

# Energy Efficiency Best Practice Guide Compressed Air Systems

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# 1 Introduction

This document is a step-by-step guide to improving energy efficiency in compressed air systems and achieving best practice. By following this guide, you will be able to determine what changes can be made in order to reduce operating costs, improve the operation and performance of equipment and improve environmental outcomes.

The guide has been developed to lead decision makers and service providers through system changes; it is not intended to be a thorough technical guide. References for more detailed technical information are provided.

## 2 What are the business benefits of compressed air efficiency?

Despite the fact that they are essential for many businesses, compressed air systems are often ignored until something goes wrong with them, or the compressors fail to keep up with rising air demand. Compressed air systems use up to 10% of total industrial electricity use in Australia, so it makes sense to look at their energy cost. Figure 1 illustrates the cost of a typical compressor system over a 10-year lifecycle, showing how important energy costs are to the overall cost of a system.

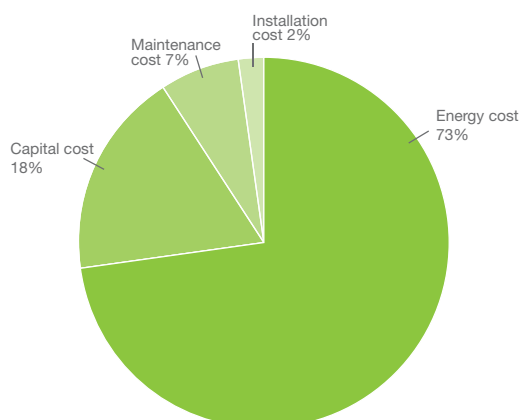


Figure 1: Compressor costs over a ten-year lifecycle<sup>1</sup>

With 73% of the cost of a compressor due to energy use, significant cost savings will be made by improving energy efficiency, as well as the added benefits of improving the performance of your system and reducing your organisation's 'carbon footprint'.

Energy efficiency will also increase the proportion of compressed air that is used for production and minimise unnecessary wastage, again resulting in significant cost savings. An example of just how much demand on the compressed air system can be wasted is shown in Figure 2 below.

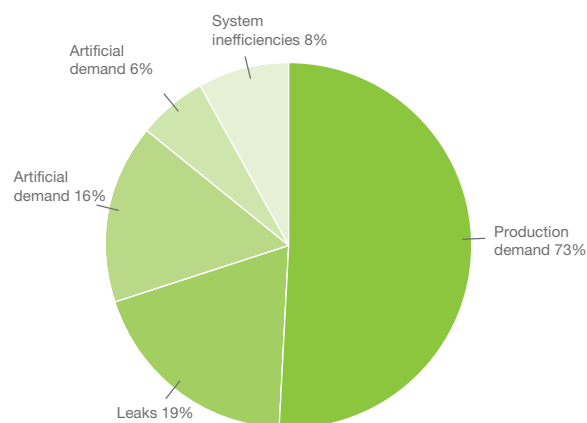


Figure 2: Compressed Air Usage and Potential Savings for the Typical Compressed Air User.<sup>2</sup>

### 3 What is your opportunity?

Delivering the best outcome for your business requires a whole systems approach to the design, installation, operation and maintenance of your compressed air system.

(Refer to Appendix A for a compressed air system overview).

Defining the limitations of your current compressed air system is the key to finding the best solution to achieving energy efficiency for your business:

- Can I make my system more efficient?
- Do I need a new compressor?
- How do I expand my existing system?
- What do I need to know to install a new system?

This guide offers step-by-step solutions to help you identify opportunities to implement best practice to achieve energy efficiency of your compressed air system.

- **Solution 1: Improve the efficiency of your existing system**

Do you have a compressed air system that is fulfilling needs but could run more efficiently? This process may only involve a small investment but can provide significant energy savings and costs. Is your existing system struggling with the demand? Do you need to upgrade your air compressor? This process will also help in selecting the appropriate compressor for your needs, which could well be smaller and cost less than you originally thought.

- **Solution 2: Design a new system**

Are you planning a brand new compressed air system? This process outlines the steps required to ensure you achieve excellent design and to help you understand where to spend your valuable capital.

Are you expanding your plant, workshop or factory and need to ensure that your compressed air system will work effectively? This will involve elements of both solutions. Firstly, ensure your existing system is running efficiently (Solution 1) and secondly, if your system needs to be expanded, design the new components (Solution 3). Following this process will ensure that you are not wasting money purchasing more than you actually need. Additionally, information gained from reviewing efficiency may guide the selection and design of the new components of the system.

## 4 Solution 1 – Improve the efficiency of your existing system

This solution firstly focuses on improving the efficiency of usage, distribution, storage and treatment of compressed air before considering the compressor itself.

### 4.1 Step 1: Review air demand

Before any improvements to your compressed air system can be made, you should first determine how it will be used and which aspects need improving by reviewing the air demand on the system.

#### 4.1.1 Inappropriate uses

Compressed air is often used for jobs because of its availability and because an alternative would require higher capital cost. Compressed air is a very expensive form of energy and the associated running costs often mean the overall cost is more expensive than alternatives. Consider using alternative equipment with lower running costs. However, there are often very good reasons for using compressed air powered equipment. Carefully consider the advantages and disadvantages when making these substitutions, such as the weight of tools or the safety risks of electric tools. Table 1 illustrates some examples of inappropriate uses of compressed air, along with some solutions.

**Table 1: Compressed Air Use and Substitution<sup>3</sup>**

Compressed Air Use	Equipment Used	Solutions
Blowing or Cleaning	Nozzle/gun	Air knife, Induction nozzle, low pressure blower, broom/brush
Cooling	Cooling induction system	Air conditioning systems, chilled water, fresh air ventilation, fans
Drying of water on product	Nozzle/gun	Solenoid control, air knife, induction nozzle

#### 4.1.2 Current and future uses

Compile a list of (i) all the equipment that currently uses compressed air and (ii) equipment that is planned to be installed that will use compressed air. Include the total number of all tools or equipment of the same type. Determine the requirements for each piece of equipment:

- **Maximum air pressure (in kPa)**

Identify the highest maximum pressure required by your system. This is the pressure that should be available as your supply pressure. Any less and your equipment may not function properly; any more and the system is running at a higher pressure than required and costing you money.

- **Average flow (in L/s)**

Add the average flows of all equipment on your system. This value indicates the average flow required of your air compressor. Although the actual demand fluctuates above and below this value, any rapid increases in this demand can be met by the stored capacity in the air receivers. Therefore, this is the flow that your compressor should be capable of producing continuously.

- **Air quality (pressure dewpoint for moisture, concentration limits for dirt and oil)**

Depending on your business, you may have all equipment needing the same air quality or have a range of air-quality requirements. A simple classification of air-quality levels is provided in Table 2.

**Table 2: Air Quality Classifications<sup>4</sup>**

Air Quality	Applications
Plant Air	Air tools, general plant air.
Instrument Air	Laboratories, paint spraying, powder coating, climate control
Process Air	Food and pharmaceutical process air, electronics
Breathing Air	Hospital air systems, diving tank refill stations, respirators for cleaning and/or grit blasting

If most of your equipment uses low-quality air while you have a few pieces of equipment that require high-quality air, such as breathing air, then consider moving that equipment on to a point of use system with a much smaller compressor and dryer. This will save on energy costs, as you will be using less energy in treating the air for your entire system.

#### **4.1.3 How much energy is your compressor using?**

Estimating how much energy your compressor is using is relatively easy. Two methods are described in Appendix B.

#### **4.1.4 System load profile**

A system load profile shows the demand on the compressed air system over time (load is another term for demand). It is important to measure and analyse the system load profile if you are to effectively improve the performance and efficiency of any compressed air system.

#### **Measuring the profile**

To obtain the load profile, the airflow from the compressor must be measured at various points over a period of time. It is also possible to measure the system pressure and the power drawn by the compressor and dryer at the same points in time in order to see how the flow, pressure and power consumed by the system changes over time. This profile should be obtained over a typical production cycle so that demand on the compressed air system can be seen at all stages of the production cycle. For example, a seven-day period that is not part of a holiday season might be a typical production cycle.

Ideally, the load profile should be measured by using flow meters on the main compressed air branch lines and the flow recorded at regular intervals by a data logger. Electronic pressure metering on the main system lines and power metering for the compressor and dryer will enable you to look at all aspects of your system's performance and better diagnose any problems. However, setting up this extent of metering is a time-consuming process that requires technical knowhow. If you do not have these resources, you could use a compressed air service provider to assist by conducting an air audit (refer to Section 6 Selecting a service provider) or you could use a less vigorous method of determining the load profile.



There are a number of ways to determine how your system is using compressed air. Power metering for the compressor will indicate the demand over time. The control system for your compressor may be start/stop, load/unload or it might run on a variable speed drive. In all cases, by looking at the power usage over time and identifying when the compressor loads and unloads, you can get a rough idea of when the peak demand times are.

Additionally, if you can obtain a pressure-flow curve for your compressor (these are usually available from the manufacturer) and your compressor has an outlet pressure gauge, you can determine the flow. Recording the pressure at various times will enable you to develop a plot of flow over time, just as flow metering would have done. You can also gain an understanding of demand by looking at the demand side rather than the supply side. If the demand cycles of the equipment that account for the largest use of compressed air are relatively short, it might even be possible to observe them yourself, noting how long and at what times they are using compressed air. In this way, you can build a rough plot of the largest uses of compressed air in the load profile.

### Analysing the profile

Once you have obtained some information for a load profile, you can identify how your compressed air system is being used. Figure 3 illustrates a typical air demand profile, showing the air demand in m<sup>3</sup>/hr (normal temperature and pressure) over time. The red lines indicate that, while the peak demand is 980 m<sup>3</sup>/hr, the average demand is only 190 m<sup>3</sup>/hr. The fact that the average demand is only a small fraction of the peak demand is a sign that the compressor is oversized, not running at its highest efficiency point and most likely wasting energy. A smaller compressor could be used with a larger air receiver and the peak demand could still be supplied to the system. For added benefit, try to improve the demand spikes as well.

With a profile such as this, you can identify which equipment is responsible for various features of the profile. You can also determine the maximum demand for each piece of equipment and how this compares to the maximum total load as a percentage. This is an effective method of ranking your equipment in terms of their compressed air consumption, or significance to the compressor system.

You may also be able to obtain a graph of the power consumption of your compressor and/or dryer over the same period of time as the load profile above. By combining these two graphs, you could see how the efficiency of the system changes over time.

A key performance indicator that can be used to monitor the ongoing efficiency of the system is kW per L/s. The lower the kW/L/s, the more efficient the system is. This profile is valuable in identifying the times at which your compressor may be running at part load and so increasing your costs per unit of air demand. Taking an average value of this graph will give you your average efficiency in kW/L/s.

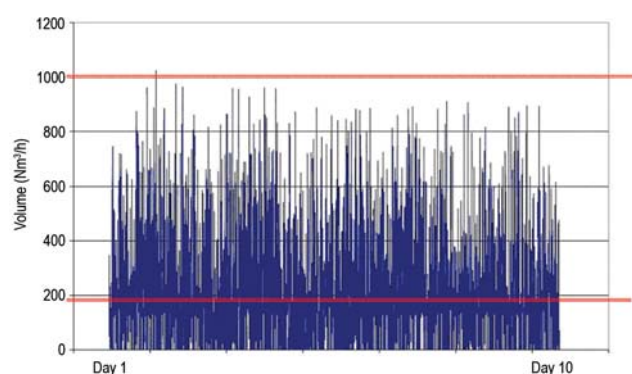


Figure 3: Compressed Air Usage and Potential Savings for the Typical Compressed Air User. <sup>2</sup>

### Optimising the profile

The compressed air system may be more effective if the profile is flattened or, in other words, if the large switching loads can be operated at different times so that the demand is more stable. If, for example, a purging function can be run while a major line or piece of plant is not running, the load profile will be more constant.

In some cases, it may be more efficient to place certain loads on a separate system. For example, if there is one load that only operates after hours while all others operate during the day, it could be placed on a separate (point of use) compressor so that the main compressor system can be shut down and not have to run inefficiently at part-load. Although there are now two compressors, the overall efficiency of your two systems will be greatly improved.

## 4.2 Step 2: Reduce leakage

Leaks can waste up to 50% of the compressed air produced by your compressor. Reducing leakage is a key measure that can be used to improve energy efficiency. Table 3 provides an indication of the cost of leaks.

### 4.2.1 Measuring leakage

If there is a flow meter installed immediately after your air compressor or receiver, measuring leakage is as simple as reading this flow meter when all compressed air equipment is turned off and all outlet valves are closed. Similarly, if you obtained data for the load profile as outlined in the previous step, then you simply need to ensure that you record data for the system load while all equipment uses of compressed air are turned off. If flow metering is not available to you, there are two methods that may be used to determine system leakage. These methods are detailed in Appendix C.

**Table 3: Air Leakage, Wasted Energy and Cost for Hole Diameter<sup>5</sup>**

Equivalent Hole Diameter (mm)	Quantity of air lost in leaks (L/s)	Annual energy waste (kWh)	Annual cost of leaks (\$)
0.4	0.2	133	13
0.8	0.8	532	53
1.6	3.2	2128	213
3.2	12.8	8512	851
6.4	51.2	34040	3404
12.7	204.8	136192	13619

### 4.2.2 Finding leaks

Leaks can occur in any number of places, such as:

- hoses and couplings
- pipes and pipe joints
- pressure regulators
- valves left open
- equipment left running or not isolated
- threaded fittings not properly sealed with thread sealant or dirty.

Apart from listening for leaks, which can be deceptively unreliable in a noisy environment, there are two key ways to find compressed air leaks. The simplest is to brush soapy water over areas suspected of leaking and look for bubbling. Although cheap and simple, this can be a very time-consuming process. The second is ultrasonic leak detection. Ultrasonic detectors can pinpoint leaks very accurately and quickly by detecting the signature ultrasound signals of high-pressure leaks. They can operate in noisy plant environments, so equipment does not have to be turned off. While some training is required in their use, operators can become competent after less than an hour.

Some compressed air service providers will be able to perform ultrasonic leak detection programs for you if you do not have the resources yourself. Once leaks are found, it is very important that you keep track of them effectively. The best way is to 'tag' the leaks with bright colours as soon as you find them. Use a site map to record the location of the leak. Give each leak a grading for the amount of air loss through it, perhaps between one and ten. Record this grading on the tag itself and on the site map. The leaks with the highest priority grading should be fixed first.

**One Australian company successfully implemented a leak management program with a compressed air parts supplier.**

The supplier attended site on a monthly basis during regular shut downs, reviewing and repairing simple leaks on the spot. Larger leaks were tagged and repaired at a later date.

#### 4.2.3 Fixing leaks

Fixing leaks often involves tightening or replacing connections, fixing holes in pipes or repairing damaged equipment such as pressure regulators. Often, simply cleaning and applying thread sealant to fittings will help. Replacing equipment will be necessary in some situations.

#### 4.2.4 Leak management program

Once leaks are regularly being repaired, the implementation of practices to avoid leaks getting out of control will ensure that the compressed air system remains efficient. These practices can include:

- regular inspection and maintenance of compressed air equipment
  - regular inspection of air pipes, bends and valves
  - ensuring that all air lines are properly supported so as not to cause leaks through excess stress
  - removing or properly isolating any unused parts of the pipe distribution network or unused pressure regulators
  - implementing a leak reporting program among staff.
- Making staff aware of the cost to the business from leaks and encouraging them to actively report leaks is an important step, as they are always present on the shop floor and are best placed to notice any changes.

### 4.3 Step 3: Fix pressure drop

Pressure drop is another major cause of inefficiency in compressed air systems. Pressure drop is the decrease in pressure between the compressor and the point of use of the system. It occurs due to the loss of energy from the compressed air as it flows through the system. A certain amount of loss is inevitable from some components such as filters, dryers and separators. However, there are ways to ensure a minimal pressure drop is obtained. A compressed air system that is performing well should have a pressure drop of less than 10% between the compressor outlet and all points of use.

#### 4.3.1 Measuring pressure drop

Using a calibrated pressure gauge, measure the pressure at the compressor outlet and at each pressure regulator, with the regulators set to maximum pressure. Determine the lowest pressure recorded after measuring at all the regulators.

Pressure drop = compressor discharge – lowest available pressure at regulators

The larger your pressure drop, the more inefficient your system is, as the compressor must work harder to obtain a higher pressure while only a lower pressure is being utilised.

#### 4.3.2 Valves

The two common types of valves that are used in compressed air systems are ball valves and gate valves. Both types have their place depending on their application. Ball valves are useful for isolating flow and have the lowest pressure drop of the two, while gate valves are useful for controlling flow.

#### 4.3.3 Piping layout

There are two common air distribution layouts – a single main system as illustrated in Figure 4 and a ring system as illustrated in Figure 5. A ring main setup is considered best practice, however, a single main setup may also be useful in many applications. Try to restrict your compressed air system to these layouts to ensure that they maintain efficiency. The more bends you have in your piping network, the higher the pressure drop will be.



Figure 4: Single Main Pipe layout with Branch Lines.<sup>6</sup>

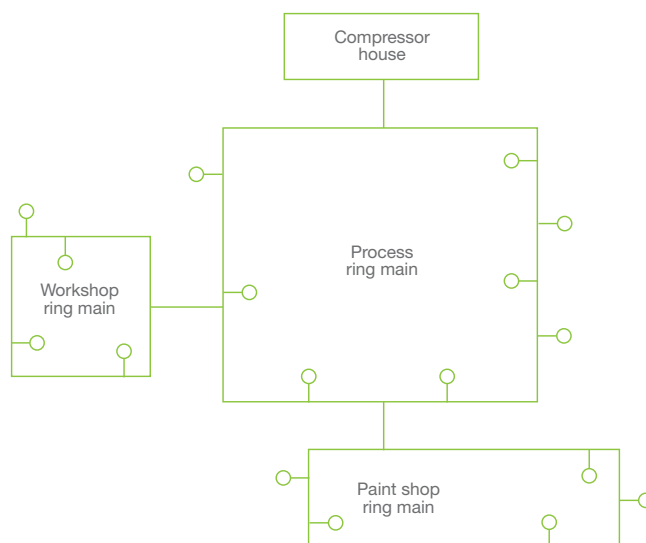
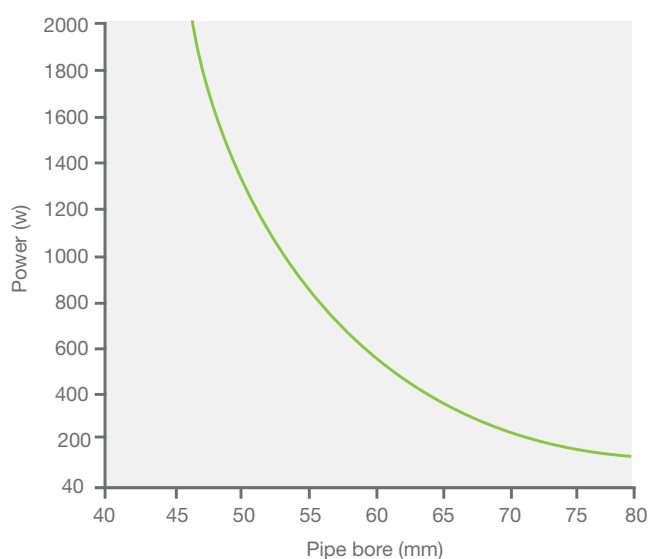


Figure 5: Example ring main with take-off points.<sup>7</sup>

#### 4.3.4 Pipe diameter

The diameter of the piping in the distribution network has a large impact on the pressure drop of the system. The smaller the pipe, the more energy is lost by the system. Figure 6 illustrates how one such power loss for a given diameter pipe may look.



While the pipe diameter may have been large enough for the capacity required at the time of installation, if demand has since increased, the pipe diameter may now be too small for the system's requirements.

#### 4.3.5 Pressure setting

Once you have ensured that you have minimised pressure drop, repeat the measurement of the pressure drop in your system. Using the information collected about the pressure requirements of the equipment in Step 1, you can determine the required pressure.

Pressure required at compressor = maximum pressure required by equipment + minimised pressure drop

### 4.4 Step 4: Review air receivers

Receivers store compressed air in order to meet rapid increases in demand. In this way, air compressors can be turned off for certain periods or run at a lower load. Compressed air systems often make use of a main air receiver to provide this storage. Although the size of the receiver may have been large enough when it was installed, equipment additions may now mean that there is not enough storage to supply each air demand event, putting greater demands on the compressor.

The typical compressor control system will measure the system pressure and, once it reaches an upper limit, will disengage or stop the compressor. Any demand for compressed air is then provided solely by the receiver.

Once the pressure drops below a set lower limit, the control system will start the compressor in order to repressurize the system.

If your receiver is too small for your air demand needs, the compressor will be running longer than it needs to. By improving the ability of your storage to meet demand, use of the compressor is minimised, reducing energy usage and wear and tear. In an existing system, there are two things you can do to improve air storage:

- Install a larger main receiver for the entire system.
- Install secondary receivers near equipment that will rapidly increase its demand for compressed air.

If you have added a large number of smaller tools to your system over the years, upgrading the size of your main receiver may be most beneficial. If, instead, you have added equipment that has high, intermittent demand, it may be more beneficial to install secondary receivers for that equipment.

## 4.5 Step 5: Maintain separators, filters, dryers and valves

Nearly all compressed air systems have some level of air treatment to remove oil, water vapour and particulate matter from the compressed air stream.

A compressed air system will usually contain:

- A separator to extract lubricant oil from the air stream. A separator is often part of a packaged compressor.
- A dryer to condense and extract water vapour from the air.
- A filter to remove contaminants. Often, there is a filter fitted to the inlet of the air compressor.

The level of quality required by your system depends upon the application. For example, food-processing applications will require a very high air quality, while a mechanics workshop will require a lower standard. Treating your compressed air to a higher quality than is required wastes energy and may also result in higher maintenance costs.

### 4.5.1 Filters

Regularly check and replace filters. Blocked filters will cause a significant pressure drop and so waste energy. Gauges can be installed that measure the pressure drop across the filter and indicate when a new filter is required.

### 4.5.2 Dryers

Dryers are often an essential part of the system. There are three main types of dryers: refrigerant, membrane and desiccant. Fitting refrigerant and desiccant dryers with control systems makes it possible for the dryer to match its energy use to the air demand at that time, therefore reducing energy usage. Whilst desiccant systems use no direct electricity, unlike refrigerant systems, they use compressed air to purge the desiccant, thus still using energy to operate. This needs to be included in any comparison of energy costs between dryer systems. Desiccant dryers will often purge a set volume of air on a regular frequency, despite the actual flow through the dryer at that time. It is possible to retrofit desiccant dryers with dependent dewpoint switching (DDS) controls.

This system will measure the dewpoint within the dryer and only purge when it is required, therefore reducing the amount of wasted compressed air. For a typical system using a 55kW screw compressor and a desiccant dryer, the installation of a DDS system could save up to 60% of annual operating costs of the dryer. Refer to Appendix D for a breakdown of this example.

### 4.5.3 Drain valves

Replace manual, disc and timed drains with new electronic level sensing drains to reduce the amount of waste. Drain valves are fitted on equipment in which water condenses, such as after-coolers, receivers, dryers and filters. There are various types, but they all release condensed water from the equipment. The longer these drains remain open, even partly open, the more compressed air is lost from the system. Electronic level sensing drains help to optimise the time that drains are open for.

## 4.6 Step 6: Select a compressor

Optimising and upgrading your compressor should be the last consideration when looking at improving the efficiency of your existing compressed air system. Make sure that you have followed Steps 1–5 first to maximise usage, distribution, storage and treatment of compressed air.

### 4.6.1 Compressor types

#### Reciprocating compressors

Reciprocating compressors work through the action of a piston in a cylinder. Pressure can be developed on one or both sides of the piston. They are usually the most expensive to buy, install and maintain, and require large foundations due to their size and the vibrations they cause. Despite these disadvantages, reciprocating compressors have their uses. They are good for high-pressure applications (13 bar pressure and above) and for high air quality applications. They are also the most efficient for quite small applications (in the 1–4 kW range).

#### Screw compressors

Screw, or rotary, compressors use two meshing helical screws, rotating in opposite directions at high speed, to compress air. These compressors are usually the lowest cost to purchase and install. They lose efficiency rapidly at part load unless variable output compressors are used.

### Vane compressors

Vane compressors have a rotor with steel sliding vanes within an eccentric housing. The vanes form pockets of air that are compressed as the rotor turns until an exhaust port is exposed. Vane compressors have similar energy efficiency to screw compressors, but often have better air quality.

### Centrifugal compressors

Centrifugal compressors use high-speed rotating impellers to accelerate air. To reach operating pressures, several impeller stages are required. They have relatively low installation costs, but are expensive to buy because they are precision machines, however, they are generally economical in large sizes, in the 200 kW and above range. They are efficient down to around 60% of their design output, below which they have little turndown in their energy consumption.

**Table 4: Advantages and Disadvantages of Air Compressor Types<sup>2</sup>**

Compressor	Advantages	Disadvantages
Reciprocating Efficiency: 7.8 – 8.5 kW/m <sup>3</sup> /min	Suitable for high pressures Can be relatively small size and weight Smaller initial cost Simple maintenance procedures Efficient multi-stage compression available	High noise levels High maintenance costs Suitable for smaller systems Requires strong foundation High oil carry over when worn
Screw Efficiency: 6.4 -7.8 kw/m <sup>3</sup> /min	Simple operation Lower temperatures Low maintenance Quiet Compac Vibration free Commercially available variable speed units with relatively good turndown.	High energy use Low air quality
Vane	Simple operation Lower temperatures Quiet Low maintenance	Limited range of capacity. Low air quality
Centrifugal Efficiency: 5.8 – 7 kW/m <sup>3</sup> /min	Energy Efficient Large Capacity Quiet High air quality	High initial cost Inefficient at low capacity Specialised maintenance Only water-cooled models available



## 4.6.2 Using multiple compressors

Depending on your load profile, the addition of another (differently sized) compressor may deliver a more efficient outcome than replacement. For example, if your load profile contains a certain level of constant demand with a small amount of fluctuating demand and you currently have one, fixed-speed screw compressor, you could add a variable screw or vane compressor to provide for the fluctuating demand while the fixed speed screw compressor provides for the base load.

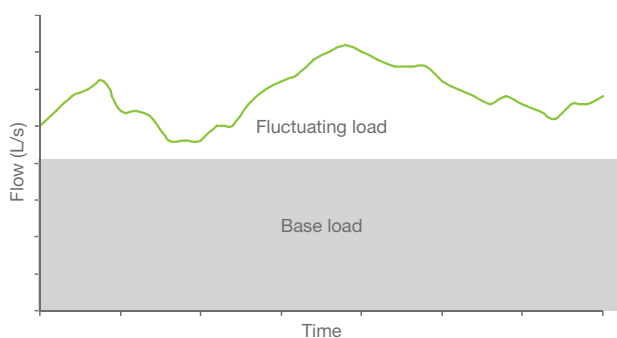


Figure 7: Graph of a Load Profile suitable for a fixed speed and variable compressor setup.

### 4.6.3 Compressor control systems

There are different types of control systems available for compressors. Your current system may not be using the most efficient method, or may have no control system at all.

#### Start/Stop

This method of control will start the compressor once the pressure drops below a certain level and stop it once the desired pressure has been reached. This method should not be used when there is a frequent increase in demand, as continually starting and stopping the compressor can be detrimental to the life of the compressor (increasing maintenance costs).

While energy is saved during the periods that the compressor is not running, the compressor must charge the receiver to a higher pressure than is required by the end uses so that a minimum pressure is maintained until the compressor starts again.

#### Load/Unload

Using this method, the compressor will charge the system to the desired pressure, then the compressor motor will continue to run at constant speed while the compressor action is disengaged. While this means that the compressor is using less power for a large amount of the time, the motor can use between 15 and 35% of full load power, meaning this scheme can also be inefficient. Figure 8 below shows a typical power consumption profile for a compressor using a load/unload control system. You can see that the compressor still uses roughly 30% of peak power while unloaded. During the time immediately after the compressor enters the unloaded stage, the oil separator performs a blow down to clean out accumulated oil. This leads to the compressor running at part load for some time, meaning that quite a significant amount of energy can still be used during unloaded operation.

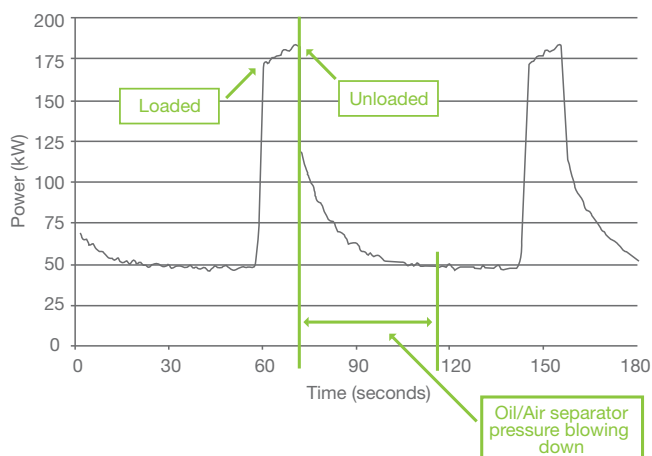


Figure 8: Typical power curve of a compressor using a load/unload control system<sup>2</sup>

### Throttling

Throttling control varies the degree to which the inlet valve is open, controlling the amount of air intake to the compressor. This method is only effective with screw or vane compressors that run at 70% load or above.

### Centrifugal compressor control

Centrifugal compressor control systems are usually more complex and involve throttling and recirculating air load, as well as venting of air to the outside environment.

### Variable-speed screw compressors

Variable-speed screw compressors control the motor speed whilst keeping the slide valve to the compressor fully open to meet fluctuating air demand. When combined with a base load compressor providing constant air supply at optimum efficiency, a variable-speed and fixed-speed combination can be the most efficient for real-world, fluctuating, air-demand patterns.

### Compressor power consumption with flow

The power drawn by compressors changes significantly with changes in airflow. Figure 9 shows the power-flow curves for a number of compressor control systems. This graph shows how the different control systems can affect the compressor's efficiency at low flow levels. The curve shows the amount of power consumed (relative to maximum power) as the flow capacity through the compressor changes. The steeper the compressor curve, the more efficiently it performs at part loads.

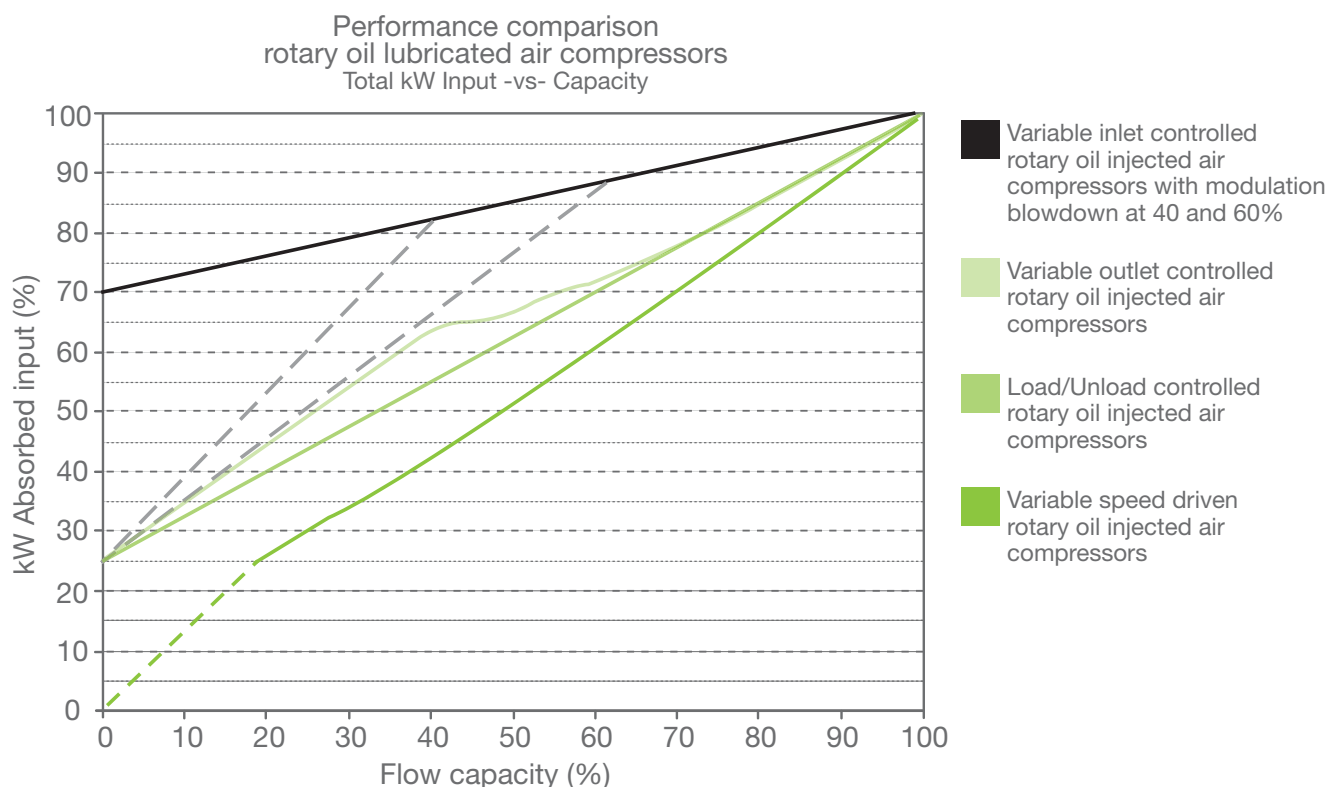


Figure 9: Typical performance of rotary oil lubricated compressors with different control systems.<sup>2</sup>



#### 4.6.4 Compressor maintenance

Ensuring regular maintenance is carried out on your compressor will also reduce energy costs. Ensure the inlet filter is not blocked and keep coolers clean and properly lubricated.

#### 4.6.5 Variable speed drives

Variable speed drives can be fitted to the motors of screw and vane compressors, and most suppliers are now offering factory-fitted, variable-speed units. These allow the motor to be run at the rate required in order to fulfil demand at that time. This method can save considerable amounts of energy. However, variable-speed drives should only be fitted in cases where air demand varies. Using a variable-speed drive for a compressor that runs at full load constantly will consume more energy. Some companies have elected to install one variable speed unit, with two or more base load units to save on capital cost.

#### 4.6.6 Multi-stage compressors

Multiple stages can be used to improve the efficiency of screw and centrifugal compressors. Additional cooling can be placed between the stages to further increase the efficiency of the second stage.

#### 4.6.7 Compressor operating conditions

Once you have selected the type of compressor system that you wish to install, you should ensure that the plant services the new compressor will require are available and that operating conditions are suitable.

#### 4.6.8 Location

When installing a new air compressor, the location of installation is important. There should be sufficient room for the equipment as well as access for maintenance. The compressor should also be as close as possible to the plant. If the compressor is to be located outside or in a compressor house that is detached from the main building, it is best to place the compressor house in the most shaded area. This is usually on the south side of the main building.

#### 4.6.9 Inlet air temperature

Lower air inlet temperatures allow your compressor to operate more efficiently. Section 5.5 (in Solution 2) illustrates how important this is and what sort of energy savings to expect. In essence, compressors produce large amounts of heat. If this is not exhausted to the atmosphere via cooling towers (water-cooling) or

through exhaust stacks, you are wasting energy. When selecting a new compressor, it is important to locate the air inlet to use the lowest temperature air practically available and to discharge the waste heat to the atmosphere if possible.

#### 4.6.10 Power

There should be suitable access to electrical power for the compressor. The distribution board from which the compressor is run should be well within its rated power limits and the cables supplying the compressor should also be rated for the current required by the compressor.

#### 4.6.11 Water

Access to suitable water should be available for cooling the compressor if required. This water should be as cool as possible, so a supply from pipes that are exposed to the sun is not recommended.

#### 4.6.12 Blowdown

Air compressors often have blowdown mechanisms, which will blow any condensed water or filtered oil from filters or condensate traps. This waste should be considered as contaminated, so there should be access at the compressor for disposal of this waste.

### 4.7 Step 7: Measure the improvement

By following these steps, you have done almost everything possible to improve the energy efficiency of your compressed air system. Repeat the measurements you made when determining the current old usage. By comparing the result, you can determine the reduction in energy used to run the system (kW/L/s) and hence the reduction in energy costs of the system.

## 5 Solution 2 – Design a new system

### 5.1 Establish air demand (quantity and quality)

Using the techniques described in Section 4.1 (in Solution 1), air demand quantity and quality can be estimated for your new or extended facility. The key principles that should be adhered to are:

- **Design ‘out’ inappropriate uses of compressed air.**

Take the opportunity to consider substitution of compressed air for other technologies (for example, electric drives instead of compressed air cylinders, low-pressure blowers for water removal).

- **Separate services using differing air quality.**

Establishing air-quality requirements is critical, as it can dictate the types of compressor and filtration used. Higher quality air is more expensive to produce and you should consider multiple compressors with separate duties.

- **Minimise compressed air demand spikes.**

By considering how equipment operates together, you can minimise pressure spikes, which in turn affects how efficiently your compressors can operate. Bear in mind that you will also be using receivers, which can also help to minimise pressure spikes.

- **Separately itemise the equipment that uses high pressure.**

If your high-pressure requirements are a relatively small proportion of your overall air demand, it may be possible to supply them via a separate compressor.

- **Minimise pressure requirements for your system.**

A compressor’s efficiency is linked to its pressure setting. Less energy is required to compress air to a lower pressure, so once you have itemised the air-quality requirements of your equipment, consider how you can minimise that even further through equipment selection and substitution.

### 5.2 Design your piping and fittings

Pipes and fittings also affect the pressure set point of your compressor. A compressed air system that is performing well should have a pressure drop of less than 10% between the compressor outlet and all points of use. There are ways to ensure a minimal pressure drop is obtained, including:

- Optimise pipe diameter, length and the number of bends. Pressure drop is a function of a number of things – importantly: the velocity of the air down the pipe (which is dictated by your air demand combined with pipe diameter); the distance of the piping between the compressor and the end uses; and the number and type of bends. By paying attention to these things, total pressure drop can be minimised.
- Select valves and fittings with low pressure drop. Section 4.3.3 and Section 4.3.4 in Solution 1 have more information on piping layout and pipe diameter.

### 5.3 Select and locate air receivers

Receivers have a key role in maximising the efficiency of your compressor. They achieve this by storing compressed air to meet rapid increases in demand, which reduces the impact of air demand surges on the compressor. This allows compressors to run at their optimum load position and minimises the number of load/unload cycles (if using fixed-speed compressors). Often, a single main receiver is used, but secondary receivers should be considered if specific equipment or work areas can be identified that induce intermittent, high, air demand.

## 5.4 Select dryers, separators and filters

Refrigerant dryers add electrical consumption, pressure drop desiccant dryers waste compressed air through purging and increasing pressure and separators and increasing pressure and separators and filters also introduce pressure drop to your system. Careful selection can minimise the negative impact on energy efficiency. Section 4.5 (in Solution 1) explores details of why and how dryers, separators and filters are used, with the key points being:

- Treating your compressed air to a higher quality than is required wastes energy and may also result in higher maintenance costs.
- Although desiccant dryers do not use energy to run, they require compressed air for purging. These energy costs should be included in any comparison between desiccant and refrigerative dryer systems.
- Regularly checking and replacing filters will minimise pressure drop across them (these can be monitored to optimise the energy costs with filter replacement costs).
- Electronic level sensing drains help to optimise the time that drains are open (drain valves are fitted on equipment in which water condenses, such as aftercoolers, receivers, dryers and filters).

## 5.5 Locate inlet and discharge air outlet

The efficiency of the compressor can be greatly improved by providing cooler air at its intake. This can be as simple as ducting air from outside the compressor house or another location on-site. Another important consideration is where the waste heat from your compressor is discharged to. Is it exhausted into the compressor house? Or into the atmosphere? Best practice would ensure that waste heat does not find its way back into heating the inlet air to the compressor. Table 5 illustrates energy savings arising from reducing the air inlet temperature to your compressor.

## 5.6 Select a compressor and control system

Selecting the control philosophy may be an iterative process that includes:

- choosing a compressor, or range of compressors (different sizes, types and so on)
- selecting how each compressor will operate in relation to the others given its range of operational options. Section 4.6 (in Solution 1) discusses factors to be considered in selecting a compressor. Suffice to say that the aim is to meet air demand at the lowest total cost, including the energy costs.

**Table 5: Annual Energy and Cost Savings with Reduced Compressor Inlet Temperature<sup>8</sup>**

<b>Air Intake temperature reduction</b>	<b>3°C</b>		<b>6°C</b>		<b>10°C</b>		<b>20°C</b>	
	kWh/yr savings	\$/yr savings	kWh/yr savings	\$/yr savings	kWh/yr savings	\$/yr savings	kWh/yr savings	\$/yr savings
Comp- arative average load (kW)								
4	80	8	160	16	264	26	528	53
7.5	150	15	300	30	495	50	990	99
11	220	22	440	44	725	73	1450	145
15	300	30	600	60	990	99	1980	198
22	440	44	880	88	1450	145	2900	290
30	600	60	1200	120	1980	198	3960	396
37	740	74	1480	148	2440	244	4880	488
55	1100	110	2200	220	3625	363	7251	725
75	1500	150	3000	300	4950	495	9900	990
110	2200	220	4400	440	7260	726	14520	1452
160	3200	320	6400	640	10550	1055	21100	2110

## 6 Selecting a service provider

Upgrading and improving your compressed air system can take considerable time depending on your circumstances. While you may want to follow the steps in this guide, you may not have the time or resources available to do so. Compressed air service providers can supply the services required to assess, upgrade or install your compressed air system. You may wish to ask them to assist you with some or all of the process. In either case, there are some questions you should ask before you begin.

### 6.1 Questions to ask service providers

#### **Will the provider take a systems approach?**

It is important that your service provider considers how to optimise your entire compressed air system, not only one or two of its components. Ensure that the provider will include the following in their investigation:

- air treatment level specifications
- leak management assessment
- pressure levels throughout the system
- flow throughout the system
- control system optimisation
- heat recovery potential.

#### **Will the provider examine the demand side as well as the supply?**

While the supply side of equipment such as the compressor, dryer, receiver and filters are important considerations, the provider should also be investigating the demand side of your system, including the distribution network, pressure regulators, the end uses and the profile of the demand.

#### **What analysis services do they offer?**

In order to ensure your system runs as efficiently as possible, the provider must first conduct a detailed analysis of various aspects of your system. While leak detection is important, your provider should also be able to measure and analyse the load profile of your system, the pressure at various points around the system and the power consumption of the compressor and dryer. Other questions to ask of your provider include:

- What training do the staff have?
- Are they qualified to work on all compressor types?
- Can they service and install equipment such as filters, drains and piping?
- Do they provide emergency service response?
- Will they take care of parts shipping?
- Will they contract out any of the work themselves?
- Do they have the capability to remotely monitor your system?
- Can they provide emergency rental compressors?

### 6.2 Database of compressed air service providers

A database of professional compressed air service providers can be found in the Sustainable Manufacturing Directory provided by the Sustainability Victoria. This directory can be found at the Sustainability Victoria website:

**[www.sustainability.vic.gov.au](http://www.sustainability.vic.gov.au)**

## Appendix A Compressed air system overview

A compressed air system consists of a number of main stages: compression – the air is put under pressure; treatment – the air quality is improved; storage – reservoirs of air to meet rises in demand; and distribution – piping of air to end uses. Each component in a typical system helps to deliver clean, dry, compressed air that is free of pressure fluctuations at its point of use. If any component is working inefficiently, the system's performance suffers and operating costs rise. A brief description of each component follows.

- Inlet filter: removes particles from the air entering the compressor. Usually part of the compressor package.
- Compressor: compresses air to a small volume, increasing the pressure.
- Motor: drives the compressor – also known as prime mover.
- Compressor controller: directs the compressor's output. It may be microprocessor, electromechanical or pneumatically based. Advanced controllers include machine protection and information management.
- Aftercooler: compression leaves the air hot and wet. The aftercooler lowers the temperature of the air leaving the compressor and removes water that condenses as the air cools.
- Separator: removes liquids from the compressed air.
- Receiver: stores a large reserve of compressed air to maintain a smooth flow to the plant, especially when air demand rises.
- Air line filter: removes solids and liquids from the compressed air stream. Can be placed throughout the system.
- Dryer: helps to eliminate any remaining moisture in the compressed air by using either a refrigerated condenser or a desiccant. Refrigerated condensers cool the air to condense water vapours into a liquid that is then drained from the system. Desiccants are powders or gels that remove water by absorbing it.
- Condensate trap: collects and discharges liquid that condenses out of the air stream. It is an integral part of aftercoolers, dryers and separators.
- Distribution piping: links the components. It distributes the air from a main header to branch lines and subheaders to drop points connected to individual tools.
- Pressure regulator: controls air pressure and flow at individual points of use.

# Appendix B Methods for estimating compressor energy consumption<sup>9</sup>

One of the two methods below can be used. Ensure that all electrical meters are installed by qualified electricians.

### Method 1

A power demand analyser or a suitable meter can be used to measure the average power (kW) of the compressor system over a test period, or kWh used over that period.

### Method 2

If the compressor is operating at a steady load, measurement of the compressor circuit three-phase currents can be used to determine compressor energy consumption. A “clip on ammeter” can be used to measure the instantaneous currents of each phase and an average phase current can be calculated. Power for the three-phase circuit:

$$\text{power (W)} = 1.732 \times E \times I_{av} \times \text{power factor, where}$$

$E = \text{supply voltage (usually 415V)}$   
 $I_{av} = \text{average phase current (amps)}$

Power factor is usually about 0.85 at full load reducing to 0.7 at half load and to about 0.2 at no load.

$$\text{monthly energy use (kWh)} = \text{power (kW)} \times \text{number of operating hours/month}$$

An accurate assessment of compressor power usage may require “no load” and “full load” tests to be conducted to determine power at full and no-load conditions. This can then be multiplied by the hours the compressor runs in each load condition to obtain kWh/annum.

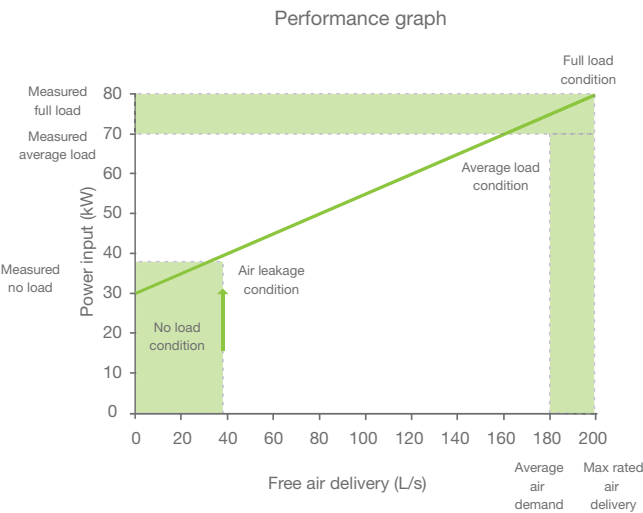
Alternatively, some modern compressors record total kWh consumed in their control systems, which may need to be read on regular basis to obtain annual consumption.

Test type	Description
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“NO LOAD” test	Shut the valve between the compressor and the air receiver. Measure the power consumed by the processor.
“FULL LOAD” test	Expel some air from the air receiver. Measure power consumed by the compressor as it builds up air pressure.

On the basis of the above electrical measurements, an approximate compressor performance graph can be drawn, as indicated below, and used with the operating hours to obtain kWh/annum.

Figure 10: Typical Compressor Performance Graph<sup>9</sup>



## Appendix C Measuring leaks

This section describes a method for measuring leaks in your compressed air system.

### Method 1

1. Let the compressor build up the system pressure until it reaches the shutoff point and the compressor stops. If the compressor NEVER reaches the shutoff point, the air leakage rate must be VERY HIGH.
2. For a period of half an hour, record the time the compressor runs and the time that it is off.
3. The quantity of air leaking from the system can be estimated as follows (F.A.D. = Free Air Delivery):

$$\begin{aligned} &\text{Quantity of air to supply leaks (l/s)} \\ &= \frac{\text{Rated FAD to compressor (l/s)} \times \text{Time on (s)}}{\text{Time off (s)} + \text{Time on (s)}} \end{aligned}$$

### Method 2

1. Run the compressor until the pressure in the air receiver builds up to its maximum operating pressure.
2. Switch off the compressor and measure the time taken for the receiver pressure to drop by, say, 100 kPa (The pressure should drop enough to allow the compressor to restart for the second half of the test).
3. Switch on the compressor and record the time taken to build up the 100 kPa pressure loss.
4. The quantity of air leaking from the system can be estimated as follows:

$$\begin{aligned} &\text{Quantity of air to supply leaks (l/s)} \\ &= \frac{\text{Rated FAD to compressor (l/s)} \times \text{Time for pressure to rise (s)}}{\text{Time for pressure to drop (s)} + \text{Time for pressure to rise (s)}} \end{aligned}$$

5. Using Figure 10, a power use corresponding to the measured air leakage level (kW) and a power requirements corresponding to the 'no load' condition (kW<sub>2</sub>) can be established. From these graph readings, the actual net power use attributable to air leakage can then be calculated as follows:

$$\text{Power attributable to air leakage} = kW_1 - kW_2$$



## Appendix D Cost savings from the installation of a DDS system

Table 6 outlines the potential savings with DDS retrofitted to a typical heatless dessicant air dryer installed with a 55kW rotary screw air compressor.

### Adsorption dryers – operating costs

Min. Inlet Pressure:	7.0 bar g
Ambient Temperature (std ref conditions):	21.0 °C
Inlet Temperature (Air compressor disch temp - +10 deg. C)	31.0 °C
Outlet Pressure Dewpoint:	-40 °C
Inlet Moisture Content:	4.1385 g/m <sup>3</sup>
Max inlet water content:	3.3751 kg/hr

### Operating costs

Energy required to produce purge air:	12.64 kWh
Energy cost per kWh:	\$ 0.100
Operating hours per annum:	3840
Annual running cost:	\$4,853.76

### Operating Costs with Dewpoint Dependent Switching System

Average Inlet Temperature (at std ref conditions):	21.0 °C
Average Inlet Pressure:	7.0 bar g
Average Flow rate (70% of Max flow rate):	9.90 m <sup>3</sup> /min
Inlet Moisture Content:	2.2849 g/m <sup>3</sup>
Average inlet water content:	1.3572 kg/hr

<b>Cost savings:</b>	<b>59.78%</b>
<b>Estimated annual savings:</b>	<b>\$2,901.58</b>
<b>Estimated annual running costs:</b>	<b>\$,1952.18</b>

Table 6: Cost savings from the installation of a DDS system.<sup>2</sup>

## Appendix E Glossary

Air Compressor	A machine that puts air under pressure by compressing a volume of air.
Artificial Demand	Air demand that is not actually used by the end uses of the compressed air, such as loss caused by pressure drop.
Control System	The mechanism that controls how the compressor meets demand through switching on/off and by varying its operation.
Demand Profile	A graph of the air demand from the system over time.
Dessicant Dryer	A dryer that uses two separate chambers to remove moisture from the air.
Inlet	The air intake for the compressor.
Leak Management	An action plan of how to check for and deal with leaks on a regular basis so that they do not cause significant loss.
Load	The demand for air that the air compressor experiences.
Piping Layout	The arrangement of the compressed air piping network.
Refrigerant Dryer	A dryer that removes moisture from the air by cooling the air so that water condenses. It uses a typical refrigeration principle and equipment.

## Appendix F

### Further reading/references

#### Further reading

The following manuals provide more detailed technical information and exhaustive best practice methods for improving compressed air efficiency:

*Compressed Air Factsheets*, published by the Compressed Air Association of Australasia, Australia.  
<http://www.energyrating.gov.au/library/detailsaircomp-brochure.html>

*Good Practice Guide: Energy Efficient Compressed Air Systems*, published by the Carbon Trust, United Kingdom.  
<http://www.bcas.org.uk/pdf/carbontrust/GPG385.pdf>

*Improving Compressed Air System Performance*, published by the Compressed Air Challenge, United States.  
[http://www.compressedairchallenge.org/content/library/pdfs/compressed\\_air\\_sourcebook.pdf](http://www.compressedairchallenge.org/content/library/pdfs/compressed_air_sourcebook.pdf)

#### References

- <sup>1</sup> Energy efficient compressed air systems, p. 1, Carbon Trust, UK, February 2005
- <sup>2</sup> CompAir Australasia Limited.
- <sup>3</sup> Improving Compressed Air System Performance, p. 23, Compressed Air Challenge, US, November 2003
- <sup>4</sup> Improving Compressed Air System Performance, p. 19, Compressed Air Challenge, US, November 2003
- <sup>5</sup> Energy Smart Compressed Air Systems, p. 48, Sustainability Victoria, Australia.
- <sup>6</sup> Energy efficient compressed air systems, p. 11, Carbon Trust, UK, February 2005.
- <sup>7</sup> Energy efficient compressed air systems, p. 12, Carbon Trust, UK, February 2005.
- <sup>8</sup> Energy Smart Compressed Air Systems, p. 49, Sustainability Victoria, Australia.
- <sup>9</sup> Compressed Air Savings Manual, p. 16-17 State Electricity Commission of Victoria

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