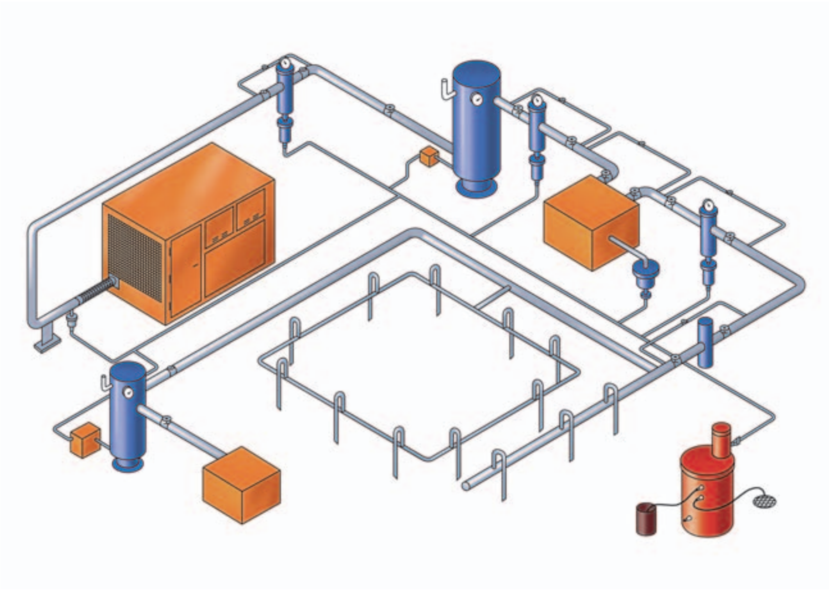
GPG385

Good Practice Guide

Energy efficient compressed air systems



CARBON TRUST

Making business sense of climate change

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This guide has been prepared for the Carbon Trust by the British Compressed Air Society Ltd and its members.

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1 Introduction

Compressed air systems are safe, reliable and versatile, but they are usually taken for granted with scant regard to cost. An essential resource for industry, business and the public sector, compressed air is often referred to as the fourth utility after electricity, gas and water. However, unlike the other three, compressed air is generated on-site, and users therefore have much more control over usage and costs.

1.1 Why take action to control compressed air

There are three important reasons why it is worth investing time and effort in reducing compressed air costs:

- It will save energy and money by identifying and eliminating waste
- It will improve the reliability and performance of the compressed air system
- It will reduce environmental impact through reduced electricity consumption and consequent lower carbon emissions.

A properly designed and maintained compressed air system that is energy efficient could save the user thousands of pounds each year. It will also minimise the risk of lost production by increasing the reliability of supply and improve the health and safety aspect of operating a pressurised system. Every pound saved on energy goes straight to the bottom line and is a very effective way of increasing profits.

Of all utilities, compressed air represents one of the largest opportunities for immediate energy savings on any site. Furthermore, most of the energy and carbon savings are achievable with little or modest investment.

Figure 1 shows that, over a ten-year life of a compressor, the cost of energy to run the system far outweighs the capital investment. It also shows that maintenance accounts for 7% of the total costs, yet this is a crucial activity for maximising the energy efficiency of any compressor. For a typical industrial system, compressed air accounts for 10% of the electricity bill, though in some sectors the proportion is higher.

Figure 1 *Compressor costs over a ten-year life*

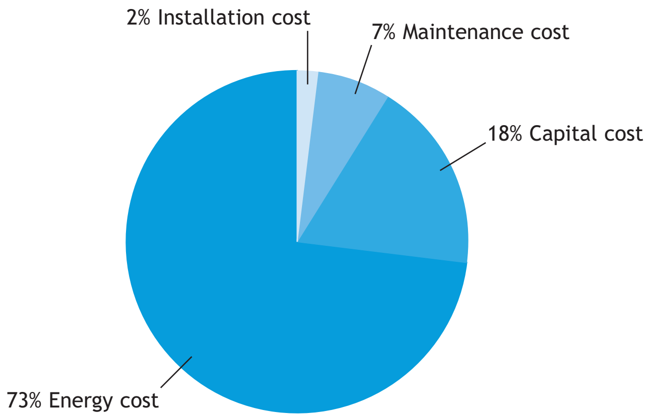


Table 1 identifies key areas where savings can be made at no or low cost with only modest investment. The greatest energy savings, typically up to 30%, can be made by reducing avoidable waste and without the need for capital investment in new technologies.

Developing and implementing a compressed air policy for an entire site is the most cost-effective way of improving the energy efficiency of a compressed air system. The features of such a policy are described in more detail in Section 2. Any, or all, of the management actions listed in Table 1 could be incorporated into a compressed air policy.

1.2 How to use the guide

This guide is intended for anyone who has a compressed air system and wants to reduce their energy bills and carbon emissions while improving the performance and reliability of their system. The guide focuses on machines rated between 10kW and 300kW, as these form the most widely used group across industry. However, the principles and ideas also apply to smaller and larger systems, and to those used in commerce and the public sector.

The guide takes an overall system management approach, as well as covering technical aspects of the components of a typical industrial compressed air system. It describes each component, briefly explaining its function before identifying cost-effective actions that will reduce energy consumption and carbon emissions.

***Table 1** Energy saving opportunities for a typical industrial compressed air system*[1]

	Potential savings[2]	Investment[3]
Management Actions		
Raise the awareness of all users to the proper use of compressed air	10-15%	Low
Develop and implement a maintenance programme for the whole system	5-8%	Low
Install metering and implement monitoring	5-10%	Medium
Use only trained and competent personnel for installation, servicing and system upgrades	5-10%	Low
Develop and implement a purchasing policy	3-5%	Low
Technical Actions		
Implement a leak reporting and repair programme	20-40%	Low
Do not pressurise the system during non-productive periods	2-10%	Low
Fit dryer controls (refrigerant and desiccant)	5-20%	Medium
Install compressor drive and system control measures	5-15%	Medium
Install heat recovery measures where appropriate	Up to 75%	Medium

[1] Operating at 7 bar(g) (700kPa(g)) with an output of 500 litres/s
[2] The percentage figures given are indicative, are not cumulative and will vary with each system
[3] Low = less than £2,000; Medium = £2,000—£10,000

The guide covers:

- How to manage a compressed air system effectively
- Examples of misuse and wastage of compressed air
- The distribution of compressed air from the compressor to points of use
- How to improve compressor efficiency
- Energy efficient storage of compressed air
- The filtration and drying of compressed air
- The collection and disposal of condensate.

The appendices include a series of checklists to help save energy and reduce carbon emissions, and a list of questions to ask when selecting a compressor. There is also a glossary and a list of further sources of information.

1.3 Taking a system approach

An energy efficient compressed air system will be one that is:

- Well maintained throughout, with all equipment serviced regularly and performance tested
- Properly designed to minimise pressure drop with respect to all fittings, air treatment, piping and connections
- Monitored continuously or on a regular basis, with specific energy consumption calculated from the data obtained
- Used by staff who are aware of the cost of compressed air and properly trained in the effective use of equipment utilising it
- Subject to an ongoing leak reporting and repair programme.

Each component in a compressed air system should help to deliver compressed air that is fit for the purpose and free from pressure fluctuations at its point of use. If any component is working inefficiently, the system's performance suffers and operating costs rise. Each component in the system interacts with others and should not be considered in isolation.

For example, upgrading to a new, energy efficient compressor will have only a limited impact if the leak rate is still too high or if the flow is restricted by an inadequately sized delivery pipe network. Any equipment's energy efficiency will be affected adversely if it is not maintained properly.

Tip: The potential energy savings of a new efficient compressor will be compromised if the air main is undersized.

1.4 Purchasing for energy efficiency

As a general rule, the more efficient equipment usually costs more to buy then the less efficient alternative. Suppliers of equipment are often unable to supply the expected lifetime operating cost, so purchase decisions are too frequently based on purchase price alone. The policy of lowest price is often detrimental to energy efficiency and any benefit derived from technology advances.

The Energy Technology List (www.eca.gov.uk/etl) is for companies and organisations wishing to buy energy efficient equipment and gives details of over 7,300 products that meet Government-prescribed energy efficiency criteria. A key feature of the Energy Technology List is that it provides details of specific equipment and suppliers. Certain compressed air technologies are included on the Energy Technology List.

Investment in products listed on the Energy Technology List may also qualify for an Enhanced Capital Allowance (ECA), a tax relief permitting businesses to deduct 100% of capital expenditure against taxable profits in the first year. Qualifying expenditure can include the cost of buying the equipment as well as the cost of transporting the equipment to the site and installing it.

For further information about the Energy Technology List, call the Carbon Trust Energy Helpline on 0800 58 57 94.

2 Managing a compressed air system

Making energy savings to reduce the cost of providing compressed air at a site is not just about the compressor. It involves looking at the efficiency and performance of all parts of the overall system (see Figure 2). The different components (e.g. air distribution, compressors, storage, air treatment, condensate management) are considered in Sections 4–8. This section explains how to manage a compressed air system effectively, while Section 3 describes ways in which compressed air is misused or wasted.

2.1 Compiling and implementing a compressed air policy

Most compressed air systems evolve instead of going through a structured design process.

A number of departments are normally involved, including:

- Production
- Maintenance/facilities management
- Accounts/purchasing
- Energy/environment.

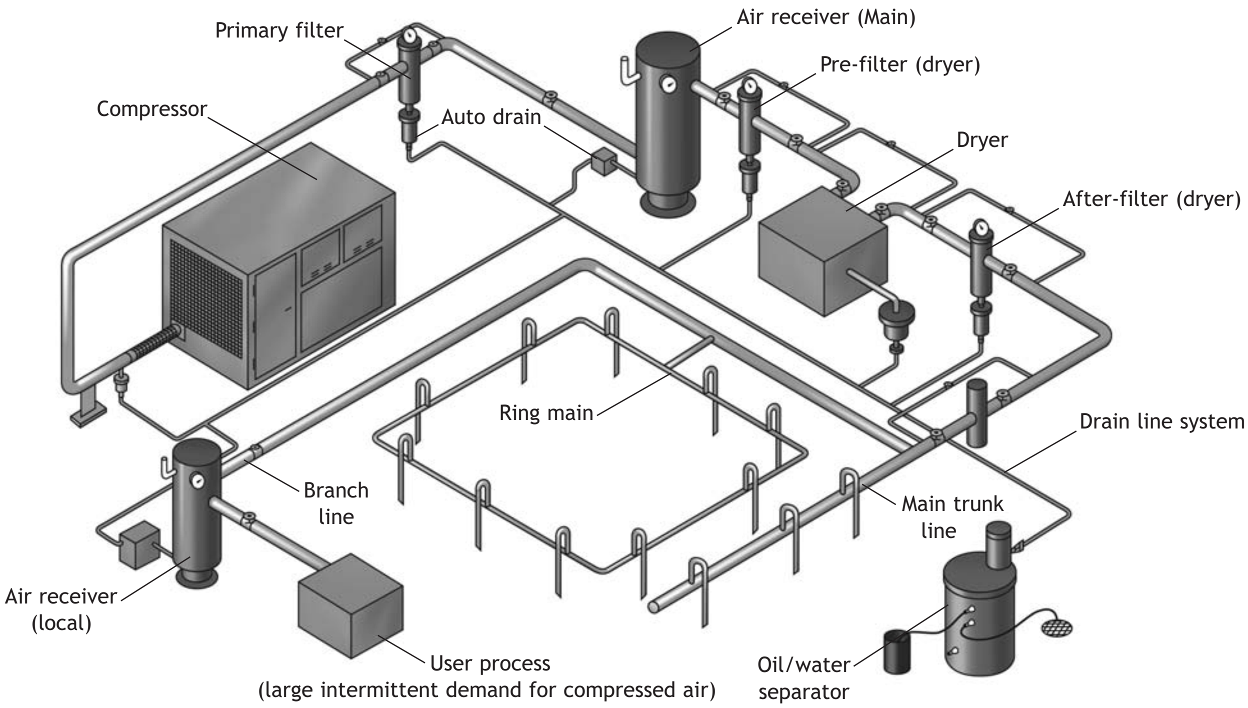
Such structures, with no overall responsibility assigned to one person, frequently lead to an uncoordinated approach to changes to the system – some of which may conflict with the needs of another department.

Formulating a compressed air policy is a key step towards improving the energy efficiency of a system. The guidelines within the compressed air policy will also help to improve air supply reliability and to comply with legislation.

A compressed air policy should:

- Appoint a manager with responsibility to ensure overall coordination of the management of the system

Figure 2 *Typical compressed air system*



- Set objectives with regard to:
  - Each department's role and responsibility
  - Raising awareness of all those who use compressed air
  - Establishing compressed air costs
  - Setting targets for reducing avoidable waste
  - Implementing a maintenance programme
  - Defining servicing and installation guidelines using trained personnel
  - Defining a purchasing policy.

This overall management approach to compressed air systems has the same principles as general energy management. This approach is essential in achieving the maximum reduction in energy consumption by the system. A reduction of 30% in energy costs is typical and achievable.

2.2 Establishing current usage and costs

Before implementing any improvements to a compressed air system, an audit should be carried out to:

- Determine annual costs
- Establish a baseline against which improvements can be measured.

If permanent metering is already installed, this will provide a demand profile and a baseline to help identify areas of avoidable waste.

If there is no metering, an estimate of the energy consumption of each compressor can be calculated from the size of the motor, its average utilisation and the number of hours it operates. For example, a 100kW compressor operates at 7 bar(g) (700kPa(g)) and is on load for 75% of the production time of 2,000 hours/year.

Energy consumption = 100kW x 0.75 x 2,000 hours/year = 150,000kWh/year

Tip: When measurements are performed on-site, the power consumed by a compressor package will, in most cases, be more than the rated electric motor power.

If electricity costs £0.05/kWh, the annual energy cost is £7,500. For a 120-hour working week, this increases to £22,500/year.

A compressed air equipment supplier or a consultant may be able to assist in obtaining more accurate costs and a demand profile. The usual method is to install a data logging system over a period of at least seven days to determine the demand and pressure variation, and power consumed during a typical week. This will identify:

- Pattern of demand (demand profile)
- Off load running time
- Demand peaks (expected and exceptional)
- Specific energy consumption (i.e. number of kW needed to produce each litre per second of air).

Typical methods used to achieve this are:

- Power metering
- Flow metering
- On/off load monitoring
- For more guidance on metering, see GPG326 *Energy metering*.

2.3 Identifying opportunities for improvement

Having calculated annual costs and established a baseline against which to measure improvement, the approach described in this guide can be used to identify opportunities for improvement. Start by carrying out a survey (see GPG316 *Undertaking an industrial energy survey*).

It is best to start by reviewing end uses (see Section 3), because any improvements here may well affect the demand for compressed air and the air distribution network (i.e. redundant pipework and reduced pressure losses).

2.4 Maintenance

Effective maintenance is essential to energy efficiency in compressed air systems. Any organisation that cuts back on maintenance will pay more in terms of energy consumed as well as decreased service life and reduced reliability of components and equipment.

By law, if a system operates at greater than 0.5 bar(g) (50kPa(g)) and has an air receiver installed, it will have to comply with the Pressure Systems Safety Regulations 2000. This requires that compressed air equipment be properly maintained to minimise health and safety risks associated with a pressurised system. Take the opportunity when preparing for the annual inspection of the system to check maintenance records and schedule. Note that the maintenance interval will not be the same for each piece of equipment within the system, so check the manufacturer's recommendations.

Tip: Effective maintenance contributes to the reliability of the air supply and safety of the system.

2.5 Staff awareness and involvement

Many users of compressed air have no idea how expensive it is and therefore waste or misuse it. Companies that have trained staff to understand the cost of producing compressed air, the interdependency of the components of a compressed air system and the importance of saving energy, have made the biggest savings.

Use the first checklist in Appendix D to improve compressed air system management.

3 Misuse and waste of compressed air

Waste and misuse often offer the greatest potential for no-cost and low-cost energy savings in a typical system. Start by looking at all the uses of compressed air on the site.

During the lifetime of an organisation, processes evolve and production methods change. Both affect the way a compressed air system is maintained, upgraded and the way in which compressed air is used. For these reasons, it is good practice to review the system and working practices regularly.

However, there are many cases where compressed air is the preferred choice and, indeed, has unique advantages over other power sources. These include:

- Air-driven equipment in hospitals to avoid electrical interference
- Air supply for remote locations where air can also be stored in tanks
- Offshore or hazardous area uses where risk of explosion excludes the use of electricity
- Cleaning out areas of extreme temperatures (e.g. freezers and furnaces).

3.1 Misuse

Compressed air is used for a myriad of applications due to its safety, flexibility and convenience. However, it is also misused – and hence wasted – for the same reasons, incurring unnecessary energy costs. Compressed air is sometimes used for an application just because an air supply is readily available, not because it is the most cost-effective or appropriate method. Table 2 gives examples of duties that do not warrant the use of treated compressed air, together with alternatives.

Tip: Check whether or not compressed air really needs to be used. Could the job be done directly with electricity?

3.2 Waste

The main areas of waste that merit attention are:

- Leaks
- Pressure drop
- Running the compressor when there is no demand for air.

Tip: If factory changes have been made, check that any unused compressed air lines are isolated and not leaking air.

Leaks

All compressed air systems have leaks. Reducing air leaks is the single most important energy saving measure that can be performed. The leak rate on an unmanaged compressed air system can be as much as 40% of the output.

Compressed air leaks also lead to additional costs through:

- Fluctuating system pressure, which can cause air tools and other air-operated equipment to function less efficiently – potentially stalling and affecting production
- Reduced service life and increased maintenance of equipment due to unnecessary compressor cycling and running time
- Excess compressor capacity.

The sources of leakage are numerous, but the most frequent causes are:

- Manual condensate drain valves left open
- Shut-off valves left open
- Leaking hoses and couplings
- Leaking pipes and pipe joints
- Leaking pressure regulators
- Air-using equipment left in operation when not needed.

Table 3 can be used as a guide to estimating the cost of air lost through leaks.

__Table 2__ Inappropriate uses of compressed air and alternatives

Inappropriate use of compressed air	Alternative
Ventilation	Fans, blowers
Liquid agitation	Mechanical stirrer or blower
Cleaning down workbenches, floors and personnel	Brushes, vacuum cleaner
Rejecting products off a process line	Mechanical arm
Transporting powder at low pressure	Blower

__Table 3__ Annual cost of air leaks

Hole diameter (mm)	Air leakage at 7 bar(g) (700kPa(g))		Power to air leaks[2] (kW)	Cost of leak[3] (£/year)	
	litres/s	cfm[1]		48 hours/week	120 hours/week
0.50	0.20	0.42	0.06	7.2	18
1.5	1.8	3.8	0.54	65	160
3.0	7.1	15	2.1	250	630
6.0	28	59	8.4	1,000	2,500

[1] Cubic feet per minute
[2] Based on 300W/litre
[3] Based on £0.05/kWh

Identifying and measuring leaks

There are a number of ways for detecting leaks. Handheld ultrasonic leak detectors provide an effective method of detecting leaks against background noise without having to stop production. These units are on the Energy Technology List and can be bought under the ECA scheme (see Section 1 or visit www.eca.gov.uk/etl).

Other methods of identifying leaks include:

- Listening for leaks when the background noise is quiet enough
- Soap solution brushed onto pipe fittings
- Leak detection sprays.

Many compressed air systems now have permanent flow meters installed for monitoring purposes. This can measure the level of air production when no tools are in use, thus providing a good indication of the leakage level. There are alternative measurement methods that can effectively determine the amount of air leaking:

- Cycle timing
- Pressure decay.

A description of these methods can be found in Appendix A.

A leak survey will help to understand the extent of the problem. If there are insufficient resources on-site to carry out a leak survey, many companies now offer a leak detection audit and repair service.

Having established the size of the leakage:

- Set a realistic target for leakage rate (typically 5-15% of the air compressor's demand)
- Initiate a programme of finding and eliminating leaks
  - Tag the leaks and record on a site plan, grading from 1-10 for priority

— Fix the largest leaks first.

- Set up a system for reporting leaks. Make sure all leaks are repaired immediately.

Tip: Have an ongoing leak test and repair programme. Leaks reappear and a 3mm hole could cost over £600/year in wasted energy.

Leaks need to be monitored constantly and a leak survey carried out at least twice a year to ensure the levels do not creep up again.

When attempting to reduce leakage, there will be a point at which the cost of locating and curing extremely small leaks is no longer justified by the small amount of energy saved.

Leak detection and repair programme halves generating costs

A chemical company in South Wales saved 50% on the cost of generating compressed air by implementing a six-monthly leak detection and repair programme. The first survey detected 412 leaks, equivalent to an annual loss of £66,500. Fixing the majority of these leaks led to a substantial saving in electricity costs and made a valuable contribution to the company's Climate Change Agreement target for carbon reduction.

The company uses a hand-held ultrasonic leak detector, and each survey is followed by a round of repairs in which typically 75% of leaks can be corrected at no cost.

Pressure drop

Pressure drop in a compressed air system is due to airflow resistance caused by pipe friction and various components within the system (e.g. valves, bends). Inadequate pipe sizing also results in pressure drop, and this is covered in the next section.

The compressor must produce air at a pressure high enough to overcome these pressure losses in the system and still meet the minimum operating pressure of the end use equipment or process. As a result, it is not uncommon for a compressor to be delivering air at a pressure of 8 bar(g) (800kPa(g)) while the pressure at the point of use only 6.5 bar(g) (650kPa(g)). This pressure drop of 1.5 bar (150kPa) through the system represents wasted energy and money.

In a properly designed and installed system, pressure drop should be less than 10% of the compressor's discharge pressure, as measured from the compressor outlet to the point of use. Thus, at a pressure of 7 bar(g) (700kPa(g)), the pressure drop should be less than 0.7 bar (70kPa).

The need to generate at a substantially higher pressure than required by the end use application is usually an indication of a pressure drop problem. If reducing the pressure, make sure the most critical process still has sufficient air to operate.

Check the required pressure and air purity levels with the equipment supplier. For example, blow guns should be regulated down to 2 bar(g) (200kPa(g)) to meet health and safety requirements.

Tip: Measure the pressure drop across the system. Every 1 bar (100kPa) of pressure drop represents a 7% increase in compressor energy costs.

Running the compressor when there is no demand for air

Compressor installations are often left on when there is no demand for air (e.g. overnight). This wastes energy because power is being used to feed leaks. Even when off-loaded, compressors can consume up to 20-70% of their full load power. Fewer running hours will also reduce maintenance costs.

- Check that compressors are switched off at the earliest opportunity and are not switched on earlier than necessary
- Check time switch settings regularly.

However, it is important to ensure that when automatically shutting down the compressor, other plant areas are not affected. Professional advice should be sought.

Important:
Compressed air operated safety systems must not be compromised by over- enthusiastic shutdown of compressor plants.

Refer to Sections 5 and 6 for more about controlling a compressor.

Use the second checklist in Appendix D to help reduce misuse and waste in compressed air systems.

4 Air distribution network

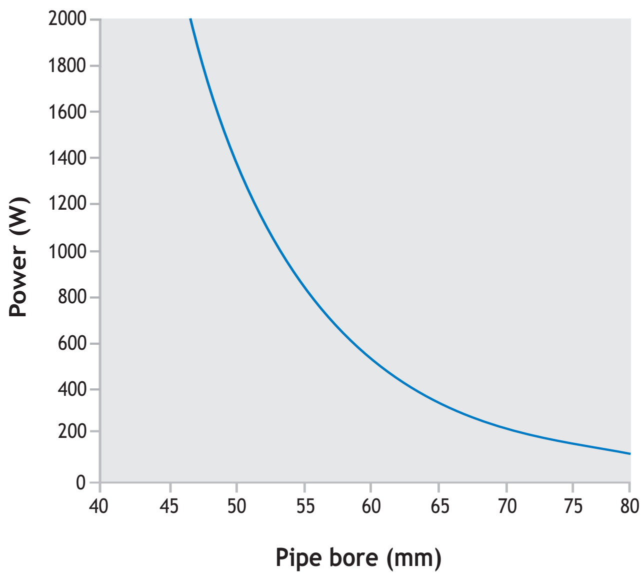
The role of the distribution network is to deliver the compressed air from the compressor discharge to the points of use with minimal leakage, minimal loss of pressure and minimal effect on the quality of the air.

Friction and leaks cause a pressure drop between the compressor output and the eventual point of use. This lost energy in the distribution network is largely due to its design and layout. This section describes how attention to pipe installation can reduce the pressure drop in distribution networks.

4.1 Pipe sizing

The cost of the air mains frequently represents a high proportion of the initial cost of a compressed air system. Therefore, smaller diameter pipe is often specified to save on capital cost. However, this is false economy since the restriction due to the smaller piping causes greater pressure drop across the system, resulting in higher energy consumption. These increased energy costs can soon exceed the price of larger diameter piping. Figure 3 shows what happens to the power required to deliver $50m^3$/hour of 7 bar(g) (700kPa(g)) air along 100m of steel pipe as the diameter changes.

Figure 3 *Power losses in various diameter pipes*



As a general rule, pipe diameters should be calculated based on having a maximum air velocity of 6m/s, in the main supply line. In branch lines with a total length less than 15m, velocities up to 15m/s are acceptable.

Appendix B contains a nomogram that can be used to estimate pressure drop in a pipe system and to determine the optimal pipe diameter.

4.2 Pipe layout

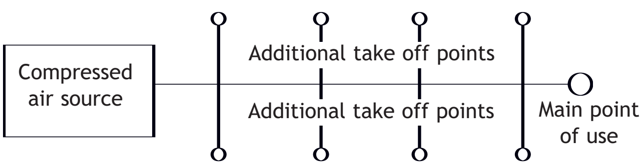
All compressed air distribution pipelines should be designed with the following points in mind:

- Pipe diameters should be selected that minimise pressure drop and allow for possible expansion. See previous section.
- Fittings and valves should be selected that create the minimum restriction to airflow. Large radius bends are preferred to elbows, for example. Full-throated valves such as ball valves should be used rather than gate valves.
- All piping must be well supported to minimise movement and sagging. This will help to minimise leaks, avoid build up of corrosion and fluids and lengthen the life of the pipeline.

The two basic distribution systems for compressed air are:

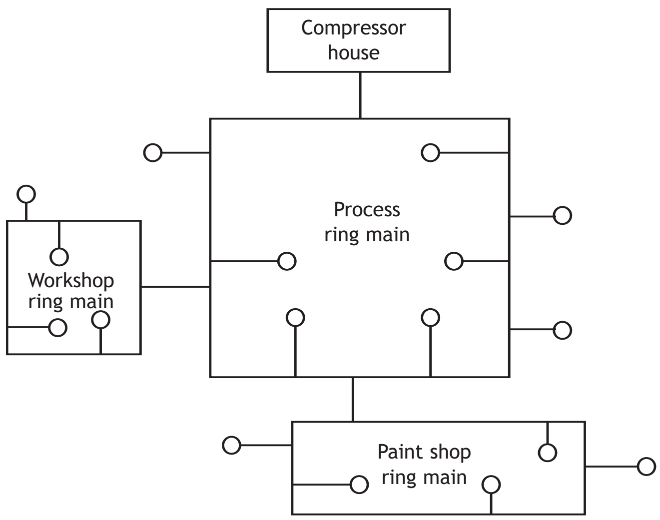
Single main (Figure 4). This is most suitable for simple installations where the points of use and the supply are relatively close together. In a well-designed system, the maximum pressure drop should be no greater than 0.2 bar (20kPa). In practice, try to make the main pipe as large as possible, especially if there may be future expansion of the system.

Figure 4 *Single main pipe with branch lines*



Ring main (Figure 5). For larger systems with numerous take-off points, a ring main is the preferred layout. Because air is supplied to any piece of equipment from two directions the velocity is halved and the pressure drop reduced. Another advantage is that isolation valves can be incorporated to enable specific sections of the system to be shut down for servicing without interrupting the air flow to other users. Such systems are more energy efficient.

Figure 5 *Example ring main with take-off points*



Tip: Use a feed pipe that is twice the diameter of that used for the ring main.

4.3 Pipe materials

Most distribution piping is made of galvanized steel, although copper, aluminium and some specialised plastics are becoming more common.

Different materials have different pressure and temperature ratings, which must be checked with the supplier's reference literature.

The price of the materials also varies considerably, and a financial assessment should be carried out to evaluate the life cycle cost of the various alternatives. When considering alternative materials, corrosion resistance is one of the factors to be taken into account. With galvanized steel pipes, moisture will eventually cause corrosion and contamination of the air. If the contaminants are not filtered out, production equipment can be damaged and/or product contaminated. Also note that problems can arise in systems using a combination of dissimilar metals.

Galvanized steel piping generally has a much rougher internal surface. Alternative materials offer less friction and flow resistance to the air. The result is a lower pressure drop for the same size pipe at the same flowrate. This can result in a lower supply pressure, saving energy.

4.4 Zoning

In many cases, it is not necessary for all parts of a compressed air system to be pressurised either to the same pressure or for the same operating hours. Splitting the system into zones and pressurising isolated zones as required will reduce leaks and save energy. This is particularly useful for 'out-of-hours' small applications. Redundant piping must be removed or isolated so that it is not pressurised.

4.5 Valves

Although valves are used primarily for isolating a branch or section of the distribution network, they are also used for flow or pressure control.

Ball valves are recommended because they cause almost zero pressure drop when fully open. This is because the throat diameter of the valve is equal to the pipe bore. The quick action handle clearly indicates if the valve is open or closed. However, their purchase price is higher than some alternatives (e.g. gate valves).

Gate valves are often used due to their low purchase price. But, because their throat diameter is smaller than the pipe bore, they present a constriction and cause pressure drop. In addition, when set fully open, the sealing surfaces can erode over time, making it impossible to obtain an airtight seal. Gate valves are often left partially open due to the number of turns required to go from fully closed to fully open. The glands are often a source of leaks.

Some other valves such as **diaphragm** and **globe valves** cause the largest pressure drop and are not recommended for compressed air systems.

Automating isolation with electronically controlled valves eliminates human forgetfulness or laziness. If the action of switching off a machine also closes the appropriate isolation valve, any air leaks associated with that machine and branch line are also isolated from the supply.

Use the third checklist in Appendix D to ensure air distribution networks are operating as efficiently as possible.

5 Compressors

The energy efficiency of any air compressor depends on its:

- Design
- Installation
- Use
- Maintenance.

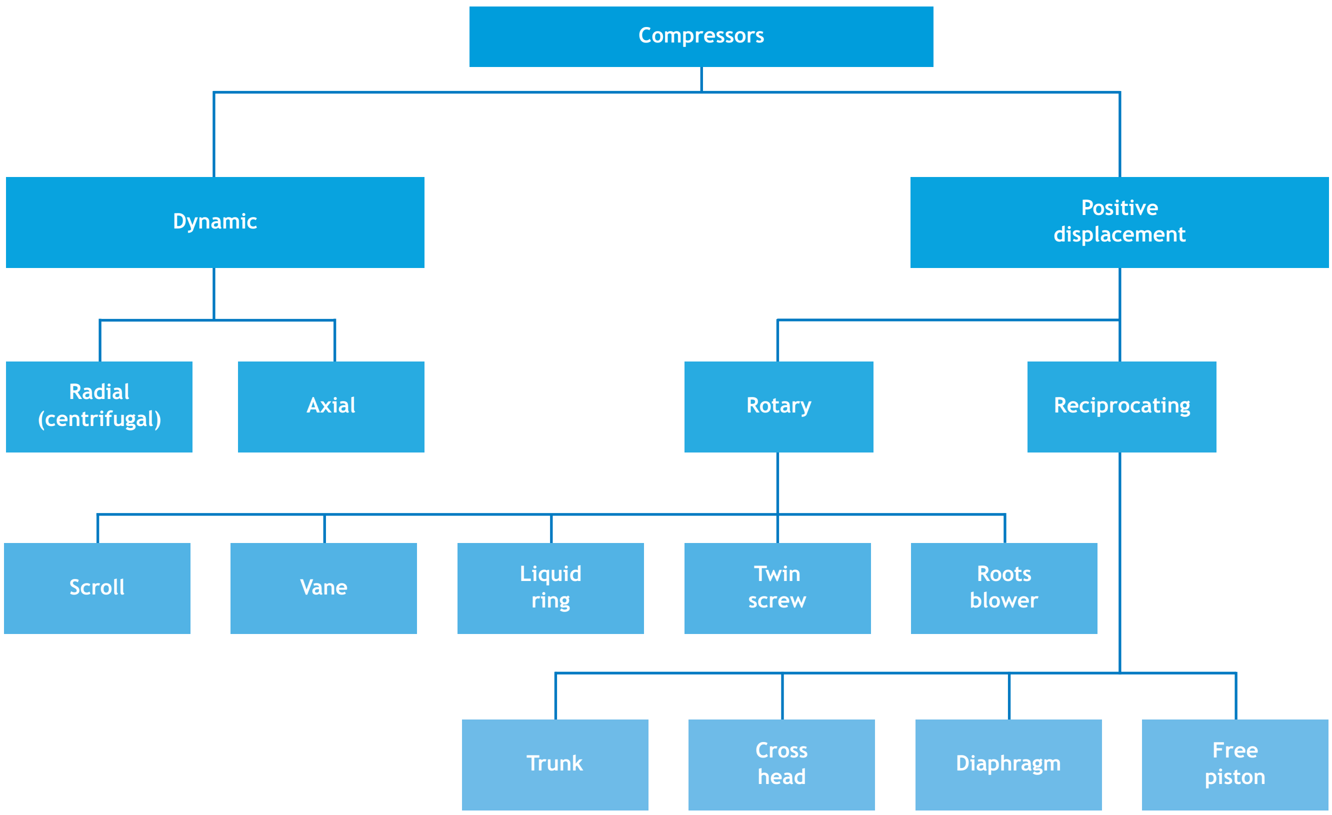
Many compressors now incorporate higher efficiency motors (HEMs). The EFF1 class of HEMs saves energy in all situations compared with a standard motor. This class of HEMs is on the Energy Technology List and can be purchased under the ECA scheme (see Section 1 or visit www.eca.gov.uk/etl).

Compressors are at their most efficient when operating at full load. Even when off-load the power consumed can be 20-70% of the on-load power. For a compressor to operate at its most efficient, it is therefore necessary to match the supply from the compressor with the air demand. This is discussed below and in Section 6.

5.1 Types of compressor

Figure 6 provides a summary of the categories of commonly used compressors, which, in most cases, are available in both lubricated and non-lubricated forms. The selection issues are discussed in Section 5.3.

Figure 6 *Basic compressor types*



5.2 Improving existing compressor efficiency

Location and installation of the compressor

Compressors should be located in a dry, clean, cool and well ventilated area. Warm, moist air requires not only more energy to compress but also extra drying to ensure that the moisture does not cause pipe corrosion and other problems with equipment. Forced ventilation may be needed to dissipate the build-up of heat in the compressor room.

The air inlet to the compressor house should be on a north-facing wall if possible, or at least in a shaded area, with a grille to prevent foreign objects from entering the area.

Dust and dirt must be filtered out of the air supply to minimise wear and avoid damage to the compressed air system. Inlet filters should be checked routinely and replaced before the pressure drop across them becomes significant.

Tip: A 4°C reduction in inlet air temperature leads to dryer air at a higher density, which will improve compressor efficiency by about 1%.

Compressor maintenance and upgrades

Compressor performance will deteriorate by over 10% of output if maintenance is neglected. The following steps should therefore be taken as part of the maintenance process:

- Make sure there is sufficient space around the compressor for maintenance access
- Replace the air inlet filter as required and check the air inlet duct regularly to make sure it is not obstructed
- Ensure coolers are kept clean
- Ensure that maintenance is carried out only by trained personnel as dictated by international standards for compressors
- Replace motors in older compressors with HEMs (EFF1 or EFF2) to gain significant energy savings.

Heat recovery

One of the key cost-reduction opportunities is to re-use the waste heat generated by the compressor in a suitable application.

Only 10% of the electrical energy driving an air compressor is converted into compressed air energy. The remaining 90% is normally wasted as heat. A properly designed heat recovery unit can recover over 80% of this heat for heating air or water. Although compressors can be purchased with a heat recovery kit, a retrofitted unit will usually be a good investment as well. The best payback is achieved when the compressed air and heat recovery systems can be designed as integral parts of the plant. For example, if the heat is used for space heating, it is beneficial to incorporate the design within the existing heating system.

Typical applications for air heating include:

- Space heating (e.g. warehouse or factory areas)
- Pre-heating boiler combustion air.

Typical applications for water heating include:

- Pre-heating boiler feed water
- Pre-heating process water (e.g. bottle washing)
- Water heating in laundries.

The potential savings from heat recovery should be evaluated carefully as they are highly dependent on the load cycle of the compressor being able to generate sufficient heat at the right times. Furthermore, each compressor is designed with an optimum running temperature range; any heat recovery system should not over cool the compressor and thus impose an unnecessary burden on its performance.

GPG238 *Heat recovery from air compressors* should be referred to for more detailed guidance.

Lubricants

Synthetic oils can reduce friction levels up to 8%, extend service intervals and may produce a more environmentally friendly, biodegradable condensate discharge. The compressor manufacturer should be consulted if any changes to lubrication are contemplated.

5.3 Compressor selection

Because every installation is unique in its design and purpose, there is no definitive compressor solution. Appendix C contains two sets of questions to be considered when selecting a compressor — those that users should ask themselves and those users should ask vendors.

The decision on which compressor is most suitable for a particular application will be based on a number of factors, but it will be primarily driven by:

- The level of air quality required by the application/process (e.g. is oil-free compressed air required?)
- The flow rate and pressure required
- The capital available and subsequent running costs.

For a typical industrial system operating between 6 and 10 bar(g) (600 and 1,000kPa(g)), a screw, vane or reciprocating (piston) compressor is typically used. Centrifugal compressors are used for the larger flowrates.

For further information on the selection of compressors, refer to GPG241 *Energy savings in the selection, control and maintenance of air compressors*.

5.4 Compressor control

Compressors can be fitted with their own individual control system to vary their output to meet demand. Such systems include:

Start/stop control. This method is normally only used for very small machines (usually piston compressors) due to the limitations associated with starting and stopping larger motors.

Throttling (modulating) control. This is generally only applicable to single-stage screw and vane machines operating at greater than 70% load.

Load/off-load control. This is often called 'automatic' control and is widely used in single-stage screw and vane compressors. For larger piston machines (double acting, two-stage compressors), three-step control is used to give full load, half load and no load operation.

Variable speed control. This system varies the air output by varying the motor speed and is generally fitted to oil-injected screw and vane machines. It can be retrofitted to existing machines, but this is not recommended without consulting the manufacturer. The system pressure can be maintained accurately as the compressor supplies only the flow required. This type of control can save a large amount of energy, but only if the air demand fluctuates. A compressor that runs at full load will consume more energy if a variable speed drive is fitted. Such units are on the Energy Technology List and can be purchased under the ECA scheme (see Section 1 or visit www.eca.gov.uk/etl).

Centrifugal compressor control. The control of these machines is more complex as performance is affected by both inlet temperature and barometric pressure. Essentially, a form of throttling down to around 75% of output is used, below which flow is reduced by progressively blowing air to the atmosphere. The use of inlet guide vanes as opposed to a traditional inlet valve offers gains in efficiency through more efficient throttling.

5.5 Control of multiple compressors

An individual air compressor is always supplied with some type of control. However, further savings can be achieved when two or more compressors are installed together.

Older compressors are controlled with pressure switches. These operate by sensing pressure and switching the compressor to an off-load state when an upper pre-set pressure limit is reached. The compressor will come back on load when the pressure falls below a lower pre-set pressure limit. Due to a lack of sensitivity of this type of control, the upper pressure in a multiple compressor installation can be as high as 1.5 bar (150kPa) above the required system pressure. These simple pressure switches should be avoided and, if possible, replaced by more energy efficient electronic systems.

Modern electronic controllers provide much greater energy savings in two ways:

- Maintaining the pressure to a much narrower range. They achieve this by constantly monitoring the pressure using an accurate pressure transducer to predict when a compressor should be switched on or off based on the rate of change of the system pressure. The pressure band can be maintained to within 0.2 bar (20kPa).
- Predicting and selecting the best combination of compressors to meet the demand. This is especially effective if using a combination of fixed speed and variable speed machines. This minimises off-load and part-load running of the compressors.

For ease of maintenance, machines can be sequenced to equalise their running hours. Most manufacturers offer system controllers that will control not only their own products, but also combinations of other machines.

Tip: For every 0.5 bar (50kPa) reduction in pressure drop on average, 3% of electrical power required by the compressor is saved.

Use the fourth checklist in Appendix D to ensure that compressors are being operated and controlled as efficiently as possible.

6 Storage

Air storage is another function of proper system control. Determining the amount of air storage should be determined not in isolation but as part of an overall strategy to obtain the most efficient and effective operation of a compressed air system.

In virtually all industrial applications, air demand varies. Air storage is therefore necessary to balance the demand from the system with the compressor plant capacity and the system control. The role of the air receiver (storage vessel) is to:

- Act as a reservoir that can be called upon to provide bursts of air to meet intermittent demands
- Create a more stable pressure in the system
- Prevent the compressor cycling too quickly.

In this way, a receiver acts like a flywheel or a water reservoir behind a hydroelectric dam.

6.1 Sizing the air receiver

The sizing of receivers is important as it has a direct impact on both the overall reliability and the energy efficiency of the compressed air system.

The size of an air receiver will depend on the amount of fluctuation in air demand. In most cases an adequately sized receiver will be able to supply the extra air during a high demand period and then recharge when the demand drops off. This function allows the air compressor to be sized for the average demand, rather than for the maximum demand. In some cases when the fluctuation is too great, a solution can be to have a smaller compressor that can 'kick in' as required.

There are a number of formulae for calculating the storage volume required. However, the following empirical rule can provide an approximation for planning purposes, taking into account the compressor(s) output and the pattern of demand.

The air receiver should be sized (in litres) to be at least 6-10 times the compressor free air output (in litres/s).

It is also worth considering the following:

- To provide optimum performance, the receiver should be sized for the largest expected air demand event.
- An undersized receiver will cause the compressor to cycle frequently in response to small changes in pressure.
- An oversized receiver will cost more and will store more air, but it will require the compressor to remain on load for longer periods to recharge the air receiver. This is balanced by the extra time the compressor will have to cool before it must come on load again.
- The volume of the pipework is often significant but is not included in the calculations.
- An effective control system will ensure that the receiver volume balances the demand from the system with the supply from the compressor.

6.2 Additional local air receivers for intermittent demands

To provide optimal performance, receivers need to be sized to handle the largest demand for air in the system. However, this event may be a process or an item of equipment with a large intermittent air demand. In situations where the demand is not continuous, it is better to install an air receiver close to the process/equipment rather than to oversize the main air receiver or to install an additional compressor that would stand idle most of the time.

To determine whether a local (auxiliary) air receiver is needed:

- Calculate the total maximum storage for the main receiver as described above
- Then calculate the storage required for the largest event. If this exceeds 10% of the total, then a local air receiver is recommended.

For example, if the total compressor output is 20 litres/s, then the maximum air storage is 200 litres. If the single largest event is 2.5 litres/s, then the maximum air storage is 25 litres. In this instance, installation of a local air receiver is recommended. The size of any reserve air capacity is dependent upon the amount of air used per operation and the pressure drop that can be tolerated; it can be calculated as follows:

$$\text{Required receiver volume} = \frac{\text{Demand per operation (litres free air)}}{\text{Acceptable pressure drop (bar)}}$$

It is important to check that the compressor is large enough to recharge the air receiver up to the original pressure before the next period of high demand.

Use the fourth checklist in Appendix D to ensure compressed air is being stored as efficiently as possible.

7 Air treatment

Although a lot of attention is given to the air compressor itself, the ancillary equipment for treating the air consumes energy and should, therefore, be viewed as a potential energy saving opportunity. This equipment includes dryers, filters and condensate drains.

The application for which the compressed air is intended determines the level of air purity (quality) required and hence the air treatment methods used. For example, the requirement for clean and dry air is much greater for processes such as paint spraying, electronics assembly and pharmaceutical production than for general tool assembly.

The first stages of water removal occur in the aftercooler and the air receiver. However, most systems require further treatment. The higher the degree of drying and filtration required, the higher the energy cost. These costs are affected by the pressure drop across the filters and dryers and also the electricity used by refrigerant dryers and the compressed air or other energy source used to regenerate desiccant dryers.

However, only part of the compressed air often needs be treated to a high level. Significant cost and energy savings can be achieved by treating all the compressed air to the minimum acceptable level, and then improving the quality at particular points of use to the desired level. However, product quality and process reliability should **not** be compromised for the sake of energy savings.

Tip: A 30kW compressor with a capacity of 5m^3/min at a working pressure of 7.5 bar(g) (750kPa(g)) will 'produce' approximately 20 litres of water every 8 hours.

7.1 Air purity (quality)

The international standard for compressed air purity, ISO 8573.1 (revised 2001), provides a system of classification for the three main contaminants (dirt, water and oil) present in any compressed air system. Dirt and oil are classified in term of size and concentration, and the water content as the pressure dew point (a measure of the humidity of the air). An explanation of the new air classifications in the revised standard is beyond the scope of this guide. It is suggested that air purity requirements are discussed with suppliers or a consulting company, who should be able to recommend an appropriate solution based on ISO 8573.1.

7.2 Filtration

Filtration is required to remove contaminants from the compressed air. Filters may be fitted before and after dryers, and also at the point of use.

In carrying out its function, the filter element will become increasingly blocked. Blocked filters:

- Can cause reliability problems
- Often compromise product quality
- Will increase energy consumption.

Filter elements should be regularly checked as part of a maintenance regime. Many filters have a diagnostic gauge fitted to their housing, which records the pressure drop across the filter element and indicates when the filter is due for replacement. The pressure drop across a new filter should be checked for comparison.

Dual filtration arrangement

Where high removal efficiency filters for either particulates or liquid are used, use of a dual stage filtration system is recommended. For example, a pre-filter is installed prior to a high efficiency coalescing filter to provide protection against premature blocking. This can save energy and reduce maintenance requirements.

7.3 Drying

As compressed air leaves the compressor and cools, the water vapour that was present in the inlet air condenses. This water must be removed from the compressed air system to avoid damage to components and product.

Various degrees of dryness can be achieved. The performance of a dryer is quoted in terms of 'pressure dew point', which is the temperature at which water vapour will start to condense out of the air. For example, a dew point of 3°C at 7 bar(g) (700kPa(g)) means that no water will condense from the air until it goes below a temperature of 3°C.

The main types of dryers are:

Refrigerant dryers. These can achieve a pressure dew point of 3ºC and are adequate for many standard applications. An energy efficient version is available that incorporates a control system that matches the cooling / drying load with the air demand. These units are on the Energy Technology List and can be purchased under the ECA scheme (see Section 1 or www.eca.gov.uk/etl).

Membrane dryers. These achieve dryer air than refrigerant dryers but, if much lower pressure dew points (-40ºC to -100ºC) are required, membrane dryers become less efficient than the desiccant dryers described below. Membrane dryers should not be used for the supply of breathing air as they can cause oxygen depletion unless specifically designed to avoid this.

Desiccant dryers. These can produce virtually moisture-free compressed air with pressure dew points down to –70ºC. They are designed such that, while one desiccant column is in use to dry the air, the other is being regenerated (i.e. dried out for re-use). Desiccant dryers fall into two categories – heated and heatless.

The standard models can add 15-20% to overall compressed air running costs. However, increasingly, more energy efficient desiccant dryers are available as outlined below.

Condition monitoring control system (dew point dependent switching). This control system is either incorporated in dryers when purchased or it can be retrofitted to existing dryers. By continuously measuring the moisture content of the desiccant, the control system ensures that the desiccant is regenerated only when it reaches a pre-determined moisture level and not simply on a timed basis. This substantially reduces the electricity used to dry the desiccant. These units are on the Energy Technology List and can be purchased under the ECA scheme (see Section 1 or www.eca.gov.uk/etl).

Condition monitoring slashes drying costs for desiccant dryer

The timing of the regeneration cycles on many desiccant dryers is set according to the peak air demand. A major pharmaceutical manufacturer reduced its drying costs by 80% by fitting condition monitoring systems on its desiccant dryers. Use of these control systems meant that the desiccant was regenerated far less frequently, as the desiccant was only heated when its moisture content was sufficiently high.

Zero purge dryers. Heatless desiccant dryers use compressed air to purge (regenerate) the desiccant. A much more energy efficient type of dryer is a zero purge heated dryer, where vacuum or blower technology is used to purge desiccant dryers with ambient air instead of using expensive compressed air.

Heat of compression dryers. This type of dryer is specifically designed for use with oil-free compressors and is typically a drum-type rotating dryer. The waste heat generated by the compressor is used to regenerate the drum. This produces substantial savings compared with traditional heatless desiccant dryers, which use compressed air.

Use the fifth checklist in Appendix D to ensure that air treatment is as cost-effective as possible.

8 Condensate management

Water vapour is always present in the air entering a compressor. With a decrease in air temperature and/or an increase in pressure, this vapour will condense. This condensate is often contaminated with oil and solid particles. All condensate must be removed from filters, dryers and air receivers and disposed of in a manner that complies with Water Resources Act 1998 to prevent pollution of the public water supply.

8.1 Collecting condensate

Condensate is collected by installing drain traps (also known as drain valves). These are attached to components where water will condense, for example:

- Aftercoolers
- Air receivers
- Dryers
- Filters.

Maintenance and energy costs differ considerably between different drain traps. The main types are:

Level sensing drains. This type has an intelligent control system that detects and discharges condensate only when it is present and without the loss of valuable compressed air. Such drains are reliable and require very little maintenance.

Timed drains. These drains require frequent adjustment of timer settings to accommodate changes in ambient conditions and system load. When set incorrectly, they discharge significant amounts of valuable air or fail to remove all of the condensate, resulting in downstream contamination. The frequency and duration of discharge for timed drains varies from system to system.

Manual drains. Manual drains require frequent checking and emptying. As a result they are often left partially open to discharge the condensate — thus also discharging expensive system air. These open valves also reduce the system pressure and may compromise the operation of downstream equipment.

Mechanical float drains. These drains are sensitive to dirt and may stick open, permanently discharging air, or stick closed, leading to downstream contamination from condensate carryover.

Disc and steam trap drains. In normal operation, these valves constantly discharge valuable, expensive air even if no condensate is present. They also emulsify condensate, preventing easy on-site separation.

Inefficient condensate drains are a major cause of leaks and hence wasted energy. Although manual and timed drains are cheap to buy, they have high running costs. A Life Cycle Costing exercise should be applied.

Electronic level sensing drains are the most efficient (see Table 4). They are on the Energy Technology List and can be purchased under the ECA scheme (see Section 1 or www.eca.gov.uk/etl). They are also known as electronic condensate drain traps.

8.2 Condensate disposal

It is illegal to pour contaminated condensate down foul sewers unless the oil content is reduced to a very low level. Otherwise, its oil content means it is classified as a hazardous waste.

Efficient on-site disposal of compressed air condensate is best achieved with an oil/water separator — a simple, economical and more environmentally friendly solution.

Oil/water separators can be installed as part of the compressed air system. They reduce the oil concentration in the collected condensate to the level allowed by the local sewerage provider and enable up to 99.9% of the total condensate volume to be disposed of safely to foul sewers (many oil/water separators are plumbed in directly to foul sewers). The small amount of concentrated oil is collected in drums for disposal by a specialist waste contractor.

Use the fifth checklist in Appendix D to ensure that condensate management is cost-effective and efficient.

***Table 4** Typical compressed air and energy losses associated with common drain types**

Drain trap type	Air loss (litres/s)	Energy waste (kWh/day)	Energy cost (£/year)
Electronic level sensing drain	0	<0.1	<£1
Timed drain (typical)	1.0	0.41	£44
Manual drain (half open)	43.3	17.3	£1,868
Mechanical float drain (stuck fully open)	4.7	1.89	£204
Disc and steam trap drain	1.8	0.76	£82

* Based on an operating pressure of 7 bar(g) (700kPa(g)).

Oil/water separator dramatically reduces disposal costs

A system with a refrigerant dryer operating for 8,000 hours/year produced about 950,000 litres/year of condensate. With an oil/water separator, the volume of oil-containing liquid requiring disposal was reduced to just 430 litres/year. The volume requiring specialist disposal as a hazardous waste fell dramatically, thus reducing disposal costs. In addition to these substantial cost savings, there are environmental benefits associated with not having to transport large volumes of waste off-site.

9 What to do next

Getting started on an energy saving programme for a compressed air system can be daunting, especially for those who are new to energy management and/or compressed air technology. However, compressed air systems offer many straightforward energy saving opportunities through minimising avoidable waste. There is a wealth of information available from the Carbon Trust and other organisations listed in the next section.

As a first step, order or download relevant publications from the Carbon Trust. *FOCUS – A practical introduction to reducing energy bills* and GIL123 – *Compressed air fact sheet* are particularly useful starting points. Use the checklists in Appendix D to help adopt a systematic approach to reducing the energy costs of a compressed air system.

Avoidable waste often results from the fact that many systems have no one with overall responsibility. Also, the high levels of waste associated with a compressed air system are not appreciated because the waste is not visible or hazardous. Making someone responsible for the compressed air system is essential for its cost-effective performance.

Resources for an improvement programme may be limited and their allocation will need to be prioritised. Conduct an initial assessment in-house by carrying out a walk-through survey. This will encourage staff involvement and increase the knowledge of compressed air users – both are important aspects of improving the system and will be valuable in any subsequent discussions with suppliers and consultants.

Carrying out a review and implementing improvements to a compressed air system, will not only save energy and reduce carbon emissions but will also result in a safer, more reliable and effective source of power.

To find out more about the free services available from the Carbon Trust to help reduce compressed air costs call the Carbon Trust Energy Helpline on 0800 58 57 94 or visit the website (www.thecarbontrust.co.uk/energy).

Remember that certain compressed air technologies are on the Energy Technology List and that tax breaks for buying listed equipment may be available. Visit www.eca.gov.uk/etl for more information.

Sources of further information

Useful publications

Publications available from the Carbon Trust

The following free publications can be obtained by calling the helpline on 0800 58 57 94 or by visiting the website (www.thecarbontrust.co.uk/energy).

- GPG216 *Energy saving in the filtration and drying of compressed air*
- GPG238 *Heat recovery from air compressors*
- GPG241 *Energy savings in the selection, control and maintenance of air compressors*
- GPG316 *Undertaking an industrial energy survey*
- GPG326 *Energy metering*
- GPG376 *A strategic approach to energy and environmental management*
- FOCUS *A practical introduction to reducing energy bills*
- GIL123 *Compressed air fact sheet*
- FL0069a *Everyone's guide to saving energy in compressed air*
- FL0036 *Action Agenda: putting energy on the workplace agenda*

BCAS publications

- *Installation guide: guide to the selection and installation of compressed air services (5th edition)*
- *Pressure and leak testing of compressed air systems*
- Information sheet 70 *Storing the air*
- Information sheet 101.1 *Blow guns*
- Energy posters – a set of ten A3 posters to raise staff awareness of compressed air use

HSE publications

- Safety of pressure systems. Pressure Systems Safety Regulations 2000. Approved Code of Practice L122. ISBN 071761767X.

Useful contacts

The Carbon Trust

The Carbon Trust Energy Helpline: 0800 58 57 94
www.thecarbontrust.co.uk/energy

British Compressed Air Society (BCAS)

UK trade association providing support, advice and training for manufacturers, distributors and users of compressed air equipment and services
33/34 Devonshire Street, London, W1G 6YP
Tel: 0207 935 2464
E-mail: info@britishcompressedair.co.uk
www.britishcompressedairsociety.co.uk

Enhanced capital allowances

www.eca.gov.uk

British Standards Institution (BSI)

389 Chiswick High Road, London W4 4AL
Tel: 020 8996 9000
E-mail: cservices@bsi-global.com
www.bsi-global.com

International Standards Organization (ISO)

www.iso.org

Health and Safety Executive (HSE)

HSE Infoline
Tel: 0870 154 5500
www.hse.gov.uk
HSE publications are available from:
HSE Books, PO Box 1999, Sudbury, Suffolk CO10 6FS
Tel: 01787 881165
www.hsebooks.co.uk

Compressed Air and Gas Institute (CAGI)

www.cagi.org

PNEUROP

European Committee of Manufacturers of Compressors, Vacuum Pumps and Pneumatic Tools
www.pneurop.com

Useful tools

Energy Wizard (developed by the Carbon Trust)
www.thecarbontrust.co.uk/energy
– refer to the resources page.

Web-based purchasing tool for compressor selection (developed by BCAS and the Carbon Trust)
www.selecta.org.uk

Conversion tool **www.onlineconversion.com**

Glossary

Absolute pressure	The pressure measured from a baseline of a perfect vacuum. Denoted by (a) after the unit of pressure. Absolute pressure = Gauge pressure + Atmospheric pressure.
Aftercooler	A heat exchanger that reduces the temperature of the air after compression before it enters the system
Cfm	The commonly used abbreviation for imperial unit used to measure flow (i.e. cubic feet per minute).
Condensate	Water formed in a compressed air system from water vapour due to a decrease in air temperature and/or an increase in pressure.
Dew point	The temperature at which air, at a given pressure, is fully saturated. Water vapour will condense if there is a further drop in temperature or increase in pressure.
Free air delivered (fad)	The actual flow delivered by a compressor at the stated intake temperature and pressure. fad is expressed in litres per second or cfm.
Gauge pressure	The pressure measured from a baseline of atmospheric pressure. Denoted by (g) after the unit of pressure. Gauge pressure = Absolute pressure – Atmospheric pressure.
Off-load	The compressor is running and consuming power but the compressor is not delivering air.
Oil injected (lubricated)	An air compressor into which oil is injected to lubricate and remove heat.
On-load	The compressor is producing air, either at part load or full load.
Packaged air compressor	Self-contained unit consisting of a compressor, a prime mover and various accessories (e.g. filters and coolers).
Pattern of use	Describes the way in which equipment is used.
Pressure drop	The drop in pressure between any two specified points in a system.
Pressure regulator (pressure reducing valve)	A device that reduces the incoming pressure to a lower level and maintains it irrespective of changes in inlet pressure and outlet flow rate.
Prime mover	A machine used to drive a compressor (e.g. an electric motor or engine).
Run-on timer	A control that switches off the prime mover when the compressor has been off-load for a specified period of time.

For other definitions and terminology, refer to the appropriate standards (e.g. ISO 5598, BS 5791 Parts 1-3 and BS ISO 5391).

Appendix A — Leakage measurement test

With both the following methods, it is assumed that the compressed air system is operating after normal plant operating hours, that the air being delivered is supplying only leaks and that there are no normal production or process requirements.

Different sections of the distribution network can be tested if well-sealing valves can be used to isolate different branches.

Method 1 — Cycle timing

The compressor capacity must be known for this method.

1. Use a timer to measure the time (T) that the compressor is actually delivering air (on-load). Repeat this for the duration of time (t) that the compressor is off-load. Repeat these measurements through at least four cycles to obtain accurate average values. If the air compressor actually switches off and on, then the exercise is straightforward. If the machine keeps running but uses an off-loading mechanism, then it is necessary to listen to the tone of the compressor as it cycles between the two states.

2. Note the delivery capacity of the air compressor (Q) from the nameplate or literature.

3. Use the following formula to determine the leak rate, Q_{leak} which will have the same units as Q (e.g. litres/s or m^3/min):

   $Q_{leak} = Q \times T/(T+t)$

4. Note: an alternative method is to ensure that the timer is started and stopped at maximum and minimum pressures using an accurate pressure gauge.

Method 2 — Pressure decay

This method is used when the compressor capacity is not known.

1. Calculate the volume of the delivery network (V) in litres.

2. Ensure an accurate pressure gauge is fitted.

3. Once the delivery network is fully pressurised, switch off the compressor and close the delivery valve between the compressor and the receiver.

4. Measure and record the time (t) in seconds for the pressure to decay by exactly 1 bar (100kPa).

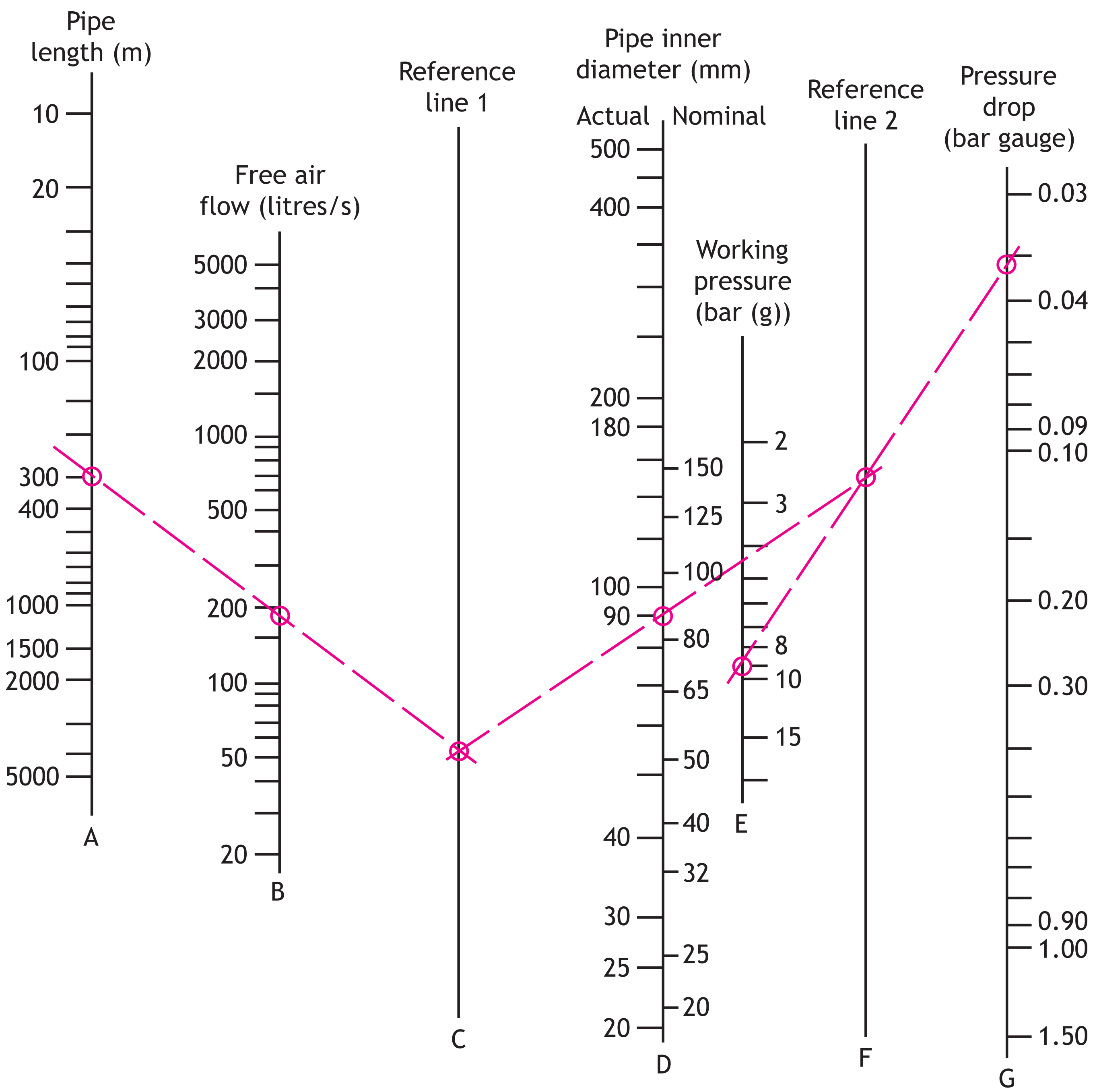
5. Use the following formula to calculate the leakage rate (free air):

   $Q_{leak} = V/t$ (litres/s)

6. Note: this method will return less accurate results at lower system pressures.

Appendix B – Determining pipe diameter and pressure drop

The nomogram below is a tool for estimating pressure drop in a pipe system and can also be used for pipe sizing. The diagram is an approximation since errors in drawing can be cumulative and various assumptions have been made.



To determine pipe diameter:

- Select the maximum permissible pressure drop on scale line G
- Select the actual working pressure on scale line E. Draw a line between these two points to locate the intersection on reference line F
- Knowing the pipe length and free airflow (output of compressors or demand), draw a line between these values on scale lines A and B, respectively
- Extend the line to reference line C
- Draw a line to connect the two points that are located on the reference lines (E and C). The point at which this line crosses scale D will give the required pipe diameter.

To determine pressure drop:

- Draw a line connecting the pipe length (on scale line A) with the airflow (on scale line B), and extend it to reference line C
- Draw a second line from the intersection on C to the pipe diameter (on scale line D) and extend it to reference line F
- Using the intersection on F as a pivot, draw a line from the actual working pressure on scale line E across to scale line G
- Read off the pressure drop from scale line G.

The nomogram is derived from the following equation:

$$dP = 1.6 \times \frac{10^{8} \times V^{1.85} \times L}{d^{5} \times P}$$

where:

dP = Pressure drop in bar

V = Free air flow in m^3/s (litres/s x 10^{-3})

L = Pipe length in metres

d = Inside pipe diameter in mm

P = Initial pressure in bar gauge

This equation can be used if accurate figures are required for pressure drop. Alternatively, if the parameters fall outside the scales shown in the nomogram, then the equation to calculate pipe size can be used.

Appendix C – Questions when selecting a compressor

Questions users should ask themselves

Pressure

1. What final pressure(s) do I need at the point of use?

While pressures of up to 8 bar(g) (800kPa) can generally be met by piston, screw, vane or centrifugal compressors, higher pressures may preclude the use of some standard compressors.

2. Does all of the air need to be at the same pressure?

If the pressure for a particular area of application is less than 2 bar(g) (200kPa(g)), a blower is usually more cost-effective than compressing air at 7 bar(g) (700kPa(g)) and then regulating it down to a much lower level.

3. What will be the estimated pressure drop from the compressor to the most distant point of use?

Pressure drop arises from numerous causes, with piping length/diameter/design and air treatment accounting for much of the pressure drop. This affects the pressure level to be generated and the energy consumption of the system.

Air purity (quality)

1. What purity of air do I need?

– Do I need an oil-free (non-lubricated) compressor?
– What filters will be required?
– Will I need a dryer? If so, what type?

An oil-free system may still require additional filtration. High purity air can be achieved using a number of different combinations of compressors, filters and dryers. For a system requiring high quality air, the life cycle costs and risks of contamination for alternatives offered need to be considered very carefully.

2. Does all the air need to be of the same quality?

If not, then different compressors for different processes may be required.

Air demand

1. Is there a continuous demand (base load)? If so, what is it?

Understand demand pattern. If possible, have an audit conducted by a reputable organisation so that comparisons can be made on the performance of different compressors or combinations of compressors on the same demand pattern.

2. Does the air demand have a regular pattern (e.g. reduced load at night or weekends)?

Intermittent demand levels may dictate the required size of the air receiver and compressors.

3. Is the production of compressed air safety critical (e.g. in explosive atmospheres)?

There are compressors specifically designed for use in explosive atmospheres.

Siting and installation

1. Will the compressor be located in a compressor house or in the factory close to personnel? Is the proposed area for siting the compressors adequately noise insulated from residential areas?

Noise issues preclude some types of compressors and others must have acoustic panels fitted to comply with the Noise at Work Regulations.

2. Is the area where the compressor is to be situated adequately ventilated with clean air?

If not, the working life of the compressor may be reduced due to contamination and the air intake filter will have to be changed more frequently. Inadequate ventilation leads to warm air being taken in and the compressor working less efficiently.

3. **Can waste heat from the compressor(s) be recovered and used elsewhere on site?**

   Heat recovery reduces the unit cost of producing compressed air on site.

4. **Is cooling water available?**

   Cooling water is required for water-cooled compressors.

5. **What is the maximum motor size I can start from the current electrical supply where the compressor is to be installed?**

   Depending on the size of the compressor, the electrical supply may need to be upgraded.

6. **Is the floor strong enough to support the weight of the compressor and of suitable construction to prevent the transmission of vibrations?**

   If vibrations are produced, they can affect the accuracy of other equipment especially if vibrations resonate.

7. **Is there access for lifting equipment to install the compressor? Is there sufficient space around the compressors for maintenance to be carried out?**

   Regular maintenance is required by law and also improves service life and keeps running costs lower. Any difficulty in accessing the compressor for maintenance puts these at risk.

8. **Is an automatic drain trap fitted to the compressor? Or is there the facility to fit one?**

   Manual drain valves require more maintenance and are often left open, hence acting as a source of leaks.

9. **Is there room available for a condensate separation unit (for oil-injected compressors)?**

   An oil/water separator is recommended for oil-injected compressors to reduce the condensate volume to be disposed of by licensed waste contractors.

Questions the user should ask the vendors

The purpose of these questions is to enable the quotes and recommendations from a range of suppliers offering various equipment options to be compared. These questions should be used in conjunction with the earlier questions in Appendix A.

It will also be helpful to prepare an installation drawing, including the position and size of all connections.

1. What type of compressor is proposed and why?
2. Is the compressor water-cooled or air-cooled?
   - If water-cooled, what is the volume and pressure of the cooling water required and what is the water quality specification?
   - If air-cooled, what is the cooling air volume and pressure capacity of the compressor cooling fan?
3. At the stated compressor delivery pressure, what is the free air delivered (fad) and **total input power consumption** of the compressor package measured to ISO 1217? NB Watch for conditions: ensure all figures are at the same barometric pressure, inlet temperature and humidity. (Total input power is equivalent to the power consumption drawn from the site’s electrical supply.)
4. What is the **off-loaded** total input power to the compressor?
5. If a variable speed machine, what is the total input power and fad at the stated delivery pressure at 75%, 50% and 25% speed? What is the minimum flow and number of starts per hour allowed?
6. What motor speed has been assumed for the performance data? Is it realistic? Is it typical of normal operating conditions?
7. What are the recommended lubricants?
8. For oil-injected compressors, what type of condensate separation equipment will be required?
9. What are the conditions of ensuring warranty validity?

Appendix D — Checklists

Please photocopy these checklists.

Monitoring, management and maintenance

- Is the company's annual cost of producing compressed air known?
- If the air supply is metered, read the meters regularly through the day to establish patterns of use relative to production activity. Look for unexplained idling losses.
- Request a 7-day data logging audit (an equipment supplier or a consultant can do this).
- If the compressors have hours-run meters, read them all at intervals through the day to estimate the demand. Compare on-load hours with total run hours to check for idle running and see whether there are more units running than necessary.
- After hours, either (a) time the load/off-load periods or (b) shut off the compressors and record the rate at which pressure subsequently falls.
- Implement a maintenance schedule for each part of the system, not just the compressor.
- Do users of compressed air know the cost of producing it? Remind staff that leaks waste energy and money. Run an awareness campaign.
- To establish the pressure drop across a system, measure the pressure at point of use and compare it with the pressure at the compressor discharge.

Notes/reminders

Misuse and waste

Misuse

- Identify inappropriate uses. Low-grade duties (e.g. blowing swarf off machinery or agitating liquids in tanks) should **not** use clean, dry air from the central system.
- Install local air blowers where there is a requirement for large volumes of low-pressure air that does not need to be dried or filtered.
- Use low-pressure blowers for appropriate applications (e.g. air knives, air lances, air agitation, blow guns, product ejection, powder transfer).
- Install local boosters (pressure intensifiers) where small volumes of higher pressure air is needed.
- Ensure air knives are operated at the minimum pressure. If in doubt, check with the equipment supplier.
- Vacuum ejectors should be limited to 10% of mean demand above which a centralised vacuum system should be used.

Waste

- Carry out a regular leak report and repair programme.
- Check for air leaks on connectors and flanges.
- Check the condition of flexible hoses and hose connections (a major source of leaks).
- Fit air fuses to hoses so that the air supply is cut off in the event of a large sudden air loss.
- When production is shut down, isolate constant bleed pneumatic controls.
- Use timers, sensors and actuators with blowers instead of providing constant airflow.
- Use energy efficient nozzles for blowing applications.
- Avoid the use of blow guns where possible. Where they are used, make sure the pressure does not exceed 2 bar(g) (200kPa(g)) (this is a health and safety requirement).
- Use safety quick-release couplings.
- Generate at the lowest pressure possible and investigate a pressure drop that is more than 10% of the compressor output.

Notes/reminders

Air distribution network

- Check overall pressure drop from the outlet to the point of use. If this is greater than 10% of the total compressor delivery pressure, then pressure drop in the system is excessive. A higher delivery pressure is required to compensate for these losses resulting in increased leakage rates and power consumption for the same flow requirements.
- Check the pipe sizes. If undersized, they will cause pressure drop and hence energy losses.
- Survey the layout of the piping. As far as possible eliminate elbows, minimise changes in direction of airflow, remove other constrictions and reduce excessive pipe lengths.
- If replacing pipe, consider smooth bore pipe to reduce friction or choose larger diameter of standard galvanized pipe.
- Isolate unused compressed air piping (a significant source of leaks).
- Fit zone isolation valves. These can be under time control or interlocked to the packing/production line served to enable parts of the site to operate out-of-hours without air going to the whole works.
- Review the number of valves fitted to the piping. Which sections really need to be closed off?

Notes/reminders

Compressors, control and storage

- Switch off compressors when there is no demand for air. (But check that there is no continuous need that would be affected).
- Look and listen. Are air-pressure safety valves operating? If so, control is inadequate. Are compressors starting and stopping frequently?
- Can the generation pressure be reduced? The higher the generation pressure required, the more energy is used.
- Maintain the compressor properly to ensure maximum efficiency. Trained personnel are required to carry out maintenance on compressors.
- Change inlet filters more often in dusty or aggressive environments.
- Use the coldest possible air source for the intake to the compressor to maximize efficiency. Reducing the air inlet temperature by 4°C increases efficiency by 1%.
- Investigate the potential for heat recovery. Divert compressor cooling air to a nearby workspace or an application that could benefit from air pre-heating.
- Consider installing a dedicated compressor for areas that require a different pressure or operating hours.
- If a compressor is more than five years old, consider replacing its motor with a higher efficiency EFF1 or EFF2 motor. Consider high-efficiency motors when purchasing a new compressor.
- Investigate the suitability of variable speed drives.
- Consider high-performance lubricants.

Air storage

- Review size of air receivers. If compressors are switching on and off load frequently (cycling), then extra storage may be required.
- Review the siting of air receivers (place auxiliary receiver close to user with intermittent high demand and for air).
- Fit improved controls on central compressors. Computerised sequence controls can reduce compressor run hours, and prevent air loss and wasted power through pressure overshoot and off-load running.
- Control the pressure at the point of critical demand – not necessarily at the compressor.

Notes/reminders

Air treatment and condensate management

- Treat the bulk air to the minimum necessary and then upgrade at point of use for applications where higher grade air is required.

Filters

- Find out how often the filters are replaced. Blocked filters cause pressure drop; replace them in line with the manufacturer's recommendations or when the pressure drop across a filter reaches 0.5 bar (50kPa).
- Fit pre-filters to prolong the life of high efficiency filters and to save energy.
- Select filters that offer the lowest initial differential pressure drop and guaranteed performance.

Dryers

- Fit dew point sensing control to desiccant dryers to minimise the electricity used to regenerate desiccant.
- Carry out performance measurement of dryers to check whether air is of desired quality.
- If purchasing a new dryer, consider those with controls that save energy.

Condensate

- Check that manual drains are not left cracked open, thus acting as a source of leaks.
- Replace manual and timed drains with electronic level sensing drain traps.
- Check level sensing drains; even though they are low maintenance, they can still become blocked.
- Install an oil/water separator for effective condensate treatment and removal.

Notes/reminders

Tel 0800 58 57 94

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