

## INTRODUCTION

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*An overview of the need for this study*

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## 1 INTRODUCTION

### 1.1 Background

During 2010 South Africa consumed 240.09 TWh of the total worldwide electricity consumption of 21 431 TWh [1]. Eskom is South Africa's primary electricity producer generating approximately 95% of South Africa's electricity [2]. By 31 March 2012, Eskom had the capacity to generate 44 115 MW of electricity when all of its power stations operated at maximum capacity [3]. The demand for electricity in South Africa increased faster than the increase in generation capacity [4].

Eskom allocated R340 billion to increase generation capacity by 17 GW in the period from 2005 to 2019 to counter the high demand [4]. This relates to a cost of R20 million per MW. This is almost four times more than the typical demand side management (DSM) benchmark of R5.25 million per MW [5]. The appropriate management of electricity demand is therefore a less expensive alternative than building new power stations.

Large losses occur from the point of generating electricity to the end-user. It is estimated that 1 kW saved at the point of use could save as much as 6 kW at the power station [6]. Eskom managed to reduce peak electricity demand by 2 997 MW from 2005 to 2012 through its DSM efforts [4]. The Eskom DSM funding opportunity could be applied to finance energy saving projects that would otherwise not be financially viable for the end-user.

The global industrial sector contributes to 41.5% of total electricity consumption [1]. It is estimated that compressed air generation contributes to 10% of industrial electricity consumption [7]. Compressed air generation is therefore estimated to consume 4.15% of total worldwide electricity consumption. The consumption amounts to 889 TWh per annum; that is almost four times more than the total electricity consumption for South Africa.

More than 14% of the electricity generated by Eskom is sold directly to the mining sector [3]. Gold mining is ranked as the third highest electricity consumer in the South African industrial sector, contributing to 15% of total consumption [8]. Platinum mining on the other hand, is ranked as the sixth highest electricity consumer contributing to approximately 6% of total electricity consumption [8].

It is estimated that compressed air contributes to 20% of a mine's total electricity expenses [8]. Compressed air generation is regarded as one of the most expensive means of energy distribution in mining operations [9]. It is estimated that compressor management can account for 25% of the total Eskom DSM savings [9].

So, improving the efficiency of the compressed air systems at South African mines could contribute substantially to electrical energy- and cost savings. This study will focus on improving the compressed air systems at South African mines. The Eskom DSM programme will also be considered to assist with the financing of the projects.

There is a further possibility that the techniques used to improve compressed air usage at South African mines could be applied and implemented at similar mines or industries abroad. The following section will provide an overview of the operation of mine compressed air systems.

### **1.1 Mine compressed air systems**

The mining industry makes extensive use of compressed air equipment due to the equipment's reliability and ease of use. A typical mine compressed air system consists of one or more compressors on the surface. The compressed air generated by these compressors is distributed across the mine via an extensive piping network.

Compressors with installed capacities of up to 15 MW are used at mines in South Africa. Most mines make use of more than one compressor. Daily compressor energy consumption on some systems can be as much as 883 MWh for a typical working weekday.

Some compressed air systems consist of more than one compressor station, also referred to as compressor houses. A single compressor station often houses more than one compressor. The compressor stations and shafts are connected by pipes with diameters that typically range between 150 mm and 700 mm. Some of these pipe sections span up to forty kilometres. The surface piping network is also sometimes referred to as a compressed air ring.

An example of a simplified mine compressed air distribution network can be seen in Figure 1. This figure indicates two main production shafts, nine decline shafts and a concentrator plant connected to the compressed air ring. In this example compressed air is supplied to the ring by means of eight compressors. Typical compressed air users such as pneumatic cylinders, pneumatic rock drills, pneumatic water pumps, etc. are also shown in the figure.

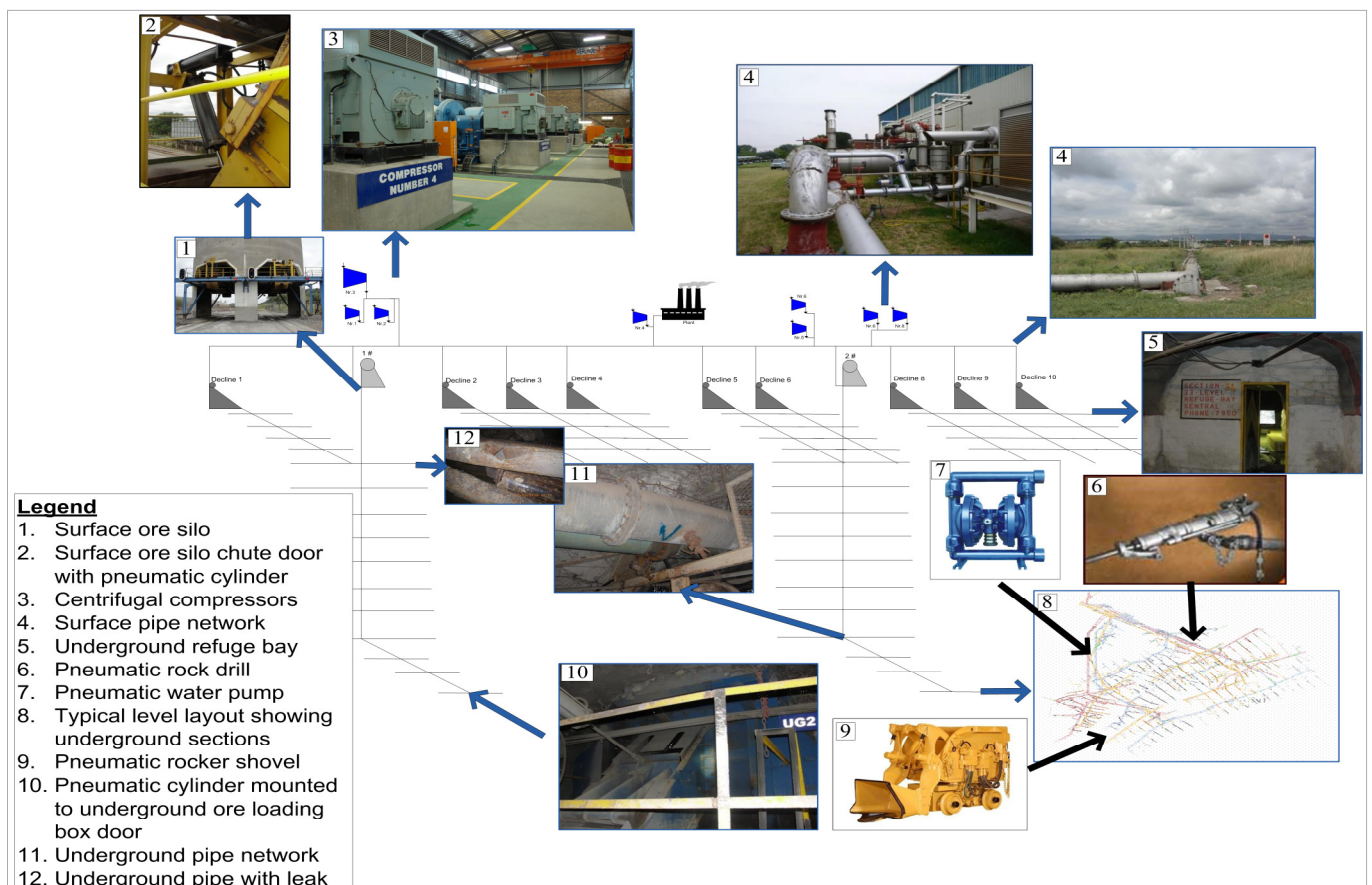


Figure 1 – Example of a simplified mine compressed air system

Compressed air is supplied to underground mining levels through a pipe network that is fed from one (or more) compressed air columns situated in the shaft. These pipe networks span across all underground levels from the shaft area all the way to the working areas. Pipe lengths of four, or even more, kilometres were noticed at the underground levels at some South African mines. Some South African mines reach depths of up to four kilometres below surface [10]. So, it is possible that some working areas are up to eight kilometres away from the connection with the surface compressed air system.

The versatility of compressed air results in the use of a wide variety of pneumatic equipment in mining operations. Some of the equipment used underground include: rock drills, loaders, agitators, venturi blowers, pumps, saws and loading boxes. Therefore, compressed air is an important energy source for underground mining. Some shafts consume in the order of 100 000 m<sup>3</sup>/h of compressed air during peak production periods.

Compressors can be broadly classified as being either positive displacement or dynamic. Dynamic compressors make use of impellers or blades to increase the velocity of continuously flowing gas or air. The velocity energy of the gas or air is then converted to pressure energy by means of both the impellers and the discharged volutes or diffusers [11]. A photo of a centrifugal compressor impeller is shown in Figure 2.

A cut-out view of a multistage centrifugal compressor is shown in Figure 3. All of the mines assessed as part of this study made use of centrifugal machines as their primary means of producing compressed air. Note that some of the figures, such as Figure 3, are only shown for the interest of readers unfamiliar with the type and magnitude of equipment used for deep-level mining. Photos and drawings do not necessarily provide academically to this study. References such as these will not be added to the bibliography and will rather be added as footnotes.



Figure 2 – Photo of an impeller of a centrifugal compressor<sup>1</sup>

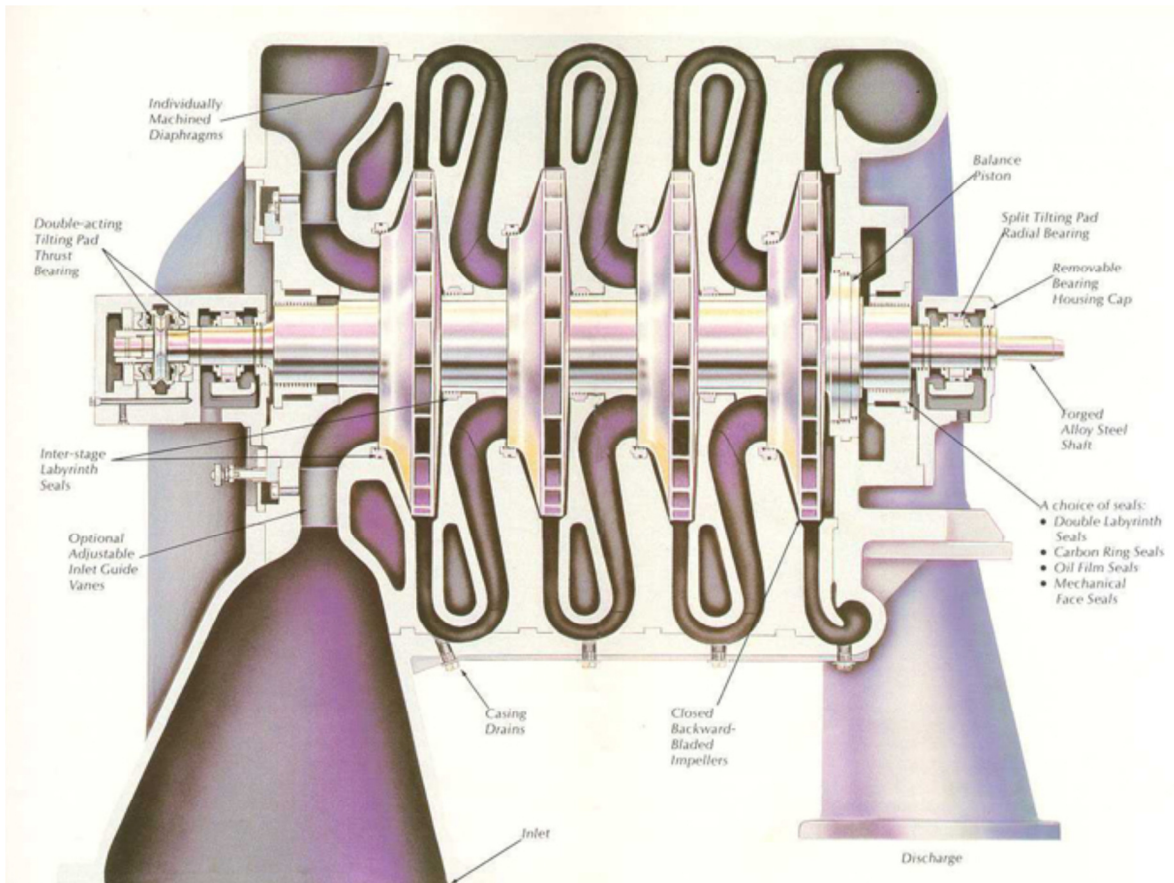


Figure 3 – Cut-out section of a centrifugal compressor<sup>2</sup>

<sup>1</sup> Photo taken at a South African mine

<sup>2</sup> Dresser Inc., “ROOTS® Type H Horizontally-split Multistage Compressor,” Houston, 2008. [Online]. Available: <http://www.dresserroots.com>

The mining industry is very reliant on compressed air mostly due to compressed air's versatility and the ease of expanding compressed air systems. Investigations at different gold and platinum mines were conducted to enquire about typical applications of compressed air. Typical pneumatic equipment found to be in operation at South African mines will now be described briefly.

- **Pneumatic rock drills**

Pneumatic rock drills are used to drill holes into rock. Explosives are placed inside the holes before being detonated to break the rock. More than one type of pneumatic drill will typically be used at a mine. Some drills are more suited to development areas of the mine whereas others are mostly used in the production areas (stopes). An example of pneumatic rock drills in operation is shown in Figure 4. A summary of the air consumption and blow rate of some popular rock drills is shown in Table 1.

*Table 1 – Air consumption of a selection of pneumatic rock drills*

<b>Drill name</b>	<b>Air consumption</b>	<b>Blows/minute</b>	<b>Footnote</b>
Boart Longyear SECAN™ S250	4.4 m <sup>3</sup> /minute @ 620 kPa	2200 @ 620 kPa	3
Tranter Rock Drills SECO S215	3.3 m <sup>3</sup> /minute @ 500 kPa	2175 @ 500 kPa	4
Tranter Rock Drills SECO S25	5.3 m <sup>3</sup> /minute @ 500 kPa	2000 @ 500 kPa	5

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<sup>3</sup> Boart Longyear, "SECAN S250: Stoper Drill," South Jordan, UT. [Online]. Available: <http://www.boartlongyear.com>. [18 May 2011].

<sup>4</sup> Tranter Rock Drills, "S215 Rock Drill," Johannesburg, South Africa. [Online]. Available: <http://tranterenergyandmining.co.za>. [18 May 2011].

<sup>5</sup> Tranter Rock Drills, "S25 Rock Drills," Johannesburg, South Africa. [Online]. Available: <http://tranterenergyandmining.co.za>. [18 May 2011].



*Figure 4 – Pneumatic rock drills in operation*<sup>6</sup>

- **Pneumatic loaders**

Pneumatic loaders are also known as rocker shovels or mucking machines. The loaders are usually track-bound and can only be used where railway tracks are available [12]. An example of a loader is shown in Figure 5.



*Figure 5 – Eimco 26B loader*<sup>7</sup>

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<sup>6</sup> Anglo Platinum limited, “2007 Annual report”, 55 Marshall Street, Johannesburg, 2001, South Africa

<sup>7</sup> Trident SA, "Eimco 26B Rocker Shovel", Germiston, South Africa. [Online]. Available: <http://www.tridentsa.co.za/pdf/26B.pdf>. [2 July 2010].

Loaders are used to lift rock from the floor to other material-handling equipment such as hoppers that are also rail-bound and are used to transport the rock to tipping points.

- **Pneumatic cylinders**

Pneumatic cylinders are sometimes used to actuate chutes and doors found on ore-handling systems [13]. Pneumatic cylinders are also used to operate railway track switches at some mines. An example of a pneumatic cylinder installed on a door of a loading box is shown in Figure 6.



*Figure 6 – Pneumatic cylinder installed on a loading box<sup>8</sup>*

- **Ventilation and cooling**

Compressed air is also sometimes used for cooling and for providing fresh air in underground working areas [14]. Open-ended pipes and compressed air ventilators are sometimes used to provide cooling.

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<sup>8</sup> Photo taken at a South African mine

A further concern at deep-level gold and platinum mines is the use of compressed air for refuge bays. Refuge bays are provided as a place of safety during underground emergencies such as fires. An example of an underground refuge bay is shown in Figure 7. An estimated fresh air supply of eighty-five litres per minute is required for each person occupying a refuge chamber. The ideal pressure inside refuge bays is between 200 kPa and 300 kPa to prevent toxic gases from entering the refuge bay during an emergency [15].



*Figure 7 – Underground refuge bay<sup>9</sup>*

- **Processing plants**

Gold and platinum processing plants are used to extract the valuable products from the ore. Processing plants are normally situated close to mining operations. Processing plants use compressed air for instrumentation, agitation and so forth. Gold plants consume between 0.08 m<sup>3</sup>/s and 0.7 m<sup>3</sup>/s of compressed air on a continuous basis throughout a typical working weekday [13]. A constant air pressure is required by most processing plants.

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<sup>9</sup> Photo taken at a South African mine

The processing plants of the gold and platinum mines are operated with minimal stoppages in the cycle to ensure uniform recoveries [16]. Compressed air for processing plants is often supplied by the same compressed air ring that feeds the shafts.

- **Other applications**

A vast array of other pneumatic equipment is available for use in the harsh mining conditions. One of the mines investigated even made use of a pneumatic engine starter to start the diesel engine of an underground locomotive. An example of a pneumatic engine starter is shown in Figure 8.



*Figure 8 – Example of pneumatic engine starter<sup>10</sup>*

Pneumatic winches are also used at some mines for the lifting of heavy equipment. An example of a pneumatic winch is shown in Figure 9.

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<sup>10</sup> Ingersoll Rand, “Engine Starting Systems”, Dublin, Ireland. [Online]. Available: <http://www.ingersollrandproducts.com>



Figure 9 – Pneumatic winch<sup>11</sup>

The availability of compressed air provides opportunities for misuse such as cooling in hot working environments. The unregulated consumption of compressed air combined with inefficiencies during the generation and reticulation present many opportunities for energy saving projects.

The influence of the different variables and constants that determine compressor power consumption will be discussed to highlight possible focus areas to reduce compressor power consumption. Compressor power consumption can be calculated using the following equation [17]:

Equation 1:

$$P_{electrical} = \frac{\dot{m}_{air} W_{comp.in}}{\eta_{motor}}$$

Where

$P_{electrical}$  = Electrical power (kW)

$\dot{m}_{air}$  = Compressed air mass flow rate (kg/s)

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<sup>11</sup> Ingersoll Rand, “Classic Winch Series”, Dublin, Ireland. [Online]. Available: <http://www.ingersollrandproducts.com>

$w_{comp,in}$  = Energy required to compress a unit mass of air (kJ/kg)

$\eta_{motor}$  = Efficiency of the electrical motor

A reduction in the energy required for compressing a unit mass of air, or a reduction in the mass flow rate, will reduce the power consumed by a compressor. An improvement in the motor's efficiency will also result in a reduction of compressor power consumption. The equation to calculate the energy required to compress air will be analysed to determine possible focus areas to reduce power consumption. The amount of energy required to compress a unit mass of air can be calculated with the following equation [17]:

Equation 2:

$$w_{comp,in} = \frac{nRT_{inlet}}{\eta_{comp}(n-1)} \left[ \left( \frac{p_2}{p_1} \right)^{(n-1)/n} - 1 \right]$$

Where:

$w_{comp,in}$  = Energy required per unit mass of air (kJ/kg)

$n$  = Polytropic compression exponent

$R$  = Gas constant (0.287 kJ/kg.K)

$T_{inlet}$  = Inlet temperature (Kelvin)

$\eta_{comp}$  = Compressor efficiency

$p_2$  = Compressor discharge pressure (kPa)

$p_1$  = Compressor inlet pressure (kPa)

The polytropic compression exponent varies between 1 and 1.4 for compressors with intercooling. The compression exponent for isentropic compression is 1.4. A compressor with a polytropic compression exponent of 1.01 would require 24% less energy to compress one unit mass of air than isentropic compression [17].

The most common type of compressor used at deep-level mines is a multistage centrifugal compressor. Multistage centrifugal compressors use intercooling between the different compression stages. The aim of multistage compression with intercoolers is to obtain a polytropic compression exponent as close to 1 as possible. The design of the compressor will therefore determine the polytropic compression exponent [17]. Proper maintenance to the cooling systems is required to ensure that the polytropic compression exponent does not deteriorate over time.

A compressor's efficiency is a fixed value that depends on the design of the machine. This study did not focus on changes to the compressor to improve the efficiency of the compressor. It would, however, be possible to change the discharge pressure of the compressor by changing the set point of the compressor control system. Equation 1 also indicates that the compressed airflow demand influences compressor power consumption. The compressed airflow demand will be analysed further.

The mass flow rate ( $\dot{m}$ ) in kg/s through a leak at a system pressure of at least two times the atmospheric pressure can be calculated by using the following equation [17]:

Equation 3:

$$\dot{m}_{air} = C_{discharge} \left( \frac{2}{k+1} \right)^{\frac{1}{k-1}} \frac{P_{line}}{RT_{line}} A \sqrt{kR * 1000 \left( \frac{2}{k+1} \right) T_{line}}$$

Where:

- $\dot{m}_{air}$  = Compressed air mass flow rate (kg/s)
- $C_{discharge}$  = Discharge coefficient
- $k$  = Specific heat ratio
- $P_{line}$  = Line pressure (kPa)
- $R$  = Gas constant (0.287 kJ/kg.K)
- $T_{line}$  = Line temperature (Kelvin)
- $A$  = Minimum cross-sectional area (m<sup>2</sup>)

The value of the discharge coefficient typically ranges from about 0.6 (for a hole with sharp edges) to about 0.97 (for a well-rounded circular hole). The coefficient will therefore depend on the physical properties of the leak. The specific heat ratio for air is 1.4 and is a constant. The gas constant will also remain unchanged regardless of changes to the system. Changes to the line temperature will influence the mass flow rate through the system [17].

The most obvious approach to reduce compressor power consumption would be to decrease the number of leaks or the sizes of the leaks. A decrease in system pressure would also result in a reduction in compressed air consumption.

### **1.2 Existing energy saving initiatives on compressed air**

It is evident from the previous section that much can be done to improve the efficiency of mine compressed air systems. The opportunity to save electricity costs through the implementation of energy efficiency measures makes it financially viable to implement a wide variety of projects. Some claim that industrial compressed air systems have the third largest energy savings possibility [18]. The international accepted savings opportunity for large compressed air systems is 15% [19].

Leaks are said to account for 10-30% of compressed air losses in industrial compressed air systems [11]. Compressed air leaks result in excessive power consumption and poor system performance (such as reduced system pressure). Effective leak management reporting and control is therefore of key importance to minimise unnecessary power consumption.

Energy efficiency audits conducted on industrial processes often find that compressor control systems result in inefficient compressor operation [7], [11], [19], [20]. It is estimated that compressor power consumption in some industrial facilities could be reduced by 15-25% by merely stopping compressors that run unnecessarily [21].

Upgrades to the compressor control systems on mine compressed air systems have resulted in energy savings of as much as 47% [22]. Savings of up to 8.26 MW have been claimed for projects where control valves were used to reduce compressed air demand [13]. Claims have been made that an increase in compressed air system pressure could result in energy savings [23].

It is estimated that 50-60% of the heat generated by a compressor can be recovered and applied to alternative uses such as water heating [11]. The compressor stations at many mines are, however, located too far away from other buildings to make use of the generated heat.

Cooling systems are required to ensure efficient operation of the compressor system. Improper maintenance of the cooling system can result in inefficient operation. Scale build-up is said to account for some inefficiencies. An energy efficiency improvement of 5-15% is being claimed by a water treatment system company [24].

Electric rock drills are considered as alternatives to pneumatic drills due to reduced energy consumption and lower noise levels [25]. Hydropowered drills are also considered to be more efficient than pneumatic drills [26].

Compressed air system audits conducted in New Zealand found that 50-70% of energy efficiency savings are obtainable from demand side improvements. The capital costs for the implementation of demand side initiatives were also said to be much cheaper than supply side initiatives. Typical paybacks for demand side projects were on average less than six months compared to payback periods of more than three years for supply side projects [19].

The correct combination of compressors used to supply a specific demand can also lead to energy savings. This approach can be best described by analysing results of an energy efficiency study conducted on a mine compressed air system. Observations of Figure 10 reveal that there is surplus compressed air supply during certain times of the day. This can be mitigated by running a different compressor combination [27].

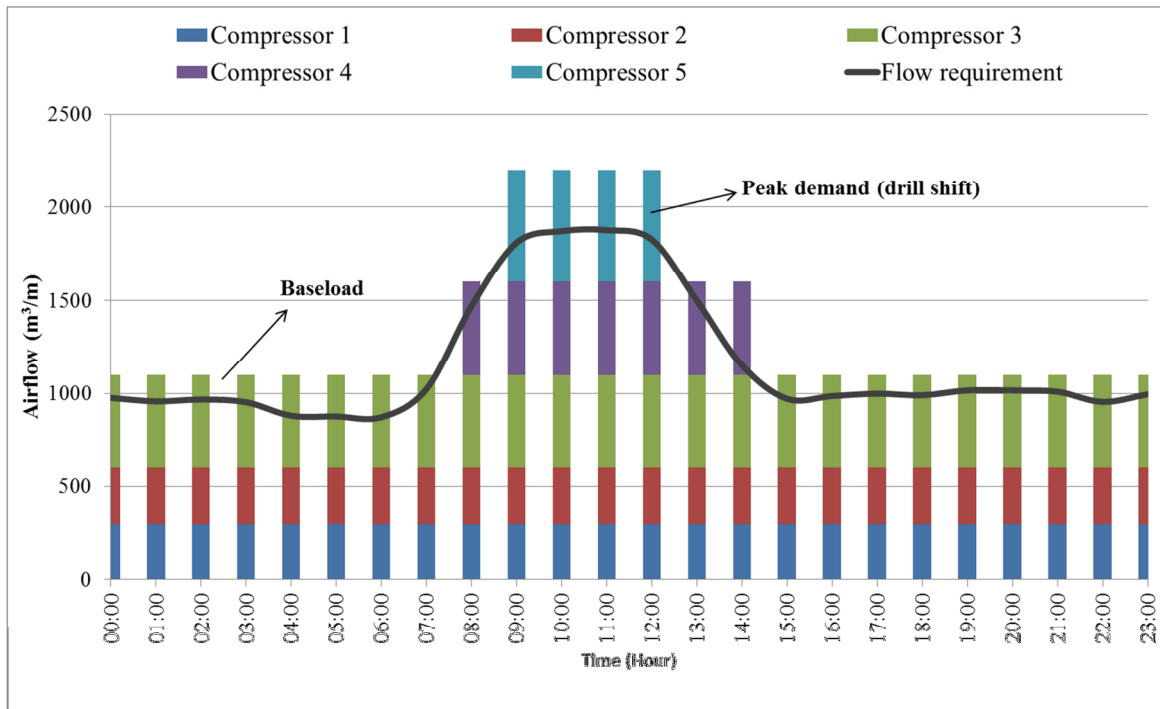


Figure 10 – Inefficient compressor selection for the specified flow [27]

A proposed revised compressor combination for the same system is shown in Figure 11. The first observation indicates that one less compressor is required throughout the day. The flow demand during the peak period is matched with the supply. Another observation indicates that there is still an oversupply of compressed air during the morning shift. No explanation was given in the specific study as to why the air supply from Compressor 2 could not be lowered to the values obtained for Figure 10. It could be possible that the compressor controller was unable to further throttle the supply [27].

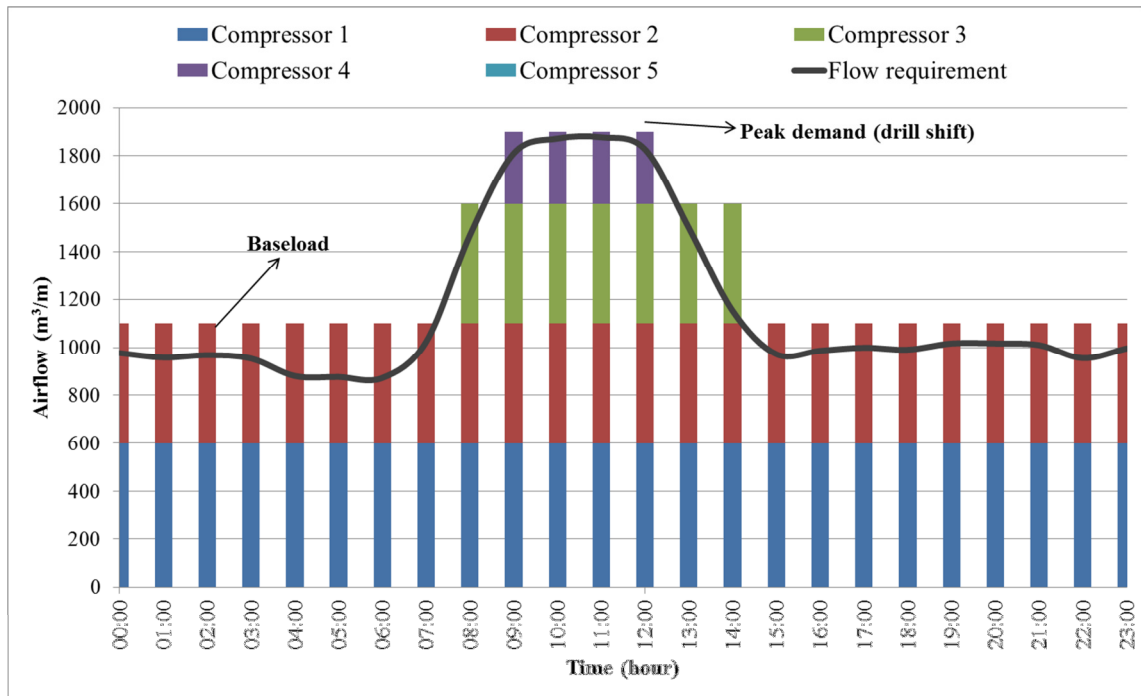


Figure 11 – Improved compressor selection for the specified flow [27]

Information published from a study that involved the replacement of an oversized compressor with a reduced size compressor at a manufacturing plant was investigated. The initial system comprised three identical centrifugal compressors each capable of delivering up to 3 058 m<sup>3</sup>/h at 862 kPa. The existing compressors were able to throttle delivery down to 2 379 m<sup>3</sup>/h by making use of inlet control valves [28].

The compressed air demand for the plant is approximately 3 400 m<sup>3</sup>/h during normal operating conditions. One compressor operating at maximum capacity would be insufficient; two compressors would generate more compressed air than required - this resulted in unnecessary compressor blow-off and high electricity costs [28].

The study showed that cost savings could be realised by an additional smaller compressor that would satisfy the normal operating system requirements. An average daily saving of 200 kW was claimed due to the installation of the new smaller compressor. This equated to a saving of approximately 30% compared to the initial system set-up [28].

The installation of variable speed drives (VSD) could result in a reduction in compressor power consumption. Claims have been made that the payback for the VSD system is less than three years. These claims are based on the assumption that the compressed air demand would be only 75% of the rated flow for most of the time. These claims were never substantiated by actual results [6].

A steam turbine-driven compressor was retrofitted with an electrical motor in a petroleum processing plant. The steam turbine used to operate at an efficiency of 65%. A VSD drive was installed on the 3 728 kW motor that resulted in a 15% increase in theoretical efficiency. However, actual results were not published [29].

### **1.3 The need for a new integrated approach**

Different measures to reduce compressor power consumption were discussed in the previous section. It is, however, not an easy task to decide which approach should be followed to reduce the electricity costs of mine compressed air systems.

The complexity of mine compressed air systems often results in a misunderstanding of the systems' response to energy saving projects. An example of the misinterpretation of results is where a claim was made that an increase in system pressure could reduce compressor energy consumption [23]. This claim was shown to be inaccurate due to invalid assumptions [30].

Several discussions with mine personnel indicated that no single mine employee knows the exact layout of the compressed air system and the location of all compressed air consumers at the mine. There is seldom one person in charge of the entire compressed air system. Asset registers are also not always updated to show the exact location of all equipment.

Therefore it is common practice that the end-user (for example the stope drill operator) will have little knowledge of anything else but the fact whether his compressed air supply is available or not. Conversations with mine employees confirmed that most of them are unaware of the real costs associated with compressed air generation.

A first approach to identify which measures must be taken is to investigate existing energy saving strategies. The challenge is, however, that a multitude of different energy improvement strategies have already been implemented on compressed air systems. A decision from management to save energy on mine compressed air systems is often tasked to a person without extensive knowledge of the entire compressed air system. This lack of knowledge could result in the implementation of energy saving projects simply based on good sales techniques.

Comparing the feasibility of all the different energy saving options available with their real impact on the system would therefore require extensive resources and can take a long time to complete. Literature regarding ways to reduce compressed air energy use in industrial applications is widely available. Information regarding mine compressed air optimisation is not that widely available.

A summary of typical power conservation measures for industrial compressed air systems has been developed by the United States Environmental Protection Agency. The summary aids the decision-making process when considering different strategies. It lists compressor power consumption strategies in a few easy steps with estimated paybacks for some initiatives. A summary of the steps and an indication towards its application in platinum and gold mines is as follows [31]:

- 1. Implement a combination of the strategies mentioned below**

It is often found that a combination of various methods will result in the best reduction in compressor power consumption. Results of as much as a 50% reduction are claimed [31].

- 2. Make use of cooler intake air**

The intake manifolds for some industrial compressors are located inside the compressor building. The use of cooler outside air as intake has shown to result in savings with paybacks of between five months and two years [31].

**3. Install and/or upgrade compressor controls**

A saving of between 0.8% and 10% can be achieved by improving compressor control systems on typical industrial systems. These upgrades would typically result in payback periods of ten months [31].

**4. Reduce pressure**

Pressure reducing projects resulted in project paybacks of four months with energy reductions of between only 0.5% and 1% [31].

**5. Eliminate/reduce components dependent on compressed air**

Compressed air used for cooling, agitation, transport and air tools were replaced with alternatives such as electrically powered tools. This resulted in an average saving of more than 0.5% with an average project payback of six months [31].

**6. Repair air leaks**

The savings achieved for leak repair varied between different facilities with savings of more than 30% in some instances. Smaller savings of 0.5% were also achieved with paybacks of only three months [31].

**7. Recover wasted heat**

Compressor waste heat has been applied resulting in a saving of approximately 2% with paybacks of ten months [31].

**8. Maintain filters and coolers**

Dirty filters and coolers result in inefficient compressor operation. Regular and proper maintenance will ensure efficient operation [31].

This summary can assist the decision-making process for industrial compressed air energy efficiency projects. The techniques mentioned in this summary were developed for industrial compressed air systems that use reciprocating or screw compressors. A similar optimisation approach to reduce compressor power consumption was developed for typical industrial applications [32].

All of the platinum and gold mines investigated for this study use centrifugal compressors. Some of the techniques could, however, be applied to centrifugal compressors and their associated network systems. Previous efforts to integrate various energy saving initiatives on mine compressed air systems proved that the saving estimations (based on a lack of accurate data; combined with a lack of a total understanding of the compressed air system) can be up to 73% more than the actual savings achieved [33]. Detailed investigations were conducted to develop a simplified approach to integrate different energy saving strategies on mine compressed air systems. More information is provided in Chapter 2.

### **1.4 Contributions of this study**

The contributions of this study are summarised as follows:

#### **1. New integrated strategy for saving initiatives on large mine compressed air systems**

- Some energy saving initiatives on mine compressed air systems are done haphazardly.
- Limited information is available on what the best sequence of actions is that will maximise savings.
- A new implementation procedure was developed to ensure maximum results in the shortest possible time.

#### **2. Methodology to identify savings potential**

- Most mine compressed air systems operate inefficiently.
- These systems are complex networks that extend over large distances.
- Limited information on layouts, sizes, and so forth makes it difficult to simulate using standard simulation packages.
- A new methodology to identify the savings potential on mine compressed air systems, using the limited information available, was developed for this study.

### **3. Refute savings claimed and quantify real benefit**

- Many claim savings from the implementation of certain initiatives.
- Some implementations are often motivated using overstated energy saving predictions.
- This occurs because it is difficult to accurately predict savings.
- A new methodology was established to predict the savings more reliably.
- Using this methodology it was proved that some energy saving ideas do lead to less than promised savings.

### **4. Simplified model to evaluate energy saving initiatives on mine compressed air systems**

- Energy saving projects involves the installation of specialised equipment.
- The viability of implementing energy saving projects is dependent on the return on investment.
- An accurate prediction of the expected impact of energy saving projects is therefore required before a project can commence.
- Standard simulation techniques are time consuming and increase the research costs of energy saving projects.
- The cost of the research cannot be recovered for projects that do not lead to viable projects.
- A simplified approach was developed to reduce the time spent to assess the impact of energy saving projects.

### **5. Real life case studies to prove claims**

- The impact of potential energy saving projects is often overestimated.
- The actual impact of projects would therefore differ from predicted savings.
- The only way to accurately determine the impact of energy saving projects is to implement the projects.
- Energy saving projects based on the integrated strategy were implemented to prove that the calculated savings were realised.

## **1.5 Overview of the study**

A brief overview of the dissertation is given below.

Chapter 1 gives an introduction to the study. An overview of mine compressed air systems was given. Examples of typical pneumatic equipment used in mining were shown.

Chapter 2 focuses on energy saving measures that have been implemented on compressed air systems.

Chapter 3 entails the development of the new integrated approach to reduce compressed air usage.

Chapter 4 gives results obtained from case studies where the technique was implemented.

Chapter 5 gives a summary of the findings and recommendations for further work.