafter the particles are spread in the pipe system and mix, among others, with the water and oil residue and pipe deposits. This can result in the growth of microorganisms. A filter directly after the compressor can eliminate these risks. Nevertheless, to have pure or sterile compressed air you must have full control over any bacteria growth after the filter.

The picture becomes even more complicated as gases and aerosol can be concentrated into drops (through concentration or electric charging) even after passing several filters. Microorganisms germinate through the filter walls and therefore exist in the same concentrations on the inlet and outlet sides of the filter.

During investigations it has been established that microorganisms thrive in compressed air systems with undried air and thereby high humidity (100%). Contamination smaller than 1 μm and thereby microorganisms, can pass unimpeded through the compressor's intake filter.

Oil and other contamination act as nutrients for growth. The most decisive factor is to dry the air to a humidity of <40%, which is achieved by using an adsorption dryer and at room temperature also with a refrigerant dryer.

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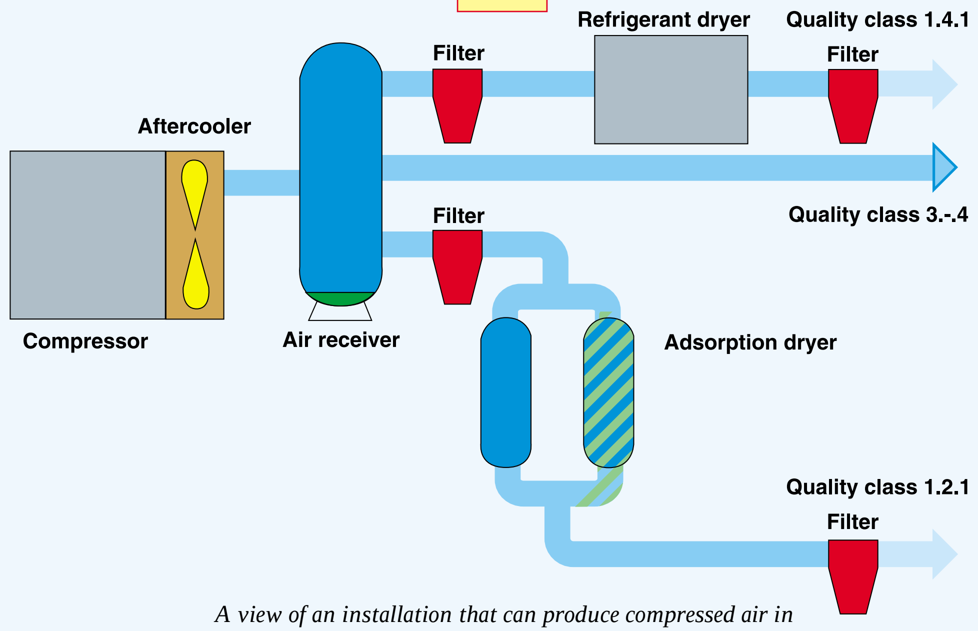

A view of an installation that can produce compressed air in different quality classes in accordance with ISO 8573-1.

3.2.5 Filters

Modern fibre filters are very efficient at removing oil. However, it is difficult to exactly control the quantity of oil remaining in the air after filtration as the temperature, among others, has an important effect on the separation process. Efficiency is also affected by the oil concentration in the compressed air and the amount of free water.

To achieve the best results the air should be as dry as possible. Oil, carbon and sterile filters all give bad results if there is free water in the air (the filter specifications do not apply in such conditions). Fibre filters can only remove oil in the form of droplets or as aerosols. Oil vapour must be removed using a filter with active carbon. A correctly installed fibre filter, together with a suitable prefilter, can reduce the quantity of oil in the compressed air to approximately 0.01 mg/m^3 at 21°C. A filter with active carbon can reduce the quantity of oil to 0.003 mg/m^3 at 21°C.

Carbon filters should have the correct quality of carbon and dimensioned to give the lowest possible pressure drop. To have the best effect the filters should also be placed as close to the application in question as possible. In addition, they must be checked carefully and replaced relatively frequently. Filters with active carbon only remove air contamination in the form of vapour, for example, oil. Sterile filters shall withstand sterilisation on site in the pipe system with the help of, e.g., steam or be removed for treatment. A filter's capacity to separate oil from compressed air varies at different operating temperatures.

Data stated in the filter specification always applies at a specific air temperature, normally 21°C. This corresponds approximately with the temperature after an air cooled compressor working in an ambient temperature of 10°C. However, climate and seasonal changes give temperature variations, which in turn affect the filter's separation capacity.

An oil free compressor eliminates the need of an oil filter. This means the compressor can work at a low pressure, which reduces energy consumption. It has been shown in many cases that oil-free compressors are the best solution, both economically and for quality.

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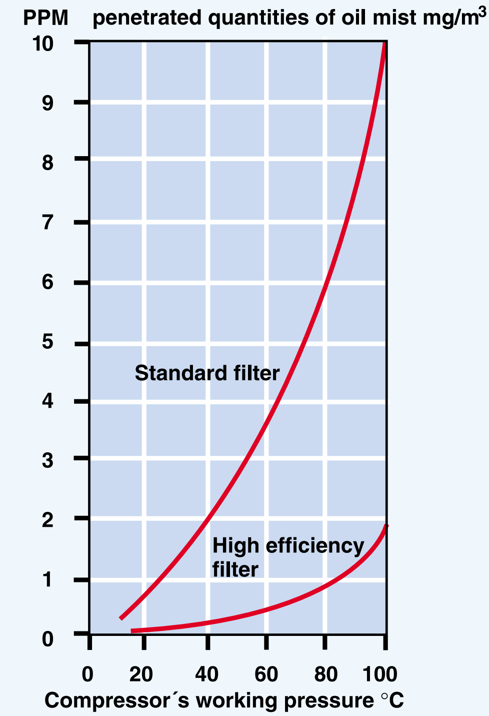

- Compressor´s working pressure: 7 bar
- 1 PPM = 1,2 mg/m^3

Temperature variations in compressed air result in quality variations with the use of filters.
Note that standard and high effect filters do not have an effect on oil in vapour form.

3.2.6 Aftercooler

The compressed air from the compressor is hot after compression, often 70–200°C. An aftercooler is used to lower the temperature, which also reduces the water content and now is frequently included as standard equipment in a compressor installation. The aftercooler should always be placed directly after the compressor. It is the heat exchanger that cools the hot air, to then precipitate the main part of the condensation water as quickly as possible that would otherwise follow out into the system. The aftercooler can either be water or air cooled and is generally fitted with a water separator with automatic drainage.

3.2.7 Water separator

Most compressor installations are fitted with an aftercooler as well as a water separator, in order to separate as much condensation water as possible from the compressed air. With the right choice and sizing of the water separator an efficiency of 80-90% can be achieved. The remainder follows with the compressed air as water mist into the air receiver.

3.2.8 Oil as droplets

Oil in the form of droplets is separated partly in, e.g. an aftercooler, condensation separator or a condensation tap and follows with the condensation water. This oil/water emulsion is classed from an environmental point of view as waste oil and must not be lead off in the sewage system or directly into nature.

New and more stringent laws are continuously being introduced with regard to the handling of environmentally hazardous waste. The drainage of condensation, as well as the collection and drainage, is involved and expensive.

An easy and cost effective solution to the problem is to install an oil/water separator, for example, with a diaphragm filter, which gives clean drainage water and leads the oil off into a special receiver.

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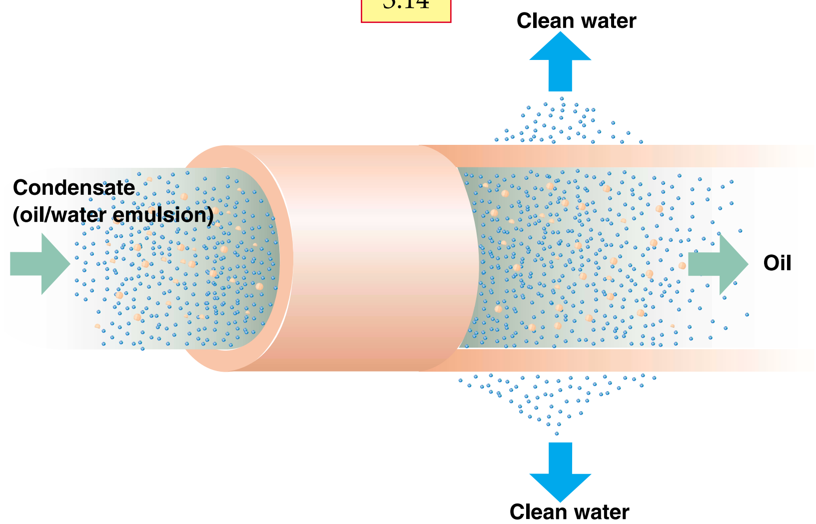

This is how a diaphragm filter for oil separation works. The diaphragm lets through small molecules (clean water), while larger molecules (oils) are kept in the system and can be collected in a container.

3.3 Cooling system

3.3.1 Water cooled compressors

3.3.1.1 General

A water cooled installation makes little demand on the ventilation of the compressor room, as the larger part of the heat produced is led off by the cooling water. The cooling water from a water cooled compressor contains, in the form of heat, approx. 90% of the energy taken up by the electric motor.

A compressor's cooling water system can be designed based on one of three main principles. As an open system without circulating water, as an open system with circulating water, and as a closed circulating system.

3.3.1.2 Open system, without circulating water

An open system without circulating water means that the water comes from the municipal water mains, a lake, a stream, or a well and is used to cool the compressor and is then discharged as waste water. The system should be controlled by a thermostat, to maintain the desired temperature as well as to govern water consumption. The cooling water pressure should be lower than the pressure the components parts are designed for.

Generally an open system is easy and inexpensive to install, but expensive to run, especially if the cooling water is taken from the municipal water mains. Water from a lake or stream is normally free, but must be filtered and purified to be used without the risk of blocking the cooling system. Furthermore, water rich in lime can result in boiler scale forming in the coolers, bringing about impaired cooling. The same applies to salt water, which however is possible to use if the system is designed and dimensioned accordingly.

3.3.1.3 Open system, circulating water

An open system with circulating water means that cooling water from the com-

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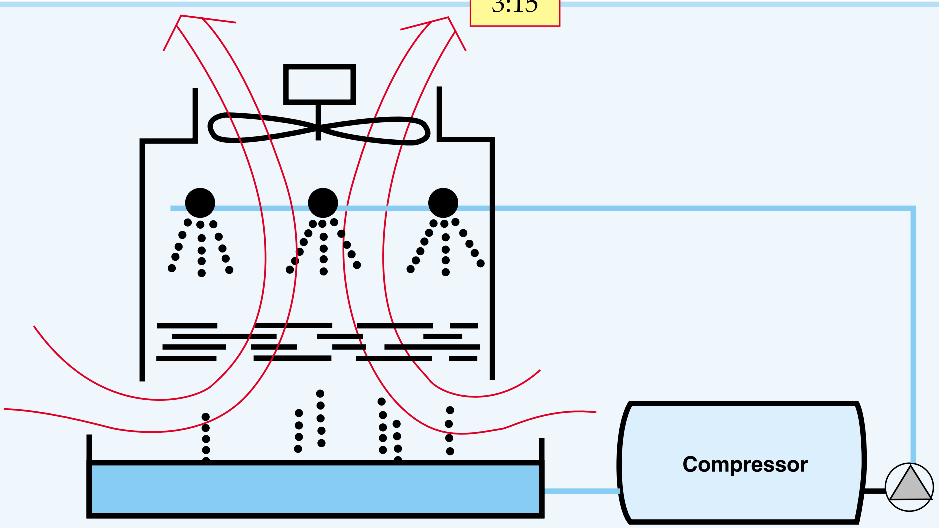

An open cooling system with circulating cooling water.

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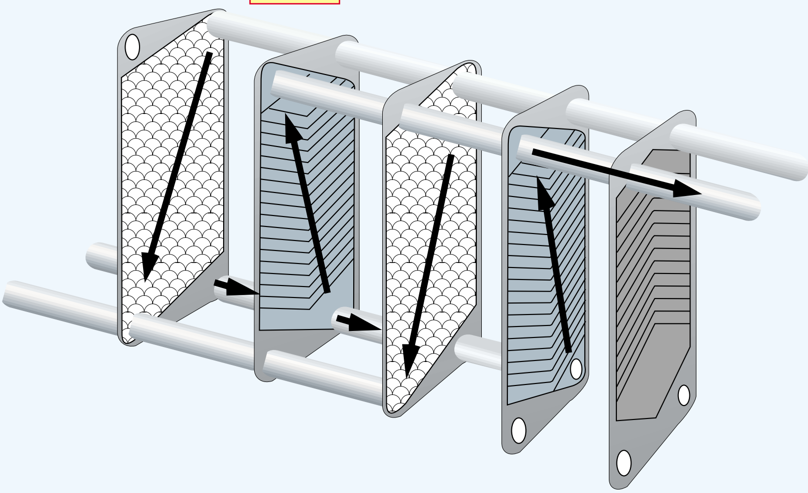

This is how a flat heat exchanger can appear. The advantage of a flat heat exchanger is that it is easy to clean, which makes it possible to indirectly cool the compressor using lake or stream water.

pressor is recooled in a cooling tower. Water is cooled in the cooling tower by allowing it to sprinkle down into a chamber at the same time as surrounding air is blown through, whereby a part of the water vaporises and the remaining water is cooled to 2˚C under the ambient temperature (can vary depending on the temperature and relative humidity). Open systems with circulating water are primarily used when the availability of water is limited. The disadvantage here is that the water becomes contaminated by the surrounding air. The system must be continuously diluted using fresh water due to evaporation.

Dissolvable salts are deposited on the hot metal surfaces, this reduces the thermal dissipation capacity of the cooling tower. The water must be regularly analysed and treated with chemicals to prevent algae from growing in the water. During the winter, when the compressor is not operating, the cooling tower must either be emptied or the water heated to prevent freezing.

3.3.1.4 Closed system

In a compressor cooled with a closed system the same water circulates between the compressor and some form of cooler. This cooler is in turn cooled either by means of another water circuit or the surrounding air. Generally when the water is cooled against another water circuit a flat heat exchanger is used.

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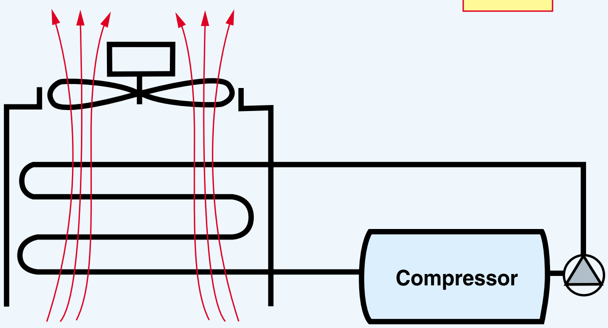


A basic air heater (air cooled heat exchanger) can be found in closed cooling systems for cooling liquids such as water/glycol, oil, etc. In aggressive environments or with aggressive liquids, materials such as stainless steel or titan are used.

When the water is cooled against the surrounding air a cooling battery is used consisting of pipes and cooling flanges. The surrounding air is forces to circulate around the battery by means of one or more fans. The air is normally filtered first to prevent blockage. This method is suitable if the availability of water is limited. The cooling capacity of open or closed circuits is about the same, i.e. the compressor water is cooled by 5°C above the coolant temperature.

If the water is cooled by the surrounding air, the addition of an anti-freeze, e.g. glycol is required. The closed cooling water system is filled with pure, softened water.

When glycol is added the compressor system's water flow must be recalculated, as the type and concentration of glycol affects the thermal capacity and the viscosity. The addition of chemical agents also affects the cooling water's capacity to crawl through the connection points.

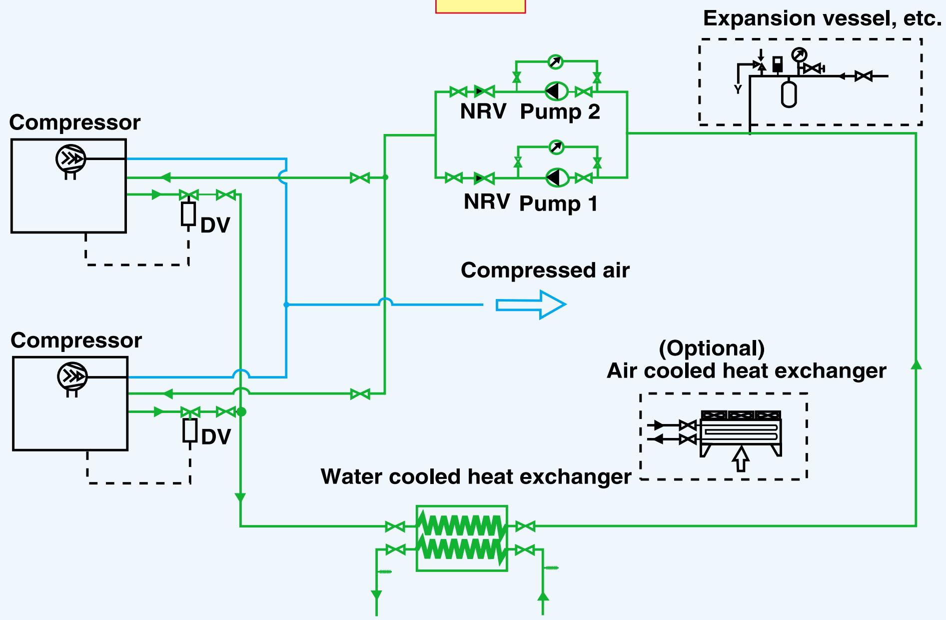
3:18

Freezing point °C	Glycol mixture %	Heat capacity kJ/°C. kg
-10	23	3.850
-15	30	3.650
-20	37	3.450
-25	43	3.350
± 0	0	4.190

The water must be protected from freezing at low temperatures. It is important to remember that the size of the cooler may need to be increased as, for example, a water/glycol mixture has a lower thermal capacity than pure water.

It is also important that the entire system is well cleaned before being filled for the first time. A correctly implemented closed water system requires very little supervision and has low maintenance costs. For installations where the available cooling water is aggressive, it is appropriate to use a cooler designed using a corrosion retardant material such as incoloy.

3:19



This is how a closed cooling system can be made up. The heat exchanger can be water or air cooled.

3.4 Energy recovery

3.4.1 General

When air is compressed heat is formed. The heat energy is concentrated in the decreasing volume and the excess is led off before the air goes out into the pipe system. For each compressed air installation you must assure yourself that there is sufficient and reliable cooling capacity for the installation. This can take place either by means of the outdoor air or a water system such as municipal water, stream water or process water in an open or closed system.

On many installations producing compressed air there are significant and frequently unutilised energy saving possibilities in the form of energy recovery from the compressors. Energy costs can, in larger industries, amount to 80% of the total cost for the production of compressed air. As much as 94% of the compressor's supplied energy can, for example, be recovered as 90° hot water from large, oil-free screw compressors. This means that each saving measure quickly gives noticeable dividends.

Presuppose that a compressor central in a large industry consumes 500 kW during 8,000 operating hours per annum. This corresponds to no less than approximately 4 million kWh/year. The possibilities to recover this waste heat via hot air or hot water are good.

The return on the investment for energy recovery is usually as short as 1–3 years. In addition, energy recovered by means of a closed cooling system is advantageous to the compressor's operating conditions, reliability and service life due to

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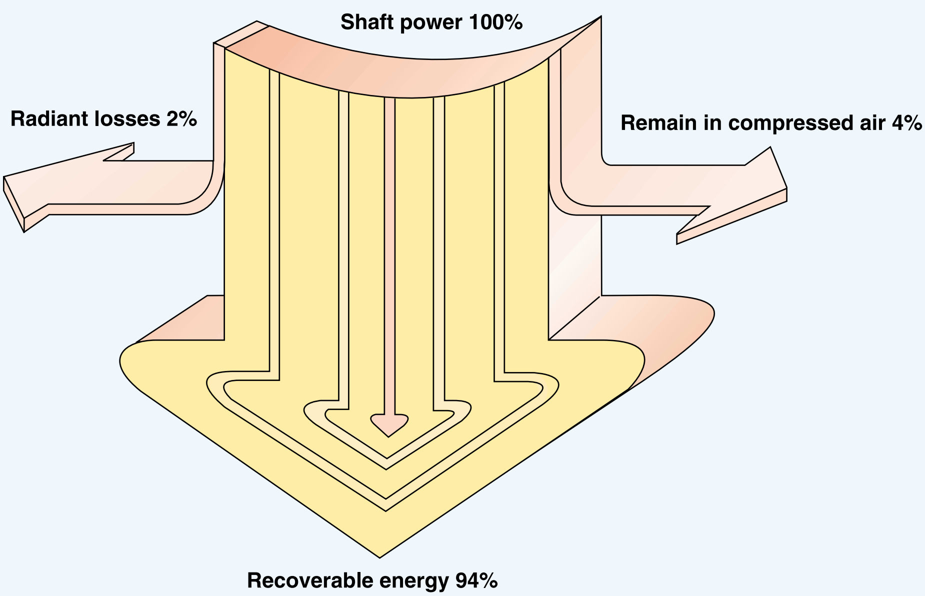

As heat is the natural by-product of compression, energy can be recovered in the form of hot water from the compressor's cooling system.

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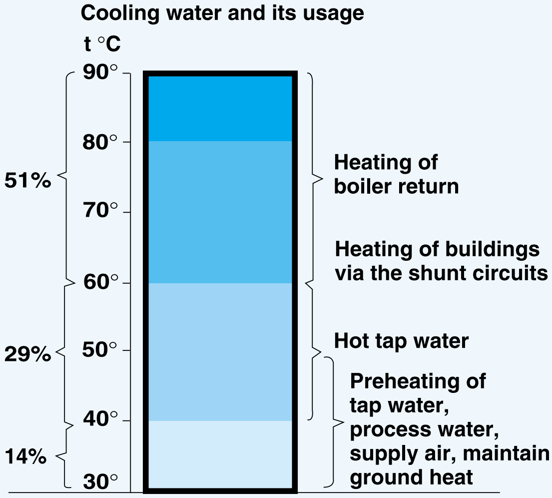

The diagram illustrates some of the typical application areas for energy recovery from the compressor's cooling water in different temperature ranges. In the highest temperature levels the degree of recovery is the greatest.

an equal temperature level and high cooling water quality to name but a few. The Nordic countries are somewhat of a forerunner and energy recovery has for long time been praxis when it comes to compressors.

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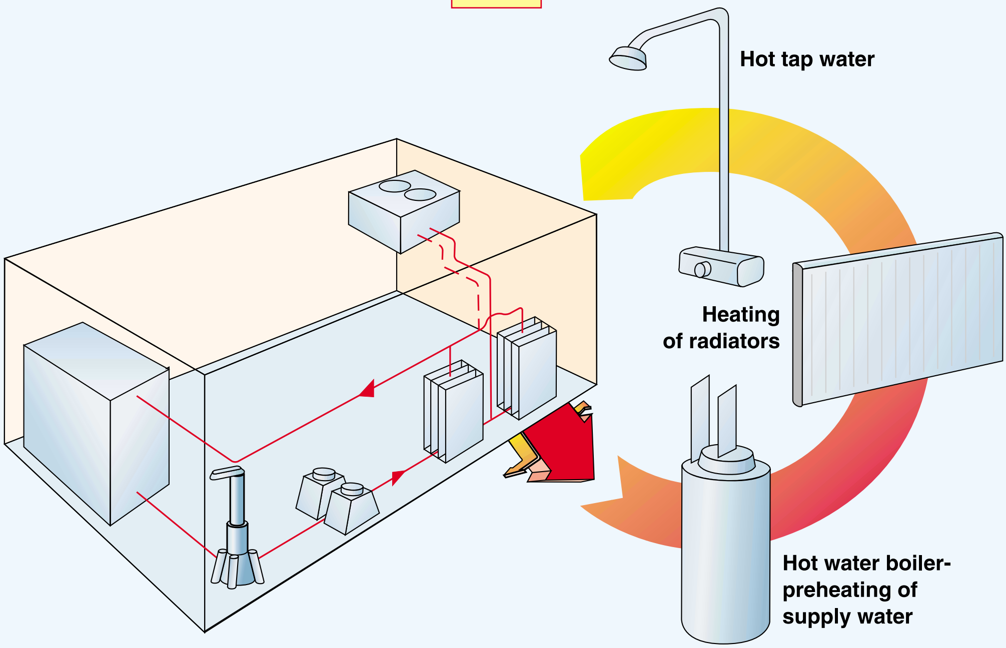

Each compressor installation represents large possibilities for energy recovery. A whole 95% of the compressor's supplied energy can, for example, be recovered from large, oil-free screw compressors.

Most compressors from the major suppliers are today adapted to be supplemented with standard equipment for recovery.

3.4.2 Calculation of the recovery potential

Virtually all energy supplied to a compressor installation is converted to heat. The more energy you can recover and use in other processes, the higher the system's efficiency. The quantity that can be recovered can easily be calculated by the relation:

Recovered energy kWh/year:

$$W = [(K_1 \times Q_1) + (K_2 \times Q_2)] \times T_R$$

Saving/year: $W \times e_p / \eta$

Saved oil m³/year: $W / 68000 \times \eta$

W =Recovered energy Wh/year)

T_R =Time per year when there is a need of recovered power hours/year)

K_1 =Part of T_R with loaded compressor

K_2 =Part of T_R with off-loaded compressor

Q_1 =Available power in coolant with load compressor (kW)

Q_2 =Available power in coolant with off-loaded compressor (kW)

e_p =Energy price

η =Normal heat source´s efficiency

In many cases the degree of recovery can exceed 90%, if the energy you gain through cooling the compressor installation can be taken care of efficiently. The function of the cooling system, distance to the point of consumption, and the degree and continuity of the demand are all decisive factors.

When it is a question of a large thermal flow it can be of interest to look at the possibility of selling the recovered heat energy. A purchaser can be the energy supplier and you can seek agreement forms for investment, suborder and delivery. There is also the possibility of co-ordinating energy recovery from several processes.

3:23

Energy recoverable power

FAD m³/min	Heat flow kW	Saving at 2000 oper.hours/year kWh/year	Oil EO1 m³/year
6.4	34	68 000	10.0
7.4	40	80 000	11.8
11.4	51	102 000	15.0
14.0	61	122 000	17.9
18.7	92	184 000	27.1
21.6	109	218 000	32.1
23.2	118	236 000	34.7
27.9	137	274 000	40.3
34.8	176	352 000	51.8
43.1	215	430 000	63.2
46.9	235	470 000	68.1
46.5	229	458 000	67.4
51.3	253	506 000	74.7
56.9	284	568 000	83.5
62.9	319	638 000	93.8
69.7	366	732 000	108
75.4	359	718 000	106
83.2	392	784 000	115
103.6	490	980 000	144
124.5	602	1 200 000	177

Example of recovery potential from compressors.

3.4.3 Recovery methods

3.4.3.1 General

Energy recovery from compressed air installations does not always give heat when it is required and perhaps not in sufficient quantities. The quantity of recovered energy will vary if the compressor has a variable load. In order for recovery to be possible a corresponding energy requirement is needed, which is normally met through an ordinary system supply. Recovered energy is best utilised as additional energy to the ordinary system, so that the available energy is always utilised when the compressor is running.

3.4.3.2 Air cooled systems

Options for air cooled compressors, which give off a large hot air flow rate at a relatively low temperature, are direct building heating or heat exchanging to a preheating battery. The heated cooling air is then distributed using a fan.

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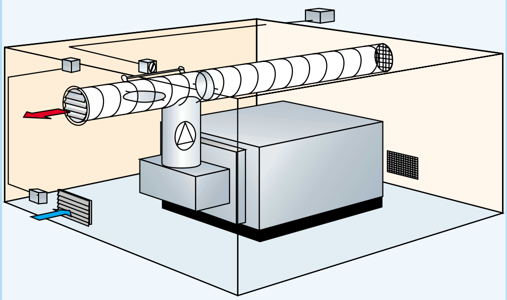

Energy recovery from an air cooled compressor.

When the buildings do not require additional heat, the hot air is led off into the atmosphere either automatically using

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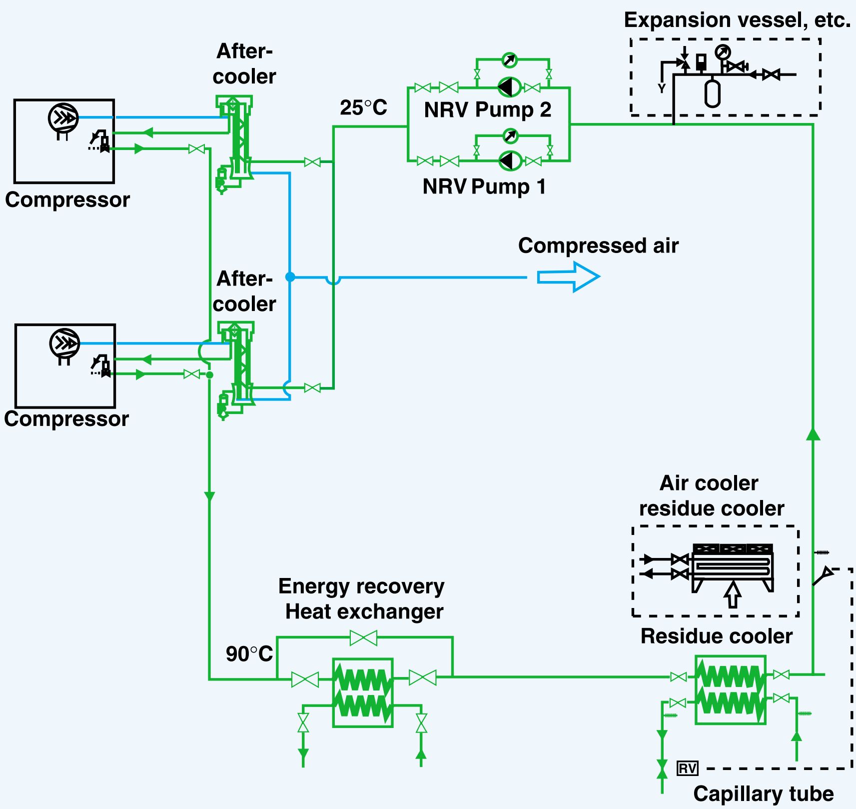
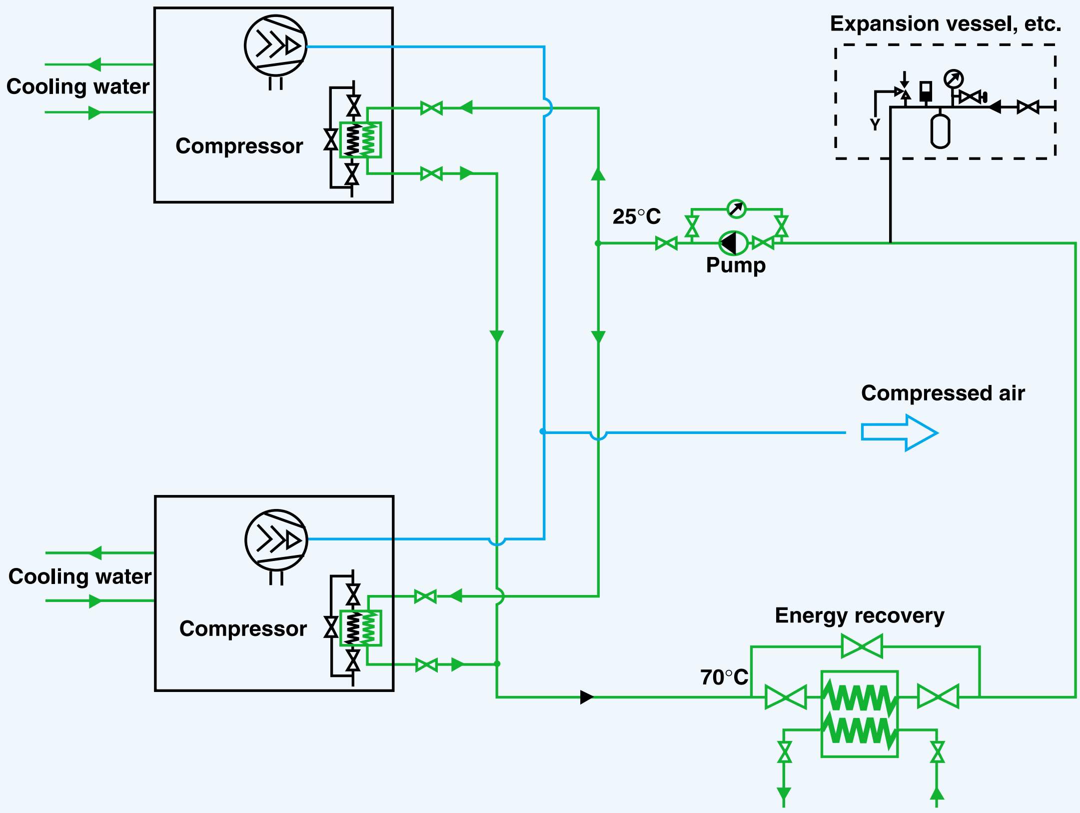


An example of water-borne energy recovery for an oil-free screw compressor.



Example of water-borne energy recovery for oil lubricated screw compressor. The residue cooler with regulation system is integrated in the compressor.

thermostat control or manually by controlling the air damper. A limiting factor is that the distance between the compressors and the building to be heated should be short, preferably it should be a question of an adjoining building. Furthermore, the possibility of recovery is limited to the colder parts of the year. Air-borne energy recovery is more common on small and medium sized compressors. Recovery results in small losses and requires little investment.

3.4.3.3 Water cooled system

On a water cooled compressor, the cooling water from the compressor with a temperature up to 90° can supplement a hot water flow. If hot water is used for washing, cleaning or showering a normal hot water boiler is still required. The energy recovered from the compressed air system provides an addition that reduces the load on the boiler, saves fuel and possibly can result in the use of a smaller boiler.

Prerequisites for energy recovery from compressed air compressors differs partly depending on the type of compressor. Oil-free compressors even in the standard design are easy to modify for energy recovery. This type of compressor in a hot water design reaches the water temperatures (90°C) required for efficient energy recovery. On oil lubricated compressors the oil, which takes part in compression, is the factor that limits the possibilities to reach higher cooling water temperatures.

In centrifugal compressors the temperature levels are lower an thereby, so is the degree of recovery. In addition the performance of the compressor is negatively affected by the increased water temperatures.

Water-borne energy recovery is best suited to compressors with an motor power over 10 kW. Water-borne recovery of energy brings about a more complex installation than air-borne energy recovery. The basic equipment consists of pumps, heat exchanger and regulation valves.

Heat can also be distributed to remote buildings using relatively small pipe dimensions (40-80 mm) without significant heat losses using water-borne energy recovery. The high initial temperature means that energy can be used to increase the temperature of the return water from a hot water boiler. Thereby the normal heating source can be periodically switched off and replaced by the compressor's waste heat. Waste heat from compressors in the process industry can also be used to increase the temperature of the process. It is fully possible even with the use of air cooled, oil lubricated screw compressors to arrange water-borne energy recovery. This requires a heat exchanger in the oil circuit, but the system gives lower temperature levels than with an oil-free compressor.

3.5 The compressor room

3.5.1 General

Not so long a go the acquisition of a compressor meant that you needed to buy the electric motor, starter equipment, aftercooler, intake filters, etc. You then needed to go through capacity and quality demands

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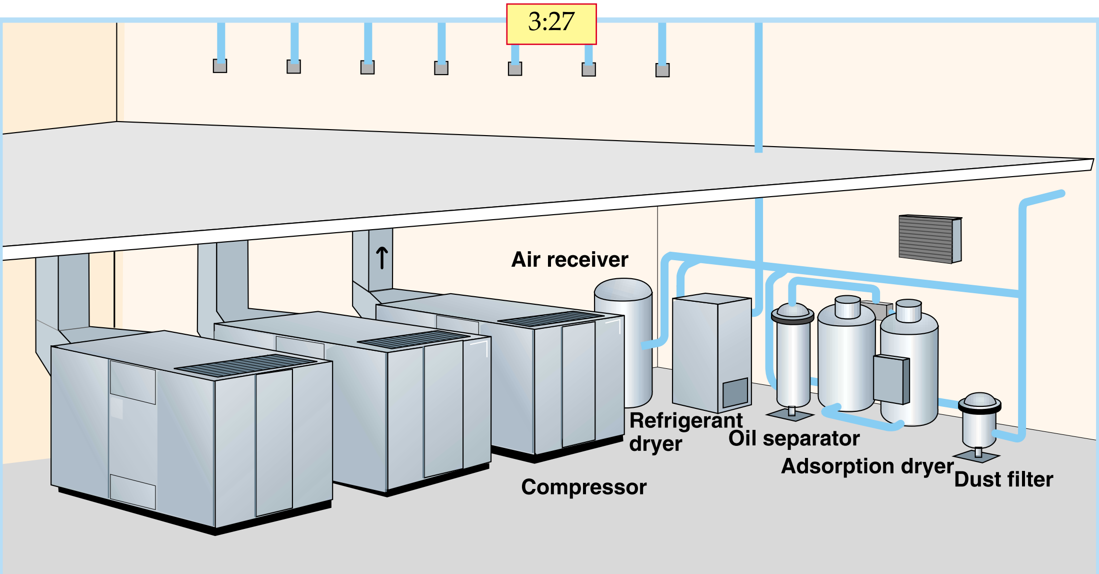

Installation in a compressor room is easier today than before. The compressor plant is now a turnkey solution ready to install and connect to requisite auxiliary equipment.

with each supplier of the different components This was necessary to ensure that they would work well together with the compressor. Nowadays, the compressor and accessories are purchased in as a turnkey solution. A compressor package consists of a box frame, on which the compressor and accessories are mounted. All internal connections between the different parts are already made. The complete compressor package is enclosed in a sound reducing hood to reduce noise levels.

This has resulted in a significant simplification of the installation and you can be completely assured from the outset that the system will work. Irrespective of this, it is important to remember that the installation method and technology still have a significant influence on the compressor system's performance and reliability.

The main rule for an installation is first and foremost to arrange a separate compressor central. Experience says that centralisation is preferable, irrespective of the type of industry. This gives, among others, improved operating economy, a better designed compressed air system, service and user friendliness, protection against authorised access, good noise control and simpler possibilities for controlled ventilation.

Secondly, a demarcated area in a building used for other purposes can be used for the compressor installation. The risk for other problems should be observed with such an installation, for example, disturbances from noise, the compressor's ventilation requirements, physical risks and/or the risk of overheating, drainage for condensation, hazardous surroundings e.g. dust or inflammable substances, aggressive substances in the air, space requirements for future expansion and accessibility for service. However, installation in, e.g. a workshop or warehouse can facilitate the installations for energy recovery. If there are no facilities to install the compressor indoors it can also be placed outdoors under a roof. You must however bear in mind the risk of freezing in condensation pockets and discharges, rain and snow protection on the air intake, suction inlet and ventilation, demands of a solid and flat foundation, e.g. asphalt, concrete slab or a flattened bed of shingle, the risk of dust, inflammable or aggressive substances and unauthorised access protection.

3.5.2 Placement and design

The compressed air central should be placed to facilitate routing of the distribution system in large installations with long piping. It can be advantageous for service and maintenance to place the compressed air central close to auxiliary equipment such as pumps and fans; even a location close to the boiler room can be beneficial.

The building should have access to lifting equipment dimensioned to handle the heaviest components in the compressor installation, (usually the electric motor) and/or the possibility of using a fork lift truck. It should also have floor space for the installation of an extra compressor with future expansion.

In addition, the clearance height must be sufficient to allow the lift of an electric motor or the like if the need arises. The compressed air central should have a floor drain or other facilities to handle condensation from the compressor, aftercooler, air receiver, dryers, etc. The floor drain shall be implemented in accordance with municipal directives.

3.5.3 Foundation

Normally only a flat floor of sufficient bearing capacity is required to set-up the compressor plant. In most cases vibration dampening is integrated in the plant. It is usual with new installations to cast a plinth for each compressor package to allow the floor to be cleaned.

Large piston and centrifugal compressors can require a concrete slab foundation, which is anchored to the bedrock or on a solid soil base. The effects of externally produced vibration has been reduced to a minimum on advanced, complete compressor plants. In systems with centrifugal compressors it may be necessary to vibration dampen the compressor room's foundation.

3.5.4 Intake air

The compressor's intake air must be clean and free from solid and gaseous contamination. Particles of dirt that cause wear and corrosive gases can be particularly damaging.

The compressor's air intake normally takes place via the sound reducing hood, but can also be placed where the air is as clean as possible. Gas contamination such as vehicle exhaust fumes, can be fatal if mixed in air to be breathed. For example, hospital applications usually make special demands on the placement of the air intake. A prefilter (cyclone, panel or rotary band filter) should be used on installations where the surrounding air has a high dust concentration. In such cases the pressure drop caused by the prefilter must be observed, so that it does not exceed the maximum limits prescribed by the manufacturer.

It is also beneficial for the intake air to be cold. It can therefore be appropriate to route this via a separate pipe from the outside of the building to the compressor.

It is important that corrosion resistant pipes, fitted with mesh over the inlet

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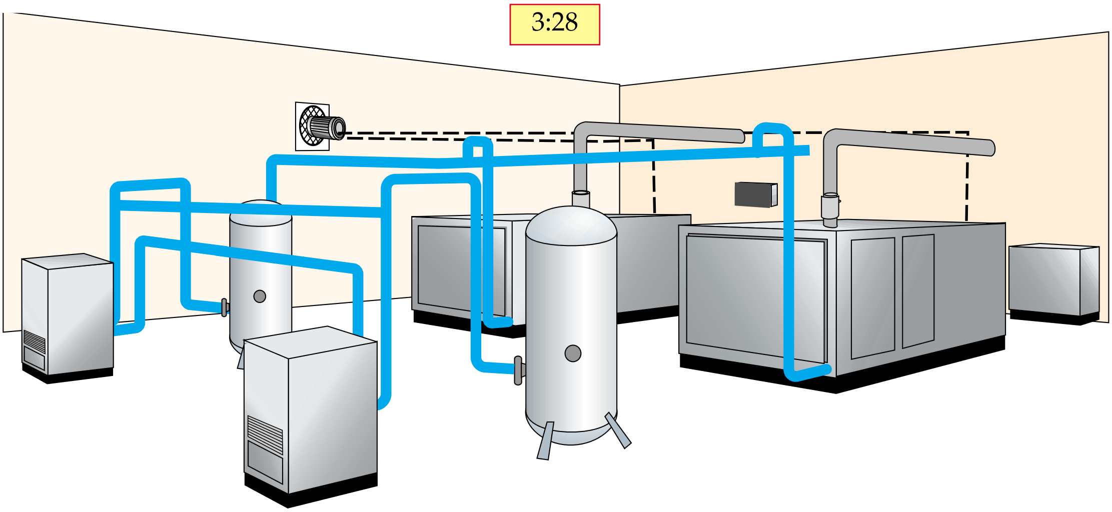

It is important that the compressor installation has a design that is service friendly and flexible to accommodate future expansion. The minimum area at service points in front of the machine's electrical cabinets should be 1200 mm.

and designed so that there is no risk of drawing in snow or rain into the compressor, are used for this purpose. It is also important to use pipes of a sufficient large dimension to gain as low a pressure drop as possible.

The design of the inlet pipes on piston compressors is particularly critical. Pipe resonance caused by the compressor's cyclic pulsating frequency, can damage the compressor, cause vibration and affect the surroundings through low frequency noise.

3.5.5 Compressor room ventilation

Heat in the compressor room is generated from all compressors. This heat is led off through ventilating the compressor room. The quantity of ventilation air is determined by the size of the compressor and whether it is air or water cooled.

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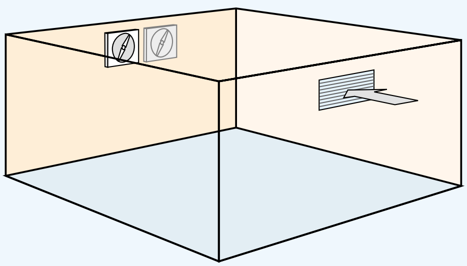

This is how a basic ventilation solution can be designed. The disadvantage is that ventilation is constant irrespective of the outer temperature. In addition difficulties can occur if two compressors are installed. The fans will be over specified if only one of the compressors is used. The problem can be solved by fitting the fans with speed controlled motors, which start via a multi-stage thermostat.

The ventilation air with air cooled compressors contains close to 100% of the energy consumed by the electric motor in the form of heat. The ventilation air with water cooled compressors contains down to 10% of the energy consumed by the electric motor. The heat must be removed to maintain the temperature in the compressor room at an acceptable level. The compressor manufacturer should provide detailed information regarding the requisite ventilation, but it can also be calculated according to the following:

$$P_V = \frac{Q_V}{1,25 \times \Delta T}$$

P_V = requisite quantity of ventilation air (m^3/s)
Q_V = heat flow (kW)
ΔT = permitted temperature rise (°C)

A better way to deal with the problem is to recover the energy and use it in the enterprise.

Ventilation air should be taken from outdoors, preferably without long ducting. The inlet for the ventilation air should be placed on a north facing wall if possible, or

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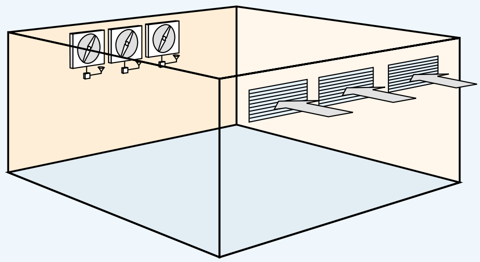

This is how a system with several thermostat controlled fans, which together can handle the total ventilation requirement, can be designed. The thermostats on the individual fans are set for different ranges, which means the quantity of ventilation air can vary depending on the outer temperature and/or the number of compressors in use (as the thermostats will switch on the fans one after another depending on the temperature in the compressor room). Alternatively, the fans can be started via a multi-stage thermostat.

in another place in the shade so that the intake air is as cool as possible during the summer. A grille should be fitted to the outside of the intake and an air stream operated damper on the inside to prevent foreign objects from entering and cold draughts.

Furthermore, the intake should be placed as low as possible, yet avoiding the risk of being covered with snow during the winter. Even the possible risk of dust and explosive or corrosive substances entering the compressor room must be taken into consideration.

The ventilation fan/fans should be placed high up on one of the compressor room's end walls, while the air intake is placed on the opposite wall. The air velocity at the intake should not exceed 4 m/s.

Thermostat controlled fans are the most appropriate. These must be dimensioned to handle the pressure drop in the ducting, outer wall grille, air stream operated damper, etc. The quantity of ventilation air must be sufficient to limit the temperature increase in the room to 7–10°C. The possibility in using water cooled compressors should be considered, if there is a problem in arranging sufficient ventilation in the room.

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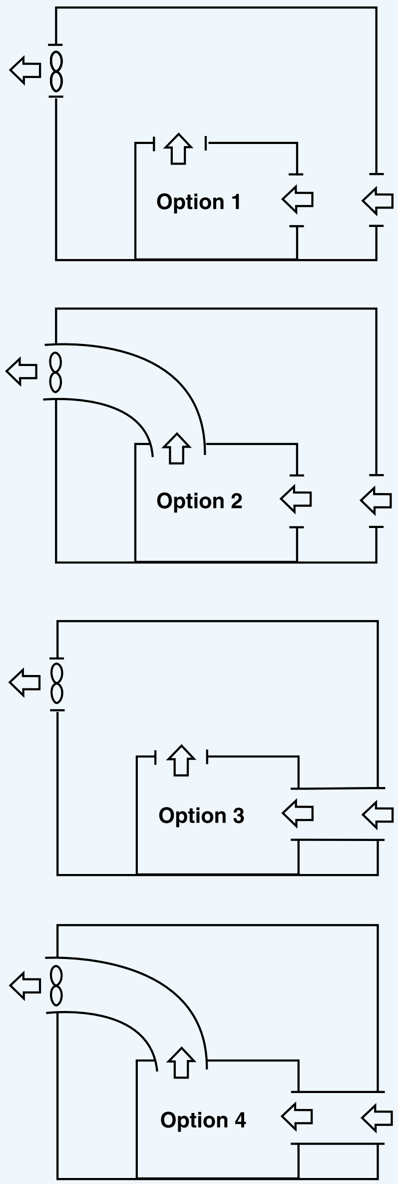

Examples of different ventilation solutions

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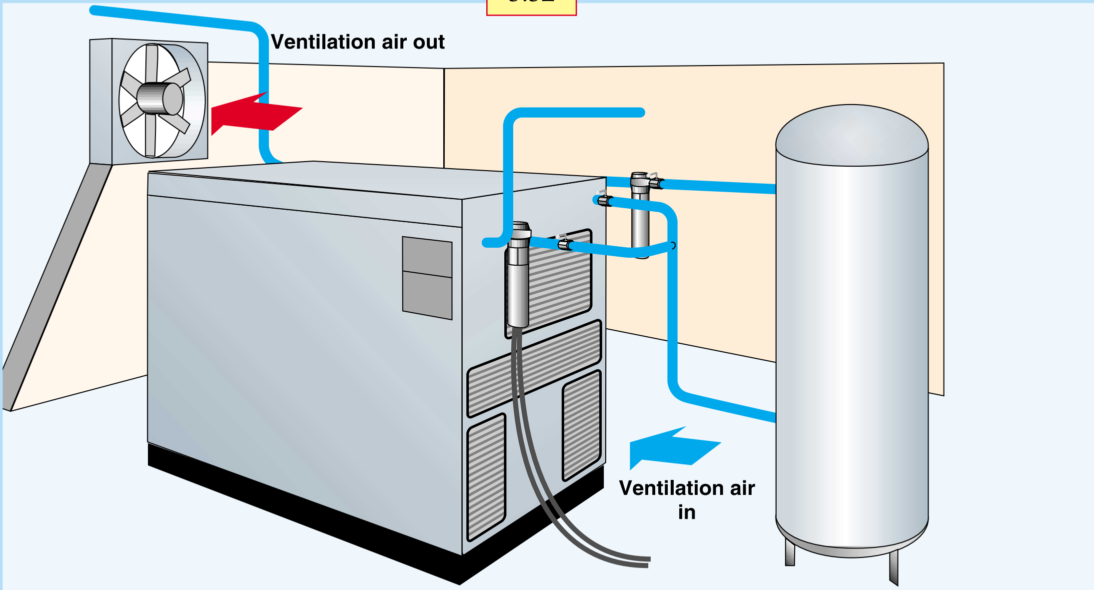

A small compressor installation in practice. The pipe for draining condensation must not open out under the water surface in the floor drain. An oil separator must be installed, if there is a risk that the waste water contains oil.

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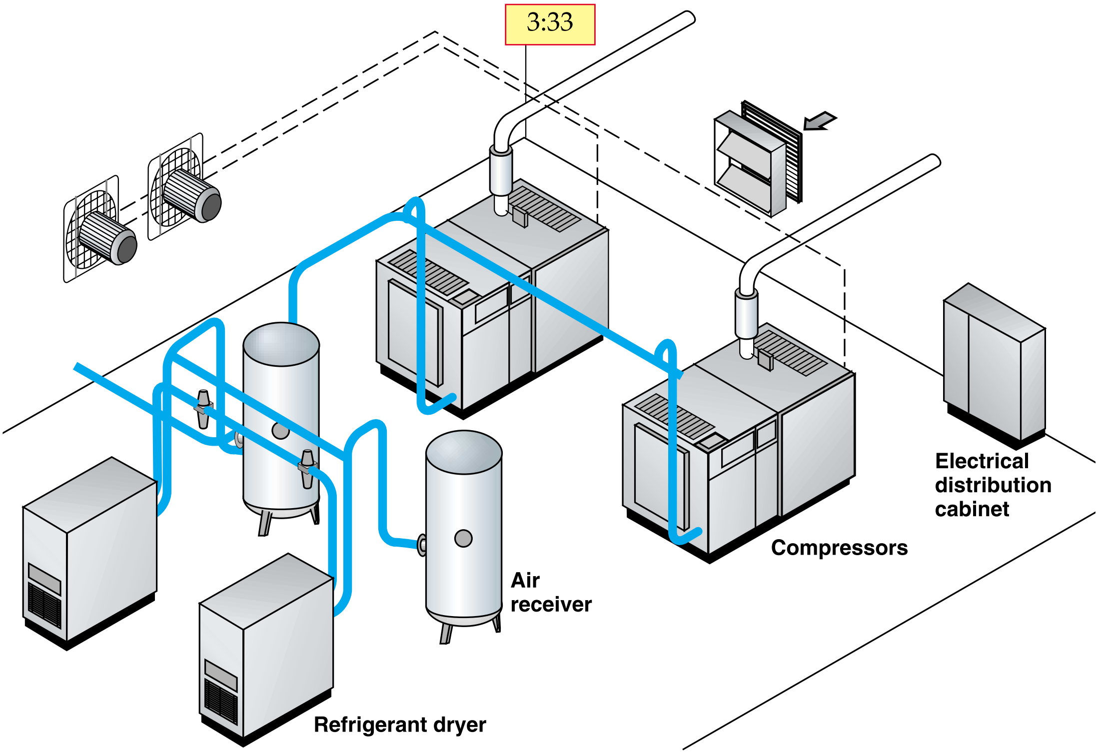

Example of a hospital installation with closed supply on the suction side and 100% reserve system (double independent system).

3.6 The compressed air network's structure

3.6.1 General

Three demands are placed on a distribution system to provide reliable operations and good economy: a low pressure drop between the compressor and point of consumption, a minimum of leakage, and the best possible condensation separation in the system if a compressed air dryer is not installed.

This primarily applies to the main pipes. The cost of installing larger pipe dimensions as well as fittings than that initially demanded is low compared with the cost of rebuilding the system at a later date. The air line network's routing, design and dimensioning are important for the efficiency of the installation, reliability and cost. Sometimes a large pressure drop in the pipeline is compensated by increasing the working pressure of the compressor from, e.g. 7 bar(e) to 8 bar(e). This gives inferior compressed air economy. When the compressed air consumption falls, the pressure drop also falls and the pressure at the point of consumption rises above the permitted level.

Fixed compressed air installations should be dimensioned so that the pressure drop in the pipes does not exceed 0.1 bar between the compressor and the furthest point of consumption. Added to this is the pressure drop in hoses, hose couplings and other fittings. It is particularly important how these components are dimensioned, as the greatest pressure drop frequently occurs at such connections.

The longest permitted length in the pipe network for a specific pressure drop can be calculated from the following empirical relation:

$$l = \frac{\Delta p \times d^5 \cdot p}{450 \times Q_c^{1,85}}$$

l = overall pipe length (m)
Δp = largest permitted pressure drop in the network (bar)
p = absolute inlet pressure (bar)
Q_c = flow, FAD (l/s)
d = internal pipe dimension (mm)

In general the best solution is to design a pipe system as a ring line around the area where air consumption will take place. Branch pipes are then taken off of the main pipeline to the points of consumption. This gives an even compressed air supply, despite heavy intermittent usage as the air is led to the actual point of consumption from two directions.

This system should be used for all installations, even if some points of consumption are at a great distance from the compressor installation. A separate main pipe is then routed to these areas.

3.6.1.1 Air receiver

One or more air receivers are included in each compressor installation. The size is adapted, e.g. according to the compressor capacity, regulation system and the consumer's air requirement. The air receiver forms a storage area for the compressed air, balances pulsation from the compressor and cools the air and collects condensation. Accordingly, the air receiver must be fitted with a drainage device.

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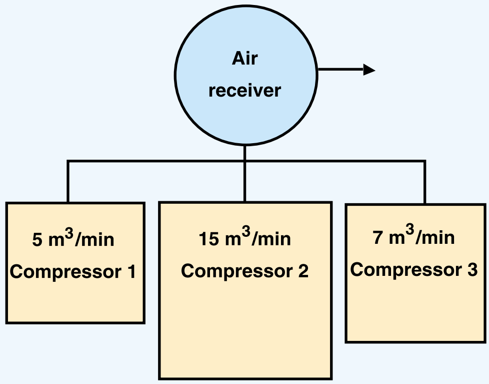

The air receiver is always dimensioned according to the capacity of the largest compressor when a system comprises of several compressors.

The following relation applies when dimensioning the receiver's volume. Note that the relation only applies for compressors with offloading/loading regulation.

$$V = \frac{0{,}25 \times Q_c \times p_1 \times T_0}{f_{max} \times (p_U - p_L) \times T_1}$$

V = air receiver's volume (l)
Q_c = Compressor's capacity (l/s) FAD
p_1 = Compressor's intake pressure (bar(a))
T_1 = Compressor's maximum intake temperature (K)
T_0 = Compressed air temperature in receiver (K)
(pu-pL) = set pressure difference between the loaded and off-loaded
f_{max} = maximum frequency = 1 cycle/30 seconds (applies to Atlas Copco compressors)

Simplified formula that applies with an ambient relation 1 bar(a) and approx. 20°C and 30 s cycle time.

$$V = \frac{Q}{8 \times \Delta p}$$

V = air receiver's volume (m^3)
Q = capacity of the largest compressor (m^3/min)
Δp = desired pressure difference (bar)

When air is required in large quantities during short periods it is not economic to dimension the compressor or pipe network according to this. A separate air receiver is then placed close to the consumer and is dimensioned according to the maximum air output.

In more extreme cases, a smaller high pressure compressor is used together with a large receiver to meet short-term, large air requirements between long intervals. The compressor will then be dimensioned for the mean consumption. The following relation applies for such a receiver:

$$V = \frac{Q \times t}{p_1 - p_2} = \frac{L}{p_1 - p_2}$$

V = air receiver's volume (l)
Q = air flow during the emptying phase (l/s)
t = length of the emptying phase (s)
P_1 = normal working pressure in the network (bar)
P_2 = minimum pressure for the consumer's function (bar)
L = filling phase's air requirement (1/work cycle)

The formula does not take into consideration the fact that the compressor can supply air during the emptying phase. A common application is the start of large ship engines, where the receiver's filling pressure is 30 bar.

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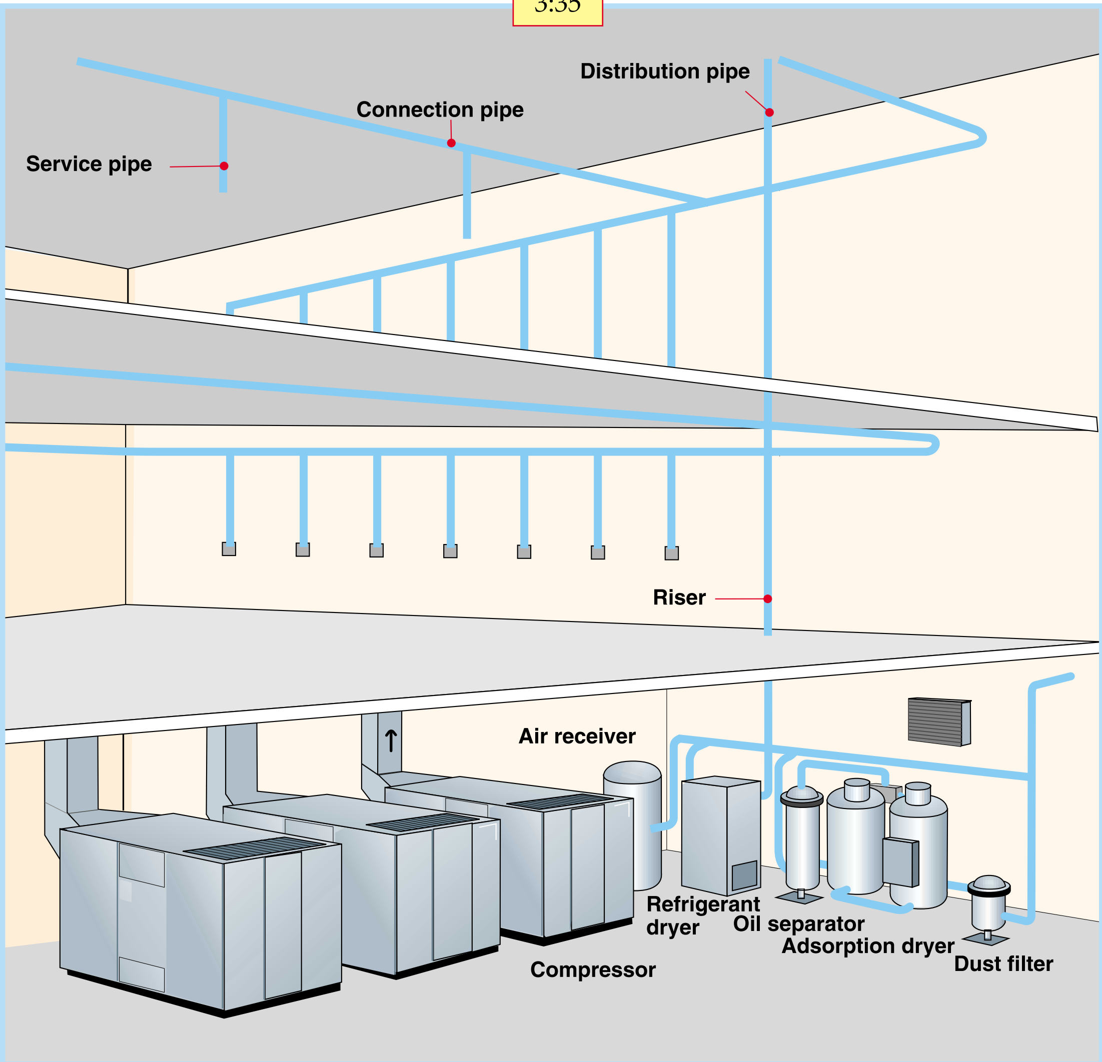


3.6.2 Design of the compressed air network

In smaller installations the same pipe can serve as the riser and distribution pipe. The starting point when designing and dimensioning a compressed air network is an equipment list with all the compressed air consumers, and a drawing indicating their placement. The consumers are grouped in logical units and are supplied via the same distribution pipe. The distribution pipe is fed in turn by risers from the compressor central. A larger compressed air network can be divided into four main parts: Risers, distribution pipes, service pipes and compressed air fittings. The risers transport the compressed air from the compressor central to the consumption area.

Distribution pipes divide the air across the distribution area. Service pipes feed the air from the distribution pipes to the workplaces. The compressed air fittings are the connections between the service pipe and the compressed air consumer.

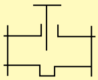
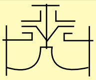
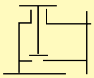
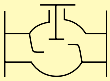
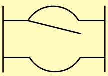
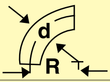
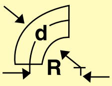
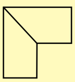
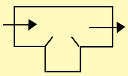
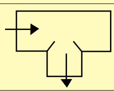
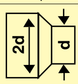
3.6.3 Dimensioning the compressed air network

The pressure obtained immediately after the compressor can generally never be utilised fully, accordingly, you must calculate that the distribution of compressed air claims some losses, primarily friction losses in the pipes. In addition, throttling and changes in the direction of flow occur in valves and pipe bends. Losses, which are converted to heat, result in a pressure drop that for a straight pipe can be calculated with the relation:

$$\Delta p = 450 \times \frac{q_v^{1,85} \times l}{d^5 \times p}$$

Δp = pressure drop (bar)
qv = air flow, free air (l/s)
d = internal pipe diameter (mm)
l = length of the pipe bar(a)
p = absolute initial pressure

3:36

Equivalent length in metres												
Component		Inner pipe diameter in mm (d)										
		25	40	50	80	100	125	200	250	250	300	400
Ball valve (full flow)		0.3 5	0.5 8	0.6 10	1.0 16	1.3 20	1.6 25	1.9 30	2.6 40	3.2 50	3.9 60	5.2 80
Diaphragm valve fully open		1.5	2.5	3.0	4.5	6	8	10	-	-	-	-
Angle valve fully open		4	6	7	12	15	18	22	30	36	-	-
Poppet valve		7.5	12	15	24	30	38	45	60	-	-	-
Flap check valve		2.0	3.2	4.0	6.4	8.0	10	12	16	20	24	32
Elbow R = 2d		0.3	0.5	0.6	1.0	1.2	1.5	1.8	2.4	3.0	3.6	4.8
Elbow R = d		0.4	0.6	0.8	1.3	1.6	2.0	2.4	3.2	4.0	4.8	6.4
90° angle		1.5	2.4	3.0	4.5	6.0	7.5	9	12	15	18	24
Tee through-flow		0.3	0.4	1.0	1.6	2.0	2.5	3	4	5	6	8
Tee side-flow		1.5	2.4	3.0	4.8	6.0	7.5	9	12	15	18	24
Reducing nipple		0.5	0.7	1.0	2.0	2.5	3.1	3.6	4.8	6.0	7.2	9.6

Some fittings and their influence on losses in pipes of a different diameter. The losses are recalculated to a corresponding increase in the length of the pipe network (m).

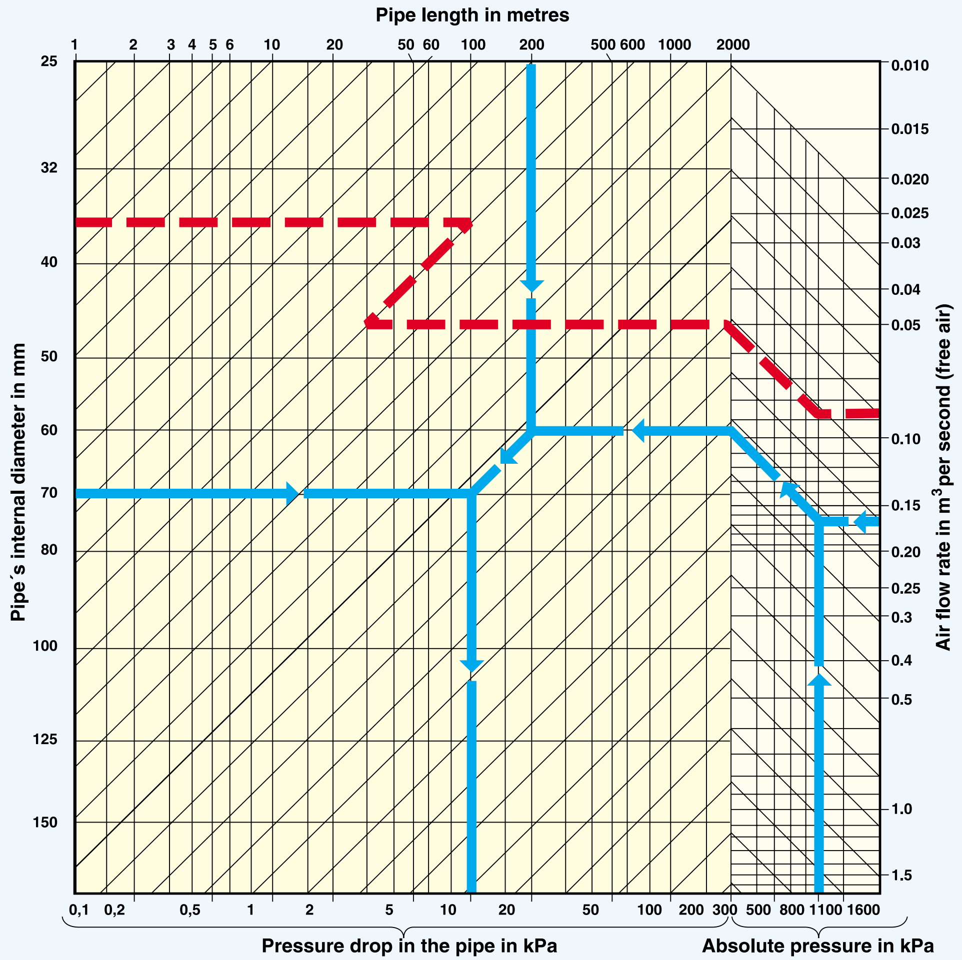
When calculating different parts of the compressed air network the following values can be used for the permitted pressure drop:

Pressure drop across service pipes	**0.03 bar**
Pressure drop across distribution pipes	**0.05 bar**
Pressure drop across risers	**0.02 bar**
Total pressure drop across the fixed pipe installation	**0.10 bar**

The requisite pipe lengths for the different parts of the network (risers, distribution and service pipes) are estimated. A scale drawing of the probable network plan is a suitable basis. The length of the pipe is corrected through the addition of equivalent pipe lengths for valves, pipe bends, unions, etc as set out in figure 3:36. When calculating the pipe diameter a nomogram, as set out in figure 3:37, can be used to find the most appropriate pipe diameter as an alternative to the formula (page 99). The flow, pressure, permitted pressure drop and the pipe length must be known to make a calculation. Standard pipe of the closest, greater diameter is then selected for the installation.

The equivalent pipe lengths for all

3:37



the parts of the installation are calculated by using a list of fittings and pipe components as well as the flow resistance expressed in pipe length. These "extra" pipe lengths are added to the starting pipe length. The network's selected dimensions are then recalculated to ensure that the pressure drop will not be too great. The individual sections (service pipe, distribution pipe and risers) should be calculated separately on large installations.

3.6.4 Flow measurement

Strategically placed flow meters permit internal debiting and economic allocation of compressed air utilisation within the company. Compressed air is a production media that should be a part production costs for individual departments within the company. With such a viewpoint it becomes interesting for all concerned to try to reduce consumption within the different departments.

The modern flow meters available on the market can give everything from numerical values for manual reading, to measurement data directly to a computer or debiting module.

The flow meters are generally mounted close to shutoff valves. Ring measurement makes particular demands as the meter needs to be able to measure both forwards and backwards.

3.7 Portable compressors

3.7.1 General

Today, virtually all portable compressors consist of a diesel engine powered, oil injected, screw compressor. Oil-free compressors only occur, for example, with service work in the process industry.

3.7.2 Noise and gaseous emissions

Modern designs of diesel powered compressors have a very low noise level according to applicable EU standards (ISO 84/536/EC) and can therefore be used in populated areas and close to hospitals, etc.

During the passed years fuel economy has been improved dramatically through efficient screw elements and more effective diesel engines. This is especially valuable, e.g. for well drilling, where the compressor works intensively under a long period. At the current time, there are engines with exhaust gas emissions that comply with the stringent demands set out in EURO-1. Contractors carrying out work in large towns must today (1998) use machinery that complies with this standard.

3:38

Pressure range	Pressure (bar)	Application area
Low	⩾7	Contract work
Medium	10 - 12	Blasting, ground work
High	20⩽	Water and energy well drilling, geotechnical investigations

Portable compressors are chiefly available in three different pressure ranges.

3.7.3 Pressure range

Modern portable compressors have a good overall economy through high operating reliability, good service characteristics, compact dimensions and a low total weight. They have a chassis normally designed for a transport speed of 30km/h or 80km/h. As for stationary compressors there is auxiliary equipment such as after-coolers, different filter packs (dust filters, carbon, etc.), after heaters and lubricating oil systems available. They can also be equipped with cold start equipment and a generator 230V/400V. There are portable, diesel powered generators built in a similar way to portable compressors for greater power requirements. The power classes start from 10 kVA and upwards.

3.8 Electrical installation

3.8.1 General

To dimension and install a compressor installation requires knowledge on how component parts affect each other and which regulations and provisions apply.

Here follows an overview of the parameters that should be especially considered to obtain a compressor installation that functions satisfactorily with regard to the electrical installation.

3.8.2 Motors

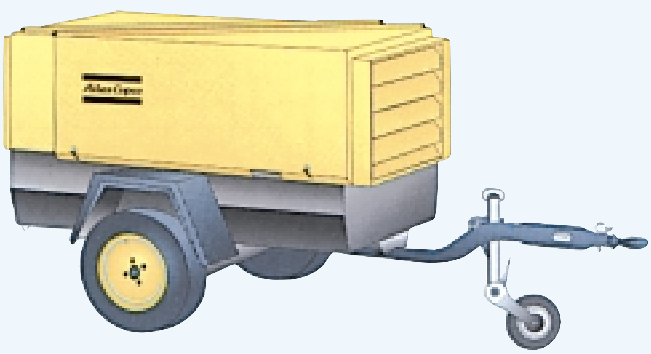
Short-circuited, three phase induction motors are used for compressor operations. Low voltage motors are generally used up to 450 kW and there above high voltage is the best option.

The motor's protection class is regulated by standards. The dust and water spray resistant design (IP54) is preferred to open motors (IP23), which require regular dismantling and cleaning. In other cases, dust deposits in the machine will eventually cause overheating, resulting in a reduced service life.

The motor, usually fan cooled, is intended to work at a maximum ambient temperature of 40˚C. At high temperatures the output must be reduced. The motor is normally flange mounted and directly connected to the compressor. The speed is adapted to the compressor, however, in practice 2 pole or 4 pole motors with a speed of 3000 rpm respective 1500 rpm are solely used.

The rated output of the motor is also determined by the compressor and should be as

3:39



Example of a portable compressor

close to the compressor's requirement as possible.

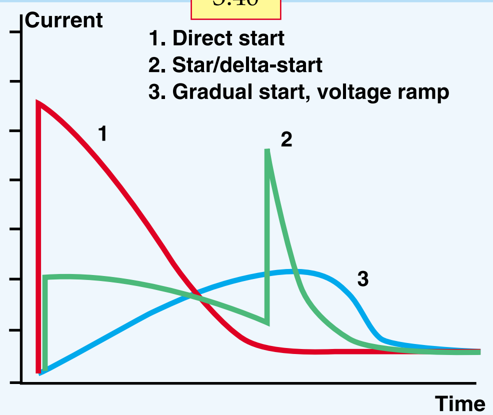
A too large motor is more expensive to buy, requires an unnecessarily high starting current, requires larger fuses, has low output factor and somewhat inferior efficiency. A too small motor becomes overloaded and consequently a risk for breakdown.

The starting method should also be included as a parameter when selecting a motor. The motor is only started with a quarter of its rated torque with star/-delta–start, which is why a comparison between the motor's and the compressor's torque curves can be justified to ensure that the compressor starts correctly.
See 3.8.3.

3.8.3 Starting methods

The most common starting methods are direct start, star/delta–start and gradual start. Direct start is easy and only requires a contactor and overload protection. The disadvantage is the high starting current, 6–10 times the motor's rated current and sometimes the high starting torque, which can, for example, damage shafts and couplings.

3:40



Connection current/time at different starting methods

The star/delta–start is used to limit the starting current. The starter consists of three contactors, overload protection and a timer. The motor is started with the star connection and after a set time (when the speed has reached 90% of the rated speed) the timer switches the contactors so that the motor is delta connected, which is the operating mode. See 1.6.5.7.

The star/delta–start reduces the starting current to approximately 1/3 compared with a direct start, however, the starting torque falls at the same time to a quarter. The relatively low starting torque means the motor's load should be low during the starting phase, so that the motor virtually reaches its rated speed before switching to the delta connection. If the speed is too low, a current/torque peak as great as with direct start, will occur during switching to the delta connection.

Gradual start, which can be an alternative start method to star/delta–start is a starter built up of semiconductors (thyristors) instead of mechanical contactors. The thyristors are controlled according to a time ramp, so that an equal rising current feeds the motor. The start is gradual and the starting current is limited to approx. three times the rated current.

The starters for direct start and star/delta-start are in most cases integrated in the compressor. It can be motivated with large compressor plant to place the units separately in the switchgear, due to space requirements, heat development and access for service.

A starter for gradual start is usually set-up separately next to the compressor. High voltage fed compressors always have their start equipment in the switchgear.

3.8.4 Control voltage

Normally no separate control voltage is connected to the compressor, as most compressors are fitted with an integrated control transformer. The transformer's primary side is connected to the compressor's power supply. This arrangement gives more reliable operations. In the event of disturbances in the power supply the compressor will be stopped immediately and blocked for restart.

This function, with one internally fed control voltage, should be copied in those cases where the starter is placed away from the compressor.

3.8.5 Short-circuit protection

Short-circuit protection, which is placed on one of the cables' starting points, can be made up of fuses or a circuit-breaker. Irrespective of which of the solutions you select it will give, if correctly matched, good protection.

Both methods have advantages and disadvantages. Fuses are well-known and work better than a circuit-breaker with large short-circuit currents, but they do not make a fully isolating break and have a long tripping time with small fault currents. A circuit-breaker breaks fully isolating and rapidly even with small fault currents, but demands more work during the planning stage compared to fuses. Dimensioning of the short-circuit protection is based on the expected load, but also on the limitations of the starter unit.

With regard to the starter's short-circuit protection see the standard according to IEC (International Electrotechnical Commission) 947-4-1 Type 1 & Type 2. How a short-circuit will affect the starter is determined by which of the options, Type 1 or Type 2, is selected.

Type 1: "damage to contactors and overload relays can occur. The replacement of components may be necessary".

Type 2: "Damage does occur to the overload relays. Light welding of the contactors is permitted. It shall be possible using basic measures to reset the starter in the operating mode."

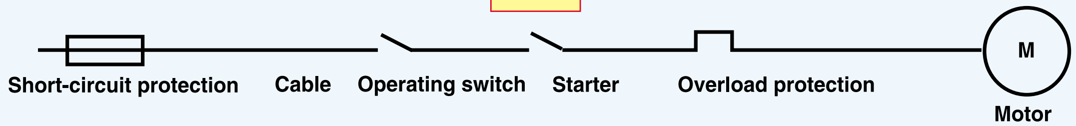
3.8.6 Cables

Cables shall, according to the provisions "be dimensioned so that during normal operations they do not accept hazardous temperatures and that they shall not be damaged thermally or mechanically with a short-circuit". The dimensioning and selection of cables is based on the load, permitted voltage drop, routing method (on a rack, on a wall, etc.) and the ambient temperature. Fuses can be used, for example, to protect the cables and can make up both a short-circuit protection and an overload protection. For motor operations a short-circuit protection is used (for example, fuses) and a separate overload protection (usually the motor protection included in the starter).

The overload protection protects the motor and motor cables by tripping and breaking the starter, when the load current exceeds the pre-set value. The short-circuit protection protects the starter, overload protection and the cables. How cables are dimensioned taking the load into consideration is set out in IEC 364 5 523 (SS 4241424).

There is a further parameter to bear in mind when dimensioning cables and the short-circuit protection, namely the "tripping condition". This condition means the installation shall be designed so,

3:41



A basic system for the connection of an electric motor to the mains supply.

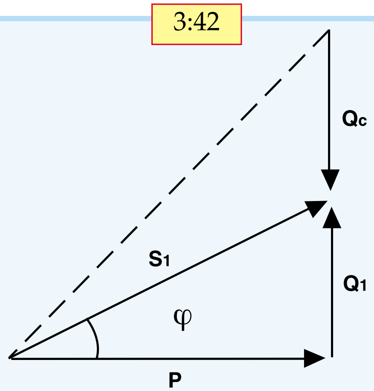
a short-circuit anywhere in the installation shall result in quick and safe breaking. Whether the condition is met is determined by, among others, the short-circuit protection, the length and cross-section of the cable.

3.8.7 Phase compensation

The electric motor does not only consume active power, which can be converted to mechanical work, but also reactive power, which is needed for the motor's magnetisation. The reactive power loads the cables and transformer. The relation between the active and reactive power is determined by the power factor, cosφ. This usually is between 0.7 and 0.9 where the lower value refers to small motors.

The power factor can be raised to virtually 1 by generating the reactive power directly by the machine using a capacitor. This reduces the need of drawing the reactive power from the mains. The motive for phase compensation can be that the power supplier may charge for drawing reactive power over a predetermined level and that heavily loaded transformers and cables need to be off-loaded.

3:42



Reactive power Qc is supplied to increase the motor's power factor (cosφ) to close to 1.

3.9 Sound

3.9.1 General

Noise is an energy form that propagates in a room as longitudinal waves through the air, which is an elastic medium. The wave movement causes changes in pressure, which can be registered by a pressure sensitive instrument, for example a microphone. The microphone is therefore one of the main parts in all equipment for sound measurement.

To measure the sound power in the SI unit Watt is difficult, due to the range covered by the sounds that surround us. Within acoustics they speak of levels instead, and measure sound in relation to a reference point. Measurement becomes manageable by apply a logarithm to the relation. The formula is:

$L_W = 10 \times \log_{10} \times W/W_0$

L_W = sound power level (dB)
W = actual sound power (W)
W_0 = reference power, usually 10–12 (W)

3.9.2 Sound pressure

The sound pressure level is a measurement of the sound's intensity. The relation is:

$$L_p = 20 \times \log_{10} \times p/p_0$$

L_p = sound pressure level (dB)
p = actual sound pressure (bar)
p_o = reference sound pressure, usually 0.0002×10^{-6} (bar)

The sound pressure level always refers to a specific distance to the power source, e.g. a machine. For a stationary compressor the distance is 1 metre and for a portable compressor the distance is 7 metres (according to CAGI Pneurop).

Information about the sound pressure level must always be supplemented with a room constant for the room where the measurement was made. Otherwise the room is assumed to be limitless, i.e. an open field. In a limitless room there are no walls that can reflect the sound waves, which would affect the measurement.

3.9.3 Absorption

When sound waves come into contact with a surface, some of the waves are reflected and some absorbed into the material of which it consists. The sound pressure at a certain moment therefore always consists partly of a sound that the sound source generates, partly of sound that is reflected from surrounding surfaces (after one or more reflections).

How effectively a surface can absorb sound depends on the material it is made up of and is usually stated as an absorption factor (between 0 and 1).

3.9.4 Room constant

A room constant is calculated for a room with several surfaces, walls and other surfaces, which depends on the different surfaces' absorption characteristics. The relation is:

$$K = \frac{A \times \bar{\alpha}}{1 - \bar{\alpha}}$$

$$\bar{\alpha} = \frac{\textit{total absorption}}{\textit{total area}} = \frac{A_1 \times \alpha_1 + A_2 \times \alpha_2 +}{A_1 + A_2 +}$$

K = room constant
$\bar{\alpha}$ = average absorption factor for the room (m^2)
A = total room area (m^2)
A_1, A_2, etc. are the parts of the room surface that have absorption factors α_1, α_2, etc.

3.9.5 Reverberation

The reverberation time is defined as the time it takes for the average sound pressure to decrease by 60 dB once the sound source has become silent. The average or equivalent absorption factor for the room is calculated as:

$$\bar{\alpha} = \frac{0{,}163 \times V}{T}$$

V= volume of the room (m^3)
T = reverberation time (s)

The room constant is obtained if this expression in put in relation to:

$$K = \frac{A \times \bar{\alpha}}{1 - \bar{\alpha}}$$

A = total room area (m^2)

3.9.6 Relation between sound power and sound pressure

If sound is sent out from a point sound source in a room without reflecting surfaces, the sound is distributed equally in all directions and the measured intensity will therefore be the same at all points at the same distance from the sound source. Accordingly, the intensity is constant at all points on a spherical surface around the sound source.

From this you can derive that the sound level falls by 6dB for each doubling of the distance to the sound source. However, this does not apply if the room has hard, reflective walls. You must then take the sound reflected by the walls into consideration. If you then introduce a direction factor the relation becomes:

$$L_p = L_W + 10\log\frac{Q}{4\pi r^2}$$

L_p = sound pressure level (dB)
L_W = sound power level (dB)
Q = direction factor (m^2)
r = distance to the sound source

For Q the empirical values apply (for other positions of the sound source the value of Q must be estimated):

Q = 1	**if the sound source is suspended in the middle of a large room.**
Q = 2	**if the sound source is placed on a hard, reflective floor, close to the center of a wall or ceiling.**
Q = 4	**if the sound source is placed close to the transition wall-floor or wall-ceiling.**
Q = 8	**if the sound source is placed in a corner close to the intersection of three surfaces.**

If the sound source is placed in a room where its border surfaces do not absorb all the sound, the sound pressure level will increase due to the reverberation effect. This addition is inversed proportionally to the room constant:

$$L_p = L_w + 10\log\left[\frac{Q}{4\pi r^2} + \frac{4}{K}\right]$$

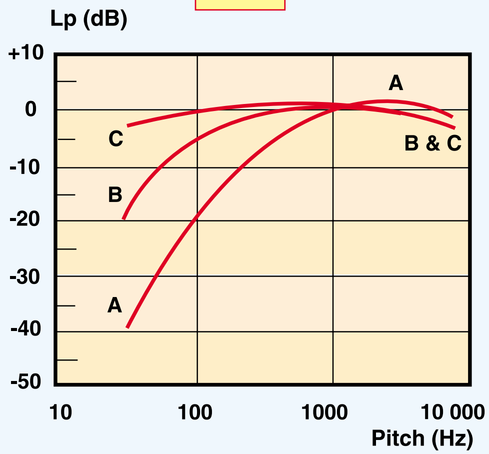
If this relation was drawn as a serie of curves it would show that in the proximity of the power source the sound pressure level drops by 6 dB for each doubling of the distance. However, at greater distances from the power source the sound power level is dominated by the reflected sound and thereby there is no decrease at all with increased distance.

The machines, which transmit sound through their bodies or frames, do not behave as point sources if the listener is at a distance greater than 2–3 times the machine's greatest dimension from its centre.

3.9.7 Sound measurements

The human ear distinguishes sound at different frequencies with different clarity. Low or very high frequency sounds must be stronger than sounds around 1000–2000 Hz to be perceived as equally strong.

3:43



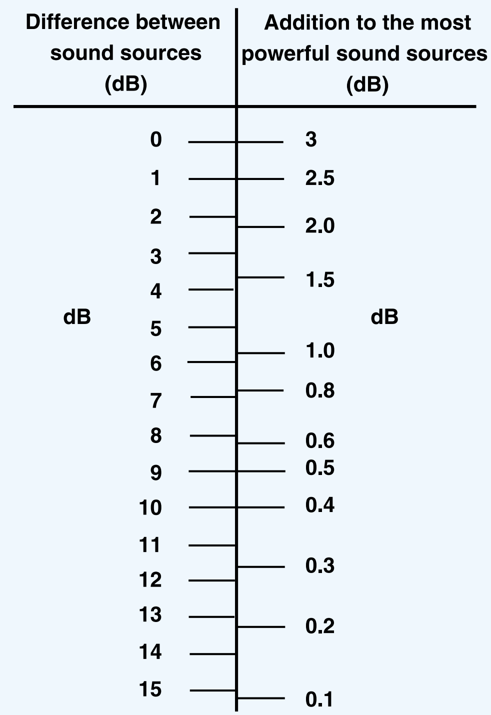
This is how the frequency curves appear for the different filters used to weight sound levels when measuring sound.

Different filters that adjust the measured levels at low and high frequencies are used to emulate the human ear's ability to hear sounds. When measuring noise an A-filter is usually used and the sound is measured as dB(A).

3.9.8 Interaction of several sound sources

When there is more than one sound source in a room the sound pressure increases. However, as the sound pressure level is defined logarithmically you can not add the sound pressure levels algebraically. When more than two sound sources are active, you start by adding two and thereafter the next is added to the sum of the first and so on. As a mnemonic rule, when two sound sources with the same levels shall be added the result is an increase by 3 dB. When ten sound sources with the same levels shall be added the increase is 10 dB.

3:44



The nomogram defines how many dB shall be added to the most powerful sound source when the power of two sound sources shall be added.

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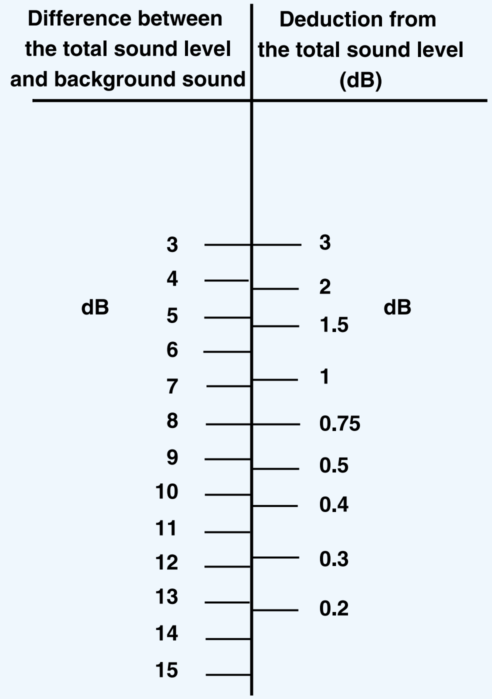

The nomogram defines how many dB shall be deducted from the total sound level at different background sound levels in order to estimate the total noise level.

Background sound is a special case. It is treated as a separate sound source and the value is deducted from the total of the other sound sources in order to give these special treatment.

3.9.9 Sound reduction

There are five different ways to reduce sound. Sound insulation, sound absorption, vibration insulation, vibration dampening and dampening of the sound source. Sound insulation involves an acoustic barrier being placed between the sound source and the receiver.

This means that only a part of the sound can be insulated, depending on the area of the barrier and the insulation characteristics. A heavier barrier is more effective than a lighter barrier.

Sound absorption involves the sound source being surrounded by light, porous absorbents attached to a barrier. Thicker absorbents are more effective than thinner absorbents and typical densities are approx. 30 kg/m^3 for polyurethane foam respective approx. 150 kg/m^3 for mineral wool. Vibration insulation is used to prevent the transfer of vibrations from one part of a structure to another. A common problem is the transfer of vibrations from a built-in machine to the surrounding barrier or down to the floor. Steel springs, cork, plastic, and rubber and examples of material used for vibration insulation. The choice of material and dimensioning is determined by the frequency of the vibration and demands of stability on the machine set-up.

Vibration dampening involves a structure being fitted with a dampening external surface of an elastic material with a high hysteresis factor. When the dampening surface is sufficiently thick, a wall, for example, is effectively prevented from vibrating and thus starting to emit sound. Dampening of a sound source gives small results, yet a good exchange in relation to the cost. In this way a reduction in the machine's total sound level by approx. 5 dB can be achieved, while integration can mean a reduction by approx. 15–25 dB.

3.9.10 Noise with compressor installations

A compressor's noise level is measured on a machine in free field. When it is installed in a room the noise level is affected by the properties of the room. The size of the room, material in the walls and ceiling as the presence of other equipment (and its possible noise level) in the room are all significant.

Furthermore, the positioning of the compressor in the room also affects the noise level, precisely as the set-up and connection of pipes and the like. Sound radiating from compressed air pipes are frequently a more problematic noise source than the noise from the compressor and its power source. It can be a question of vibration transferred mechanically to the pipe, often in combination with vibration transferred through the compressed air. It is therefore important to fit vibration insulators and even enclose part of or the entire pipe system with a combination of sound reducing material and a sealed barrier.

3.10 Standards, laws and provisions

3.10.1 General

In the compressed air sector, as in many other sectors, there are regulations that apply. It can be demands that are defined in laws and provisions as well as optional regulations, as in national and international standards. Sometimes the regulations in standards are also binding, for example, when they come into force through legislation. If a standard is quoted in an agreement it can thereby also be made binding.

Binding regulations can apply, for example, to safety for people and property while optional standards are used to facilitate activities such as work with specifications, selection of quality, measurements, manufacturing drawings etc.

3.10.2 Standards

Standards are quoted in many cases by legislators as a way of creating the desired level of safety. You can be considered as complying with the legislation's different demands if you follow the detailed directives given by the standards with regard to design, equipment and testing. Standards are useful to the manufacturer and the consumer. They increase interchangeability between components from different manufacturers and the possibility of comparison under the same conditions.

Standards are produced and issued nationally as well as on European and international levels. International standards, ISO or EN usually come into force as national standards (SIS in Sweden).

It is the standardization body ISO (International Organization for Standardization) with its base in Geneva respective CEN (Commission Européenne pour la Standardization), that organise the international work.

SIS (Standardiseringskommissionen i Sverige) is the Swedish party in this work and in addition manages national standardisation in Sweden with the help of a number of specialised standardisation bodies. You can purchase all standards, national as well as international from SIS.

Besides official standards there are also documents produced by trade bodies such as PNEUROP an association of European manufacturer's of compressed air equipment. An example of such a document is the measurement standards for, e.g. compressor capacity, oil content in the compressed air, etc. which are issued while awaiting a standard to be drawn up.