

ENERGY EFFICIENCY OPPORTUNITIES IN MINE COMPRESSED AIR SYSTEMS

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ABSTRACT

TITLE : ENERGY EFFICIENCY OPPORTUNITIES IN MINE COMPRESSED AIR SYSTEMS

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Demand Side Management (DSM) is one of the most viable and sustainable short term methods to address the shortfall in electricity generation in South Africa. This is because DSM projects can be implemented relatively quickly and inexpensively when compared with alternative generation options. This specifically applies to the mining industry.

South African mines presently consume 15% of Eskom-generated electricity. Mine compressed air systems are some of the biggest users, consuming approximately 21% of mine electricity consumption. Electricity savings on compressed air systems are therefore important.

With this study, various Energy Efficiency methods on compressed air systems were investigated. These methods include variable speed drives on compressor motors, temperature control of compressor discharge, minimising pressure drops in the air distribution systems, eliminating compressed air leaks, and optimising compressor selection and control.

The most efficient strategies were identified, taking into account factors such as financial viability, sustainability, and ease of implementation. The best strategies were found to be the optimised control and selection of compressors, minimising compressed air leaks, and the

optimal control of system pressure. These strategies were implemented and tested on large compressed air systems in gold and platinum mines.

Savings of between 10% and 35% on the maximum demand of the systems were achieved. In present monetary terms this translates to as much as R108 million savings for the mines per year at the end of 2009 tariffs. If total mine compressed air electricity consumption can reduce by 30%, it will result in nearly a 1% reduction in total Eskom demand. This shows that mine compressed air savings can make a significant contribution to the drive for Energy Efficiency in South Africa.

SAMEVATTING

TITEL	:	ENERGIE DOELTREFFENDE GEBRUIKS GELEENTHEDE IN MYN KOMPRESSOR DRUKLUG STELSELS
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SOEKTERME	:	DSM, ENERGIE DOELTREFFENDHEID, ENERGIE BESPARINGS, MYN DRUKLUG SISTEME, MYN KOMPRESSOR

Demand Side Management (DSM) is een van die mees doeltreffendste en volhoubare kort termyn oplossing vir die huidige elektrisiteits tekortkominge in Suid-Afrika. Die hoof rede hiervoor is omdat DSM projekte relatief vinnig en goedkoper geïmplimenteer kan word in vergelyking met ander elektrisiteitsopwekking metodes. Hierdie hou spesifiek verband met die mynbou industrie.

Suid-Afrika se mynbou industrie verbruik huidiglik sowat 15% van die totale elektrisiteit wat deur Eskom gegenereer word. Myn druklug stelsels is een van die grootste verbruikers, met 'n gemiddelde verbruik van 21% van die totale myn se elektrisiteitsverbruik. Om hierdie rede is die besparing van elektrisiteit in myn druklug stelsels ongelooflik belangrik.

Tydens hierdie studie is metodes ondersoek om druklug sisteme meer energie doeltreffend te bedryf. Hierdie metodes sluit in, die installering van varierende spoed motors op kompressors, temperatuur beheer op kompressor uitlate, minimering van drukvalle in distrubisie sisteme, eleminering van druklug lekke en optimisering van kompressor seleksie en beheer.

Die mees effektiewe strategieë is geïdentifiseer, gebaseer op finansiële uitvoerbaarheid, volhoubaarheid en die komplikasies van implimentering. Daar is bevind dat die beste

strategieë die optimisering van kompressor beheer en seleksie, minimering van druklug lekke en die optimale beheer van die totale sisteem druk is. Hierdie strategieë is geïmplimenteer en getoets op druklug stelsels by goud en platinum myne.

Besparings wat wissel van 10% tot 35% op die maksimum aanvraag van die sisteem is behaal. Gebaseer op 2009 elektrisiteits tariewe, kan dit lei tot finansiële besparings van so veel as R108 miljoen per jaar. Indien die totale myn druklug elektrisiteitsverbruik verminder kan word met 30% kan dit ongeveer 'n 1% verlaging in die totale Eskom aanvraag bewerkstellig. Dit is dus duidelik dat elektrisiteits besparings in myn druklug sisteme 'n geweldige bydrae kan lewer tot die dryf vir energie doeltreffendheid in Suid-Afrika.

NOMENCLATURE

#	-	Shaft
°C	-	Degrees Celsius
acfm	-	Actual Cubic Feet per Minute
BEP	-	Best Efficiency Point
c/kWh	-	Cent per Kilowatt Hour
CALDS	-	Compressed Air Leak Documentation System
CCR	-	Central Control Room
cfm	-	Cubic Feet per Minute
DME	-	Department of Minerals and Energy
DSM	-	Demand Side Management
ECS	-	Energy Conservation Scheme
EE	-	Energy Efficiency
ESCO	-	Energy Services Company
GHG	-	Green House Gases
GJ	-	Gigajoule
GPS	-	Global Positioning System
GWh	-	Gigawatt Hour
IGV	-	Inlet Guide Vanes
km	-	Kilometre
kPa	-	Kilopascal
kW	-	Kilowatt
kWh	-	Kilowatt hour
LAN	-	Local Area Network
MV	-	Measurement and Verification
m/s	-	Meter per second
m ³ /h	-	Cubic meters per second
ML	-	Mega Litre
MVA	-	Megavolt Ampere

MW	-	Megawatt
NERSA	-	National Energy Regulator of South Africa
NMD	-	Notified Maximum Demand
OCGT	-	Open Cycle Gas Turbine
OPC	-	OLE for Process Control
P & ID	-	Piping and Instrumentation Diagram
PLC	-	Programmable Logic Controller
R	-	Rand
R&D	-	Research and Development
REMS3	-	Real-time Energy Management System
REMS3-CM	-	Real-time Energy Management System – Compressor Manager
REMS3-OAN	-	Real-time Energy Management System – Optimisation of Air Networks
rpm	-	Revolutions per minute
RSA	-	Republic of South Africa
SCADA	-	Supervisory Control and Data Acquisition
SCV	-	Surface Control Valve
TOC	-	Total Cost of Ownership
TOU	-	Time of Use
UCV	-	Underground Control Valve
VSD	-	Variable Speed Drives

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INTRODUCTION



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This chapter will discuss the existing electricity situation in South Africa. There will be a short outline of the effect of electricity generation on the environment and the country's economy. Following that there will be a focus on the corrective measures taken by Eskom to solve the problem of electricity generation shortages.

CHAPTER 1: INTRODUCTION

1.1. Background

In South Africa the demand for electrical power is rapidly outpacing the available generating capacity. Eskom is the primary producer of electricity and one of the top 10 utilities in the world by generating capacity, producing 95% of the electricity used in South Africa [1]-[3]. It is the largest single supplier of electricity in Africa producing more than 45% of the electricity used in Africa [1], [2].

It was predicted that in 2007 electricity consumption by South Africans would create a winter peak demand of 36 606 MW [4]. As of 1 June 2007 Eskom had 38 368 MW available on their grid [3]. This increased to a nominal capacity of 43 037 MW over the last year or two with mothballed power stations re-commissioned and other Eskom initiatives. A net maximum demand of 38 744 MW was recorded in 2008 [5]. It is clear from the information above that any unforeseen circumstances will result in major power failures across the country.

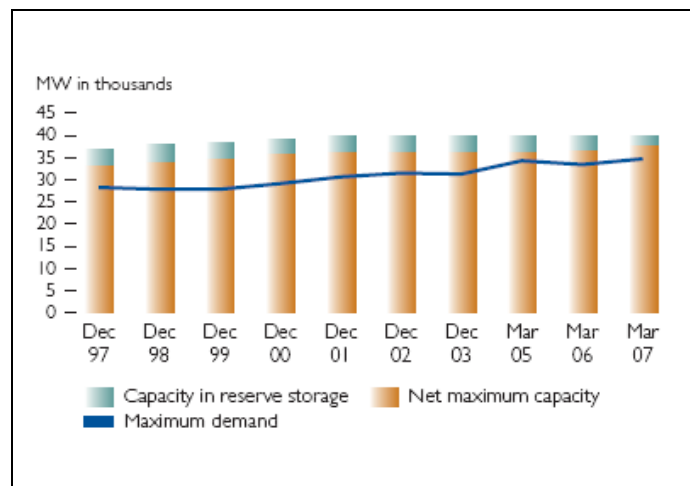


Figure 1: Maximum demand profile and Eskom capacity [1]

In Figure 1 it is clear that the demand for electricity is rising steadily and that Eskom's generation capacity has been stable for the past few years [1]. In Figure 2 the projected growth in the demand for electricity is shown and compared with Eskom's existing capacity [6]. From the graph in Figure 2 it can be seen that there could be a constant increase in the electricity demand of around 3% per year over the next 20 years [6].

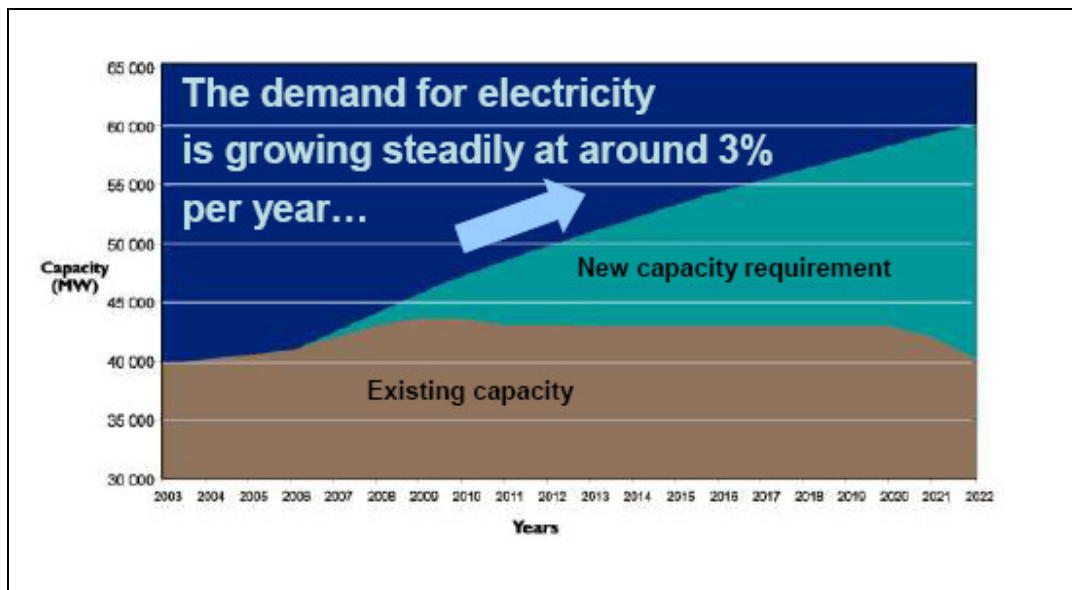


Figure 2: Projected growth of the demand profile of Eskom [6]

With this constant growth in electricity demand, Eskom needs a plan to overcome the electricity generation shortages in the next few years. If nothing is done to change this situation parts of the country may go for days without electricity. In 2007 and the first half of 2008 the electricity supply was still under control with only a few days during which load shedding was necessary. There has been a significant improvement for Eskom over the past 18 months because of the economic downturn which has taken the strain off the utility's power grid.

Load shedding occurs when electricity distribution control is implemented and consumers then have to function without electricity for a few hours during the day in certain areas when the demand exceeds the supply. Different areas get different times in which load shedding is

applied, and because of this distribution control system, most consumers have electricity for most of the day.

1.2. Impact of electricity generation on natural resources

1.2.1. Preamble

Electricity generation has an enormous impact on South Africa's natural resources and the true effects need to be investigated. Some of these effects will be discussed in the following paragraphs.

1.2.2. Impact on fossil fuels

In generating electricity in South Africa, coal has played a major role since the first plants were built in the 1880s [7]. South Africa relies primarily on fossil fuels as an energy resource, with coal providing 88% of the electricity supply [1], [8]. Eskom's reliance on coal can be seen in Figure 3 [1].

In 2007 Eskom budgeted to burn 115.3 Mt of coal, and by the end of the year the actual amount of burnt coal was 119.11 Mt to generate electricity throughout that year [1]. In South Africa coal is the second largest mining sector after platinum group metals, with sales contributing 16% of export revenue [9]. South Africa is the fourth largest exporter of coal in the world, exporting 27% of its production [10]. If coal should be depleted it could have severe effects on the country's economy. It could also mean that SA could become a coal importer rather than an exporter.

Coal reserves are currently limited in South Africa with an estimated 34 billion tons remaining. Most of the coal produced in South Africa is consumed locally, with 41% of the total coal production used by power generation [9].

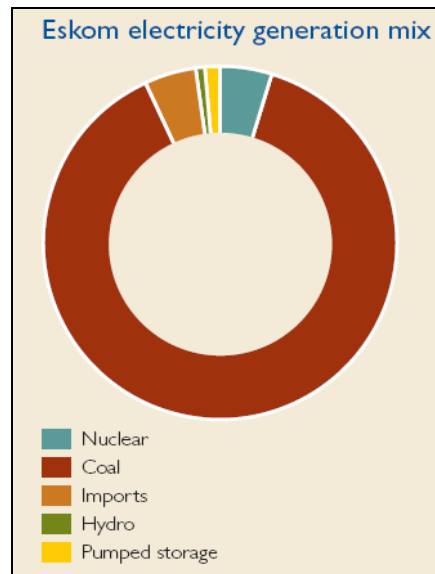


Figure 3: Eskom's electricity generation mix [1]

Part of Eskom's future plans is to reduce the amount of electricity generated from coal to achieve a more diverse electricity mix. The expected plan is to achieve a reduction of 18% from the present 88% in 2007 to 70% by 2025 [1], [11]. This will result in nuclear and renewable energy contributing significantly to the South African grid.

1.2.3. Impact on climate change

Climate change can no longer be regarded as a theory but has to be seen as a reality that needs to be faced and managed [12]. A major cause of climate change is the Greenhouse Effect. This occurs when Greenhouse Gases (GHG) trap the energy from the sun in the atmosphere, thus warming the earth [13], [14]. Figure 4 shows the relative carbon dioxide (CO₂) emissions by Eskom power stations into the atmosphere [1]. A slight improvement from 2006 to 2007 can be seen from this graph and Eskom will target to keep these emissions as low as possible.

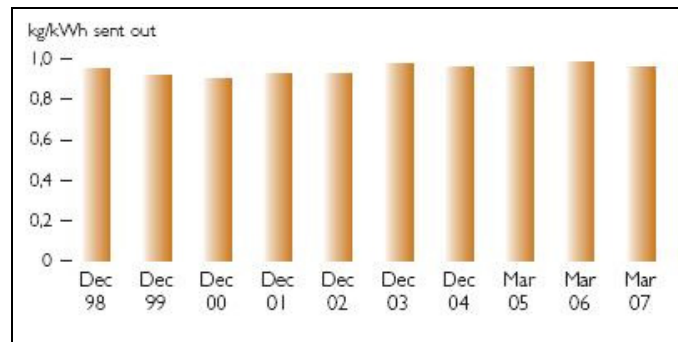


Figure 4: Relative carbon dioxide (CO₂) emissions by Eskom power stations [1]

Most of these gases are released into the air when burning fossil fuels such as coal, oil and natural gas. South Africa emits by far the most GHGs in Africa and is one of the highest carbon emitting countries in the world [14]. These higher temperatures as a result of the Greenhouse Effect will influence rainfall; low rainfall regions will become drier and high rainfall regions will become wetter [15].

1.2.4. Impact on water resources

Another part of nature that is greatly affected by power stations is water resources. South Africa's water resources are limited and scarce. South Africa has been identified as one of the 20 driest countries in the world [16]. The changing rainfall patterns are not helping to improve the scarcity of water.

The need for water conservation and water demand management is of great importance to agriculture, industry, mining and power generation sections. This is especially necessary because the last mentioned sector has the largest expected growth in terms of water demand. In 2003 this sector used approximately 16% of the total water supply in South Africa [17].

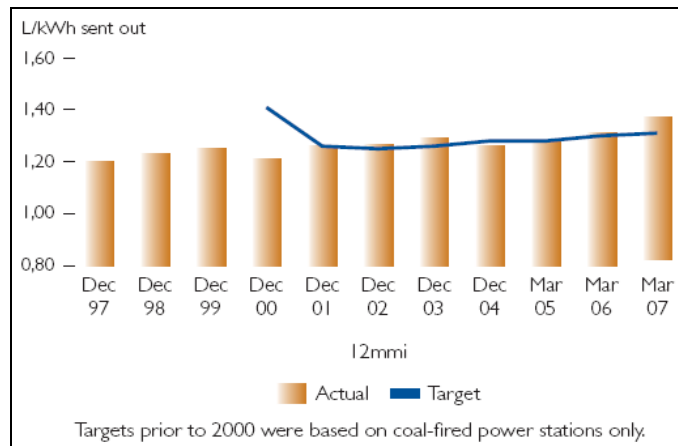


Figure 5: Specific water consumption by Eskom [1]

During 2007 Eskom used 313 064 ML of water to generate electricity in comparison with the 291 561 ML of water used in 2006, which is an increase of 7.4%. Figure 5 shows the increasing water demand for Eskom to generate the growing electricity demand in South Africa [1].

There is an opportunity for water conservation through the use of dry cooling at power stations instead of wet cooling systems, which consume much more water [17].

1.2.5. Renewable energy resources

The only part of nature that can relieve the effects of generating electricity from coal in South Africa is also a natural energy resource. The most important difference and the greatest advantage is that it is renewable. Renewable energy utilises natural resources such as sunlight, wind, tides and geothermal heat as the energy source instead of coal. All these natural resources can be maximised in various types of renewable energy technologies to generate electricity, such as:

- Solar power,
- Wind power,

- Wave power, and
- Hydroelectricity.

It would be of great value to many sectors if other forms of energy sources could start to contribute more to South African electricity generation efforts. Renewable energy resource power stations have a lead time of three years in comparison with the five year lead time of a traditional coal power station [18]. Scattered smaller generation plants would have a shorter lead time than a single coal fired power station to generate the same amount of electricity [18]. Renewable energy is still much more expensive than the conventional coal fired power stations.

In order to reduce the natural and economic impact that coal power stations have in South Africa, the government has to act fast and force the electricity suppliers to expand the use of renewable energy resources.

1.3. Influence of the South African mining industry on Eskom's future

The mining industry is a great contributor to the electricity consumption in South Africa and is growing into one of the largest electricity consumers. From 2007 to 2009 the mining industry consumed approximately 15% of the total electricity generated by Eskom [1], [5], [19], [20]. In Figure 6 the consumption of electricity by the South African mines compared with other industries can be seen [21].

In the South African Energy Efficiency strategy, a target is set for the mining industry to reduce the actual amount of electricity used by between 10% and 15% before 2015. This strategy was set in 2005 and will compel the mining industry to maintain an average year-on-year reduction of 1% to 1.5% until 2015 [22].

Eskom and the Department of Minerals and Energy (DME) developed an Energy Conservation Scheme (ECS), which set a target of 8% for the mining industry [23]. These savings would be in respect of customer’s consumption during the baseline period from October 2006 to September 2007 [23].

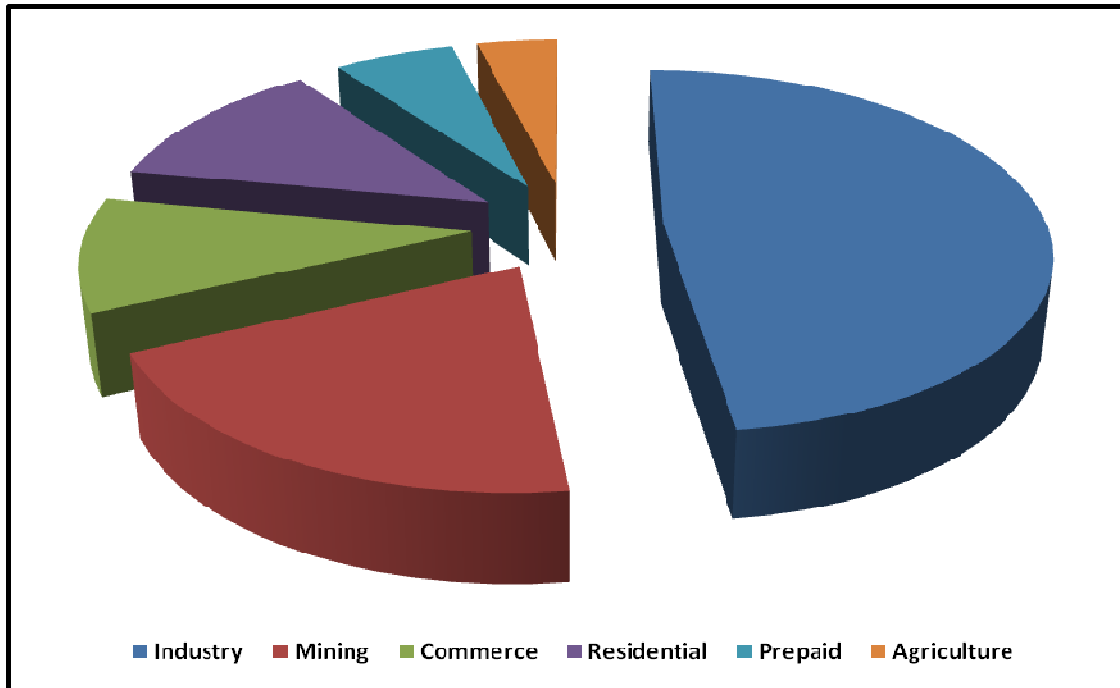


Figure 6: Electricity consumption by the different sectors in South Africa [21]

On average, for the South African mines, electricity supplies 67% of the total energy demand by the mines [22]. It is necessary to determine which mining sectors consume the most electricity.

Figure 7 is an illustration of which mining sectors consume the most electricity [21]. It is easy to see that the gold and platinum sectors are by far the biggest consumers of electricity in South Africa.

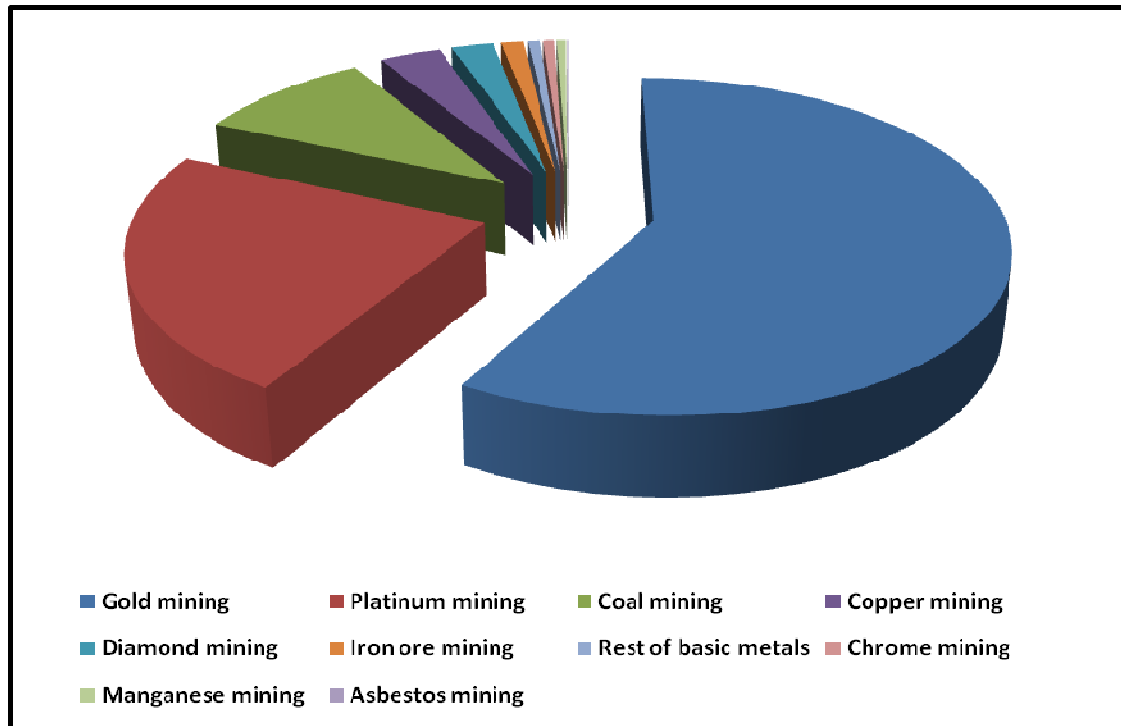


Figure 7: Electricity consumption by individual mining sector [21]

In typical gold and platinum mines, compressors are the main users of electricity, consuming as much as 21.3% of the total electricity consumed by the mine. Table 1 shows the main electricity users on a typical mine and the percentage contribution of each to the total electricity consumed on the mine [24].

Table 1: Main electricity users on a typical mine [24]

Electricity Consumer	Percentage of total electricity consumed by the mine (%)
Compressors	21.3
Underground Mining Systems	18.9
Underground Pumping Systems	17.7
Winding Systems	14.2
Smelting Plants and Mineral-Processing Equipment	13.7
Ventilation and Cooling	7.9
Office Buildings, Hostels and Essential Services	6.3

The mining industry will be one of the biggest contributors to the drastic increase in the expected demand of the next 15 years. Some sources expect that the demand will almost double by 2025 [25].

1.4. Corrective measures taken by Eskom

1.4.1. Preamble

Eskom decided to take action and boost their capacity of electricity generation by investing millions of Rands to expand their electricity generation network.

Over the next five years Eskom plans to spend R150 billion on capacity expansion of which 70% will be used only for generating expansions [1], [26]. Eskom's reserve margin is precariously low at 8% when compared with international standards for reserve margins of 15% [1].

There is a lot to be done and many ways to help Eskom to overcome this existing electricity shortfall. In this section some of Eskom's plans will be discussed.

1.4.1. Return-to-service and refurbished power stations

In order to supply the growing demand for electricity that was expected by the winter of 2008, Eskom needed extra generation capacity in the minimal possible time. Since 2005 Eskom has started to refurbish some of the power stations that were mothballed in the late 1980s and early 1990s [27]. Below are some examples of power stations refurbished or currently being refurbished.

- **Camden** power station has once again been contributing to the national grid since end of March 2007. This power station has a capacity of 1 580 MW and the last unit was commissioned on 31 July 2008 [2], [28].
- **Grootvlei** power station has a generating capacity of 1200 MW and the first of its units was re-commissioned at the end of 2007, with the balance of its units by October 2009 [29].
- **Komati** power station is due to return to service in its full capacity by 2011. It has a generating capacity of 961 MW [1], [2].

1.4.2. New power stations

Further steps Eskom is taking to increase their reserve margin and keep up with growing demand include the building of new power stations. Below are some examples of new power stations.

- The construction of two Open Cycle Gas Turbine (OCGT) power stations started in the Western Cape at Atlantis (**Ankerlig** power station) and Mossel Bay (**Gourikwa** power station). These power stations will contribute a total of 2 053 MW [1]. These stations had already opened in October 2007 and since then another seven units have been added and were commissioned in May 2009 [19].
 - A new pump storage scheme near Ladysmith in the Drakensberg, **Ingula**, is scheduled for completion by 2012 and will serve as a peak-load plant adding 1 352 MW for peak electricity demand [19].
 - In May 2007 construction started at the new coal-fired base-load, **Medupi** power station in the Lephalale (Ellisras) area. The station will deliver a minimum of 4 500 MW to the overall system, and the first units will come into service in 2011 [1]. It is also the first new coal-fired power station built by Eskom in the last 20 years.
 - The most recent power station is the new coal-fired base-load, **Kusile** power station near the town of Witbank in Mpumalanga. It will consist of six generating units that will generate a total of approximately 4 800 MW. The first unit is scheduled for
-

completion in 2013. Final completion is scheduled for 2017. It will be the first power station to have flue gas desulphurisation technology installed [31].

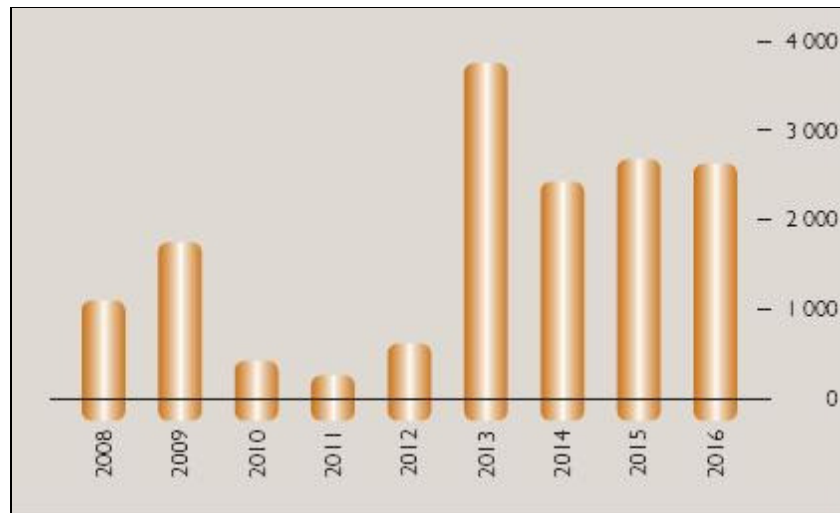


Figure 8: Eskom planned capacity expansion (MW) [5]

Figure 8 shows a summary of the planned capacity expansion up to 2016. The economic downturn has affected organisations across the globe and forced Eskom to postpone three projects, namely Tubatse Pumped-Storage Scheme, Majuba Rail, and Sere Windfarm, due to funding shortfalls [28], [30].

1.4.3. Demand Side Management

Definition: Demand Side Management (DSM)

Planning, implementing, and monitoring activities to encourage consumers to use electricity more efficiently, including both the timing and level of electricity demand [1].

One of Eskom's first initiatives to solve the electricity problem in South Africa was to implement a programme called Demand Side Management (DSM). DSM is the process by which electricity utilities achieve predictable changes in the demand and load profile of

customers [32]. DSM is not a new concept and has been implemented all over the world since 1980 [33], [34].

In short, Demand Side Management is a way to reduce electricity usage by manipulating the time of use and the efficiency of use of electricity [35]. This brings the benefits of electricity cost reduction and lowers the electricity usage of the consumers [36]. If electricity is managed by these DSM standards, the electricity supply to customers is more stable and the electricity suppliers are more able to supply the demand for electricity.

In order to control the demand for electricity Eskom inaugurated a time of use (TOU) tariff structure. This tariff comprises different electricity rates for the same tariff component during different time periods and seasons [37]. This TOU tariff structure influences the decision makers of the electricity users and supports the Eskom DSM initiative by steering the electricity user in the right direction. Eskom has two peak periods during a 24 hour day in which the system demand is relatively high. In Figure 9 these two peak periods are clearly shown, with the first peak from 07:00 to 10:00 and the second, shorter but higher peak, from 18:00 to 20:00 [1].

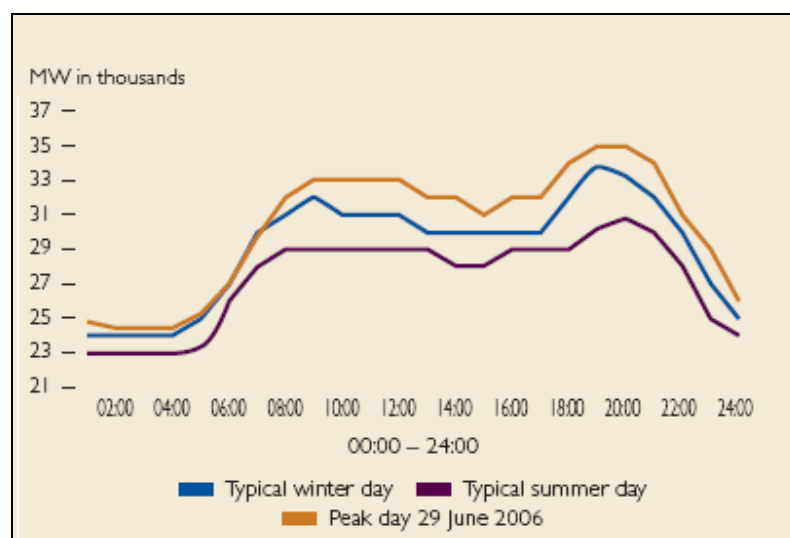


Figure 9: Typical electricity demand profile for a 24 hour period [1]

Eskom has three urban tariffs to motivate changes at the times when high demands are experienced, namely Megaflex, Miniflex and Ruraflex [38] by means of the TOU tariff structure. These tariffs have three time-of-use periods which are peak, standard and off-peak. In Figure 10 these three time-of-use periods for the tariffs are illustrated for weekdays, Saturdays and Sundays [38].

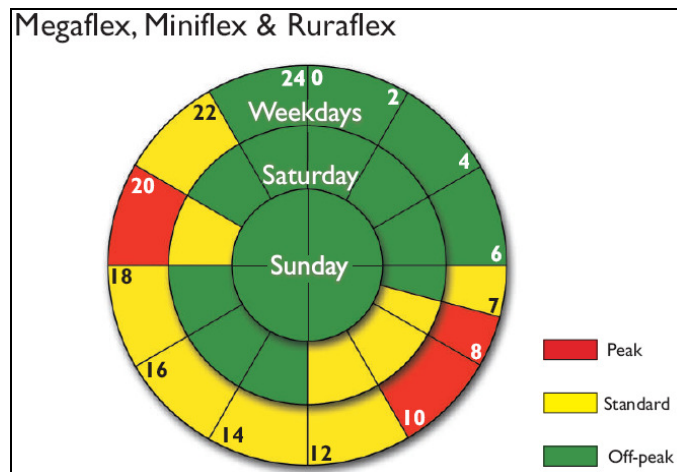


Figure 10: Illustration of Eskom’s three time-of-use periods [37]

Most of the South African mines use the Megaflex tariff structure because of the high electricity demand on the mines, and therefore more attention is given to this TOU structure.



Megaflex is applicable to any urban consumer requiring a TOU electricity tariff with an NMD (Normal Maximum Demand) greater than 1 MVA and that is able to shift load [38].

Table 2: Eskom's Megaflex active electricity charge - 09/10 [38]

High Demand Season	TOU-PERIOD	Low Demand Season
111.11 c/kWh	PEAK	31.05 c/kWh
28.91 c/kWh	STANDARD	19.04 c/kWh
15.47 c/kWh	OFF-PEAK	13.34 c/kWh

From Table 2 it can be seen that there are two different demand seasons, namely high demand and low demand season [38]. High demand season is from June until August and the low demand season is from September until May [38]. The high demand season covers the winter months during which the electricity demand is much higher than during the summer months. This higher demand during winter months is illustrated in Figure 9.

One objective of Demand Side Management is to produce a load-shape change. The success of the programme rests with balancing the needs of the electrical utility and the customer [39]. The requirement of the utility is to save as much electricity as possible while the customer does not want the production to be effected. DSM will have the same effect as a new generation plant for Eskom and is often referred to as a virtual power station [32].

This TOU intervention from Eskom does not change the amount of electricity used by the mining industry itself. But it can set the base for DSM projects to have a greater impact on the national electricity situation by steering the decision makers towards electricity savings. This encourages the consumer to use more electricity in the cheaper periods and less electricity in the more expensive peak periods.

DSM interventions can be divided into four broad categories. These four categories are load shifting (Figure 11a), peak clipping (Figure 11b), Energy Efficiency (Figure 11c), and valley filling (Figure 11d) [6], [36].

In the Eskom DSM programme the biggest contributors to electricity savings are load shifting and peak clipping. Only now during the last few years have Energy Efficiency projects been getting higher priority.

Eskom appoints an Energy Services Company (ESCO) to identify, design, implement and manage DSM projects in various industries [40]. It is the core business of an ESCo to sell energy services [14]. Eskom provides the funding for this project, in accordance with the

available electricity savings on the specific project. This funding includes the cost for the ESCo and the necessary infrastructure to achieve the electricity savings.

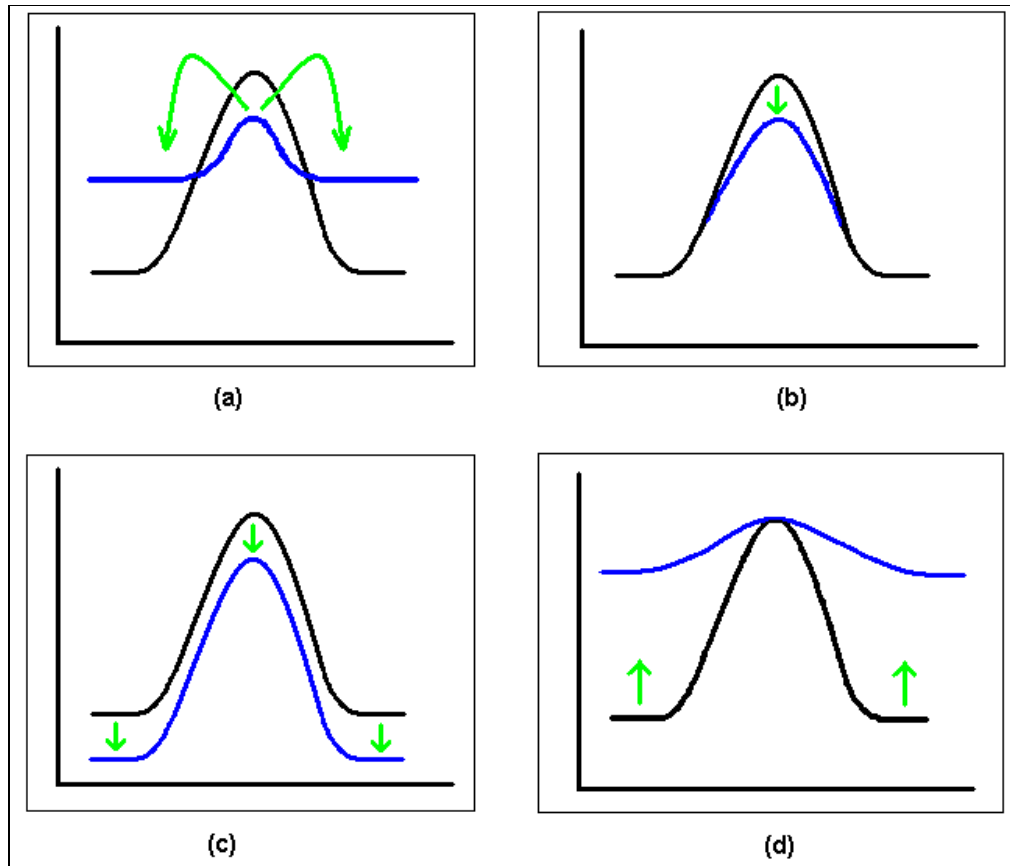


Figure 11: The different categories of Demand Side Management [6]

In Figure 12 a comparison is shown between the different TOU prices of electricity for both the high and low demand seasons. During the winter months electricity is about 3.85 times more expensive than in the summer months, and the winter peak rate is 7.2 times higher than the off-peak rates.

It is clear that it would be beneficial to any urban consumer to lower their electricity demand, especially during Eskom's allocated peak hours and high demand season.

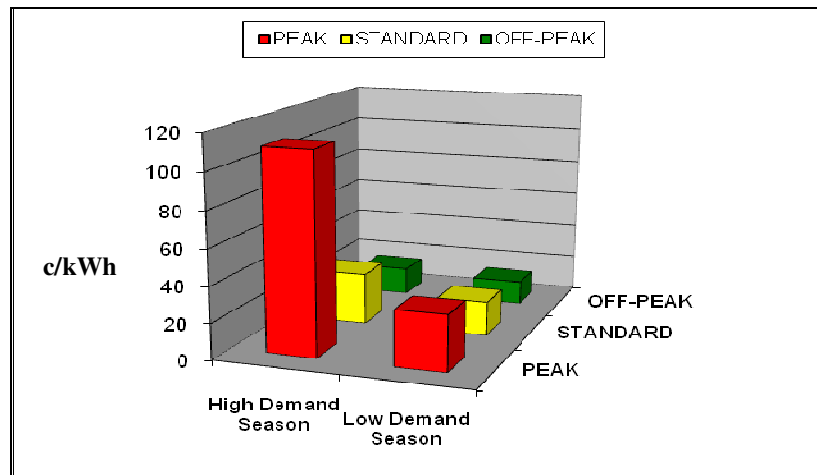


Figure 12: Comparison of time-of-use tariffs

It is understandable from all of the above that Demand Side Management can be beneficial to both the electricity consumers and suppliers. The electricity consumer (end-user) can save substantially on electricity costs and the power utility will experience a reduction in electricity demand during the set peak hours. Eskom clearly needs this lowering in demand when looking at the amount of load shedding that occurred during 2007 and the start of 2008.

1.4.4. Other solutions and possibilities

Eskom also has other solutions to this problem, but they are mostly long term solutions which will not contribute much to the overall system in the short term. These solutions will increase Eskom's reserve margin but can only be achieved in a few years from now.

- A large amount of money is being invested in research on the Pebble Bed Modular Reactor (PBMR) in South Africa. This is a nuclear power generator, and the first demonstration model will be built at the site of Koeberg. The planned capacity of this demonstration model is expected to be 165 MW [2]. If the approval of the environmental impact study is obtained by 2013 construction should start in 2014 [41].

- Wind energy is also a renewable source of energy that is not used effectively in South Africa. Eskom built a wind energy test facility in the Western Cape near Atlantis with an installed capacity of 5.1 MW, named the Klipheuwel Wind Energy Demonstration Facility [42]. In South Africa the east and west coast regions are considered the best wind energy areas [43]. The wind resource is described as moderate and extremely seasonal. All of this results in relatively low capacity averages for wind power generation in South Africa. It is also only in the premature stages of development in South Africa and has some potential to be expanded.
- Solar energy has great potential in Southern Africa and the three countries with the most significant solar resources are RSA, Namibia and Botswana [43]. Some of the highest levels of solar radiation in the world are found in South Africa. The average daily solar radiation varies from 4.5 to 6.5 kWh per square meter [44], [10]. In some places like Upington the daily average solar radiation is about 8.17 kWh per square meter [45]. Solar energy is still in the feasibility assessment phase and remains very expensive to commercialise.
- Wave power is by far the most promising ocean energy source in South Africa. Professor Deon Retief from the Stellenbosch University said that 8 000 to 10 000 MW of electricity could be generated on the west and south coasts of the Cape [46]. South of Saldanha Bay, a stretch of 40 km ocean was identified to be suitable to generate 770 MW [46]. It will be done at a cost of 60 to 75c per kWh [46]. This is a renewable energy source that is not being viewed as proven by Eskom, but will get the necessary attention in the near future.

1.5. Problem statement and objectives of this study

The electricity situation in South Africa and other parts of the world has been described in the preceding chapter. The problem that exists is the efficient management of electricity in any sector. Reserve generating capacity is below acceptable levels and a reliable electrical supply to the consumer can no longer be guaranteed. An example of the negative effect this has on the SA economy is the recent cancellation of the electricity supply contract for the COEGA planned Aluminium Smelter [47].

DSM implementation will benefit Eskom in the long term to meet the growing electricity demand and build up a reserve margin of more than 15% in the next few years. It will also benefit the electricity user when the continuously increasing electricity prices are taken into account.

In the mining industry there exists a great potential to save large amounts of electricity for the end-users and Eskom. The DSM programme is used to fund projects in these cases to achieve the best savings possible.

Throughout this thesis opportunities to save electricity will be investigated in compressed air systems in the mining industry. Energy Efficiency opportunities will be identified and tested in actual systems on South African mines.

The main objectives of this thesis are to:

- Identify DSM opportunities in mine compressed air systems, especially how this can be expanded into Energy Efficiency opportunities.
 - Investigate the impact of these opportunities on the Energy Efficiency of the mine's compressed air systems.
 - Verify the feasibility of the identified opportunities on actual South African gold and platinum mines.
-

- Verify the advantages of the Energy Efficiency opportunities for the client and Eskom.

1.6. Overview of this document

This section will give a short overview of this thesis and the major areas discussed in each chapter.

Chapter 1 discussed the existing electricity situation in South Africa. There was a short outline of the effect of electricity generation on the environment. Then the chapter focused on the corrective measures taken by Eskom to solve the problem of electricity generation shortages.

Chapter 2 is necessary to understand why compressed air is needed in mines and it is an important step before an investigation can be done on how to save electricity on compressed air systems.

Chapter 3 will discuss the various methods identified to optimise mine compressed air systems and how Energy Efficiency can be introduced into these systems.

Chapter 4 will discuss the results from various case studies to illustrate the successful implementation of Energy Efficiency projects in South African mine compressed air systems.

Chapter 5 will conclude this thesis and make recommendations for any other further studies in this field.

DSM OPPORTUNITIES ON MINE COMPRESSED AIR SYSTEMS



(Photo taken by HVAC International Personnel)

In this chapter it is necessary to understand why compressed air is needed before an investigation can be conducted on how to save electricity in compressed air systems.

CHAPTER 2: DSM OPPORTUNITIES ON MINE COMPRESSED AIR SYSTEMS

2.1. Introduction to a typical mine compressed air system

In most cases in the mining industry the air is compressed during four or more stages in a compressor to pressures of between 300 kPa and 650 kPa. It supplies motive force, and is preferred to electricity because it is safer and more convenient.

In the mining industry compressors are the main electricity consumers, especially on the gold and platinum mines in South Africa. The purpose of compressed air will vary from mine to mine, but the most common uses of compressed air are: [48]:

- Pneumatic underground drilling
- Mechanical ore loaders
- Carriage systems or loading boxes
- Refuge bays
- Pneumatic control systems
- Instrument air

Typical compressed air systems are made up of complex subsystems. A detailed and intensive study will be required in order to optimise and generate electricity savings.

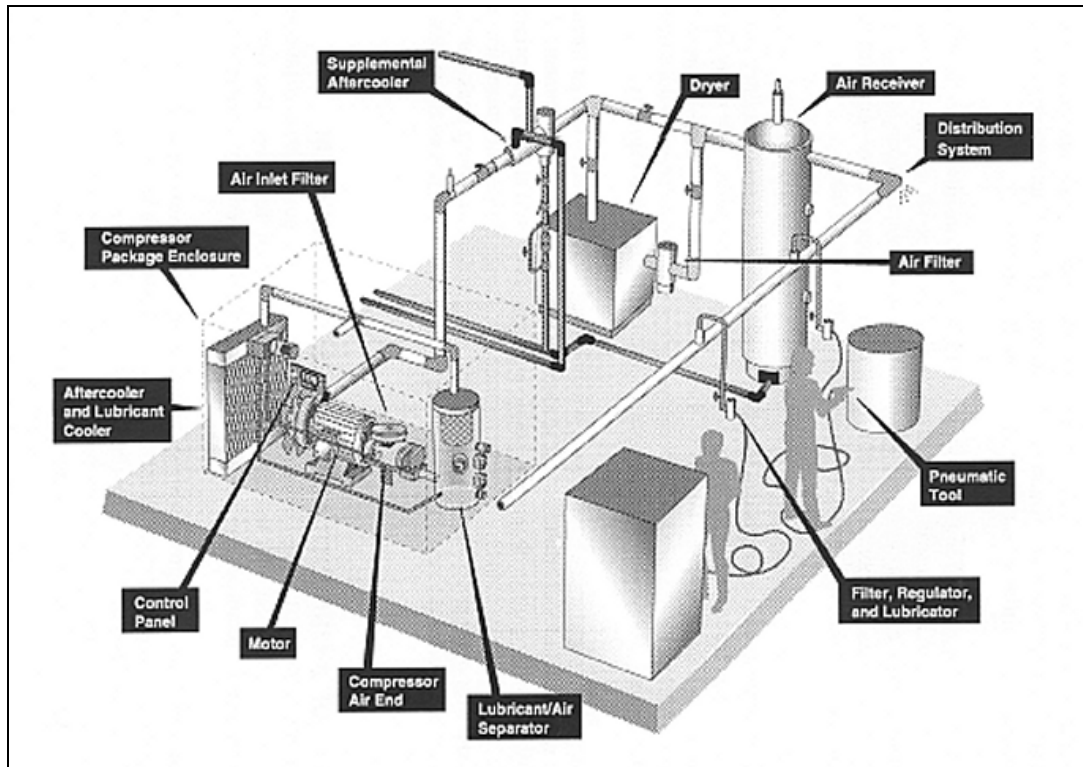


Figure 13: A typical compressed air system [46]

In Figure 13 is an illustration of a typical compressed air system to illustrate the different components that form part of these intricate systems [49]. This is obviously a very small system in comparison with a typical mine compressed air system and only serves as an illustration.

2.2. The operation of compressed air systems in South African mines

2.2.1. Preamble

A compressed air system is one of the most important systems on a typical South African mine because of all the uses for compressed air. The system is also one of the largest electricity users on most gold and platinum mines throughout the world [24].

In order to efficiently save electricity by optimising a compressed air system it is important to understand the operation of a typical system. This can only be done if each part of the compressed air system is studied in some detail.

To improve the understanding of the operation of a typical compressed air system, the following parts will be discussed in more detail:

- The compressor
- Air coolers and dryers
- Distribution systems
- Air consumers

2.2.2. The compressor

The compressor is effectively the most important part of the compressed air system and can be seen as the heart of the system. A compressor is a device that is used to increase the pressure of a compressible fluid. There are many different types of compressors available on the market. Figure 14 shows these different types and their classifications [49], [50].

The most commonly used type of compressor is the continuous flow compressor. The older mines still use the mechanical piston compressor, but in most cases these have been replaced by centrifugal compressors.

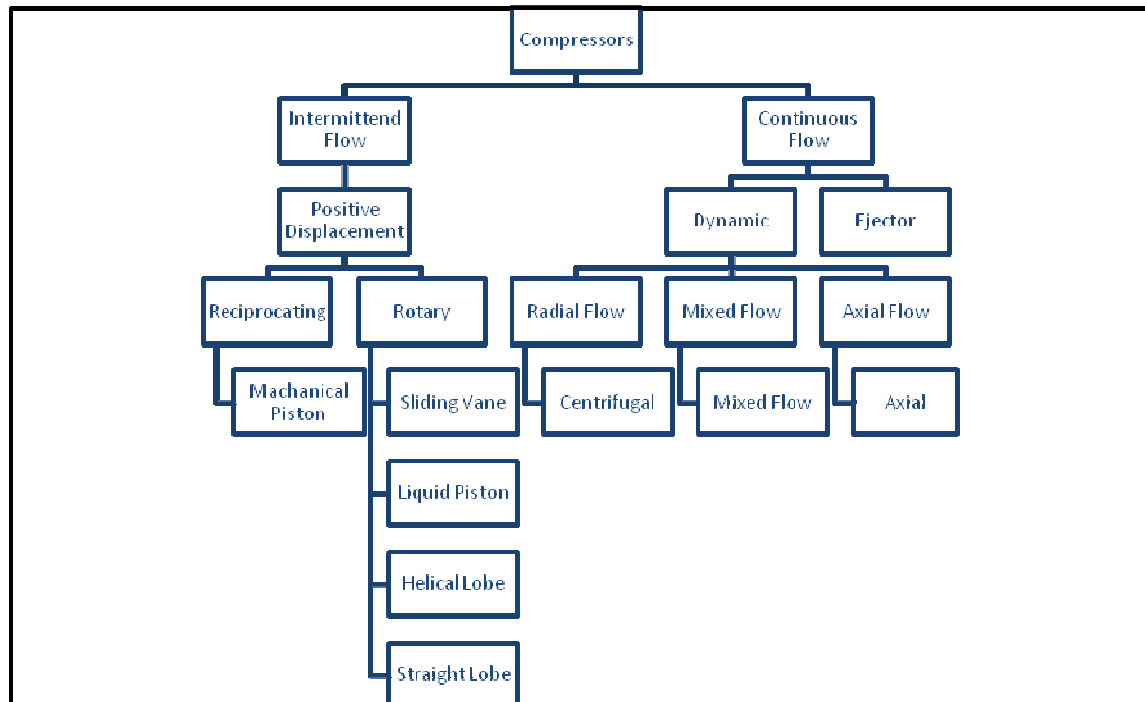


Figure 14: Compressor classification diagram [49]

The centrifugal compressor is very popular in the mining industry due to its proven reliability and smaller size than an equivalent axial flow compressor. The centrifugal compressor is able to deliver 1700 m³/h to 255 000 m³/h at different pressure ratios [50].

During the mid 1970s there was an electricity cost increase around the world which changed the focus and the allocation of compressor development funds from the reliability of machines to the efficiency of machines. This change caused the centrifugal compressor to become the most popularly used compressor in most cases.

Another reason for its popularity is the pressure ratio in comparison with other machines, which is probably the best parameter to compare compressors. The centrifugal can have pressure ratios of as high as three and above in a single-stage compressor [50]. Multistage machine usually operate at pressure ratios of less than two per stage.

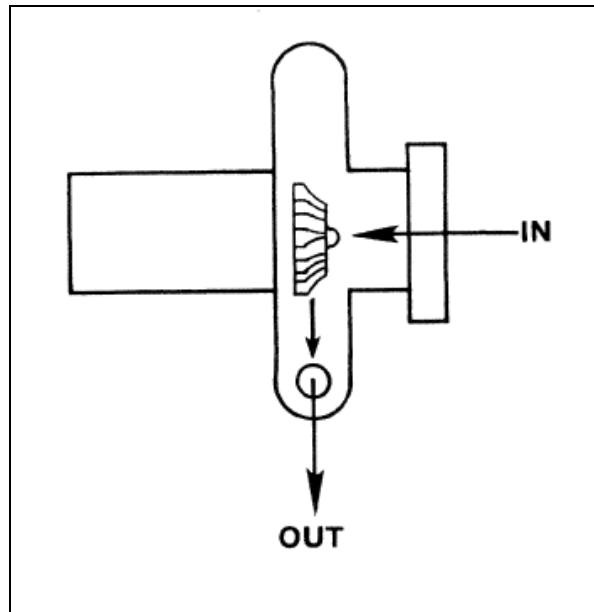


Figure 15: Illustration of a single-stage centrifugal compressor [50]

In the centrifugal compressor the flow through the compressor is turned perpendicular to the axis of rotation; this is shown in the illustration in Figure 15 [50]. The high capacity of flow through these compressors is due to the fact that the flow is continuous through the machine. It is a dynamic compressor which depends on the transfer of energy from a rotating impeller to the air.

Another advantage of these compressors is the oil-free design. The oil lubricated running gear is separated from the air by shaft seals and atmospheric vents. The quality of compressed air is much higher if there are no oil particles mixed into the air during compression.

2.2.3. Air coolers and dryers

Another intricate part of the compressed air system is the air cooler which lowers the temperature of the compressed air after each stage of compression. In Table 3 the outlet temperatures of different types of compressors is shown for ambient inlet temperatures [51].

Table 3: Compressor outlet temperatures [51]

Type of Compressor	Average Outlet Air Temperature (°C)
Oil Flooded Rotary	93.3
Oil Free Rotary	176.6
Two-stage Reciprocating	148.8
Centrifugal	107.2

Compressed air at these temperatures contains large quantities of water vapour. The water vapour condenses as the air is cooled down throughout the system up to the end-user if it is not removed directly downstream of the compressor. In order to reduce this most compressors are fitted with aftercoolers.

The aftercooler is a water or air cooled heat exchanger. In the compressed air aftercooler condensate forms when the air temperature is reduced. In most cases aftercoolers are designed to cool compressed air down within 2.7°C to 11°C of the ambient air temperature [51]. As the compressed air is cooled down in the aftercooler up to 75% of the water vapour condenses [51].

The aftercooler makes it possible to remove the water early in the compressed air system by means of a moisture separator installed at the discharge of the aftercooler. The moisture separator removes most of the liquid moisture and solids. It uses centrifugal force to collect moisture and solids at the bottom of the separator. In most cases the separator is fitted with an automatic drain to remove the collected moisture and solids.

The main functions of the aftercooler are [51]:

- Cool air is discharged from the compressor;
 - Moisture levels of compressed air are reduced;
 - System capacity increases;
 - Downstream equipment are protected from excessive heat;
-

- The risk of hot compressed air pipes igniting a fire is reduced.

Ideally, the aftercooler should be fitted as close as possible to the discharge of the compressor. However, most compressors used on the mines are multistage compressors. After each stage, an intercooler is used to lower the stage outlet temperature and the inlet temperature of the next stage.

When the air is cooled down by the aftercooler there is still some moisture in the compressed air. In order to remove this remaining moisture an air dryer can be installed in the compressed air system.

Compressed air dryers reduce the quantity of water vapour, liquid water, hydrocarbon and hydrocarbon vapour. Moisture is harmful to any compressed air system. Water can damage a compressed air system in several ways [52]:

- Erosion – Piping, valves and other components are eroded by water mist.
- Corrosion – When water mist condenses and combines with salts and acids it forms a highly corrosive solution inside the compressed air system.
- Freezing – Water can freeze in the compressed air pipelines which could shutdown the system, but it is very seldom the case on South African mines.

The damage wet compressed air inflicts on the system can be minimised by drying the air early on in the system. The most common results of this damage to the system are lower productivity, increased maintenance, and higher system operating costs.

Most pneumatic equipment has specified working pressures, dryness levels and a maximum operating temperature to work to its best efficiency. This makes it important to ensure that the system's dryness exceeds the levels required by the equipment it will power. Table 4 indicates some equipment's recommended working dew point [52].

Table 4: Recommended dew point [52]

Application	Pressure Dew Point (°C)
Air motors	-40 to 3.3
Breathing air	-40 to 3.3
Instrumentation (industrial services)	-40
Instrumentation (laboratory services)	-51.1
General services	-73.3 to 3.3

The importance of air cooling and drying becomes very clear in this section. It prevents unnecessary maintenance and damage to the compressed air system.

2.2.4. Distribution system

The distribution system is the second most important part of the compressed air system after the actual compressor. The compressed air is delivered to a main header and then to the individual air users. The distribution system is the link between supply and demand.

The most important element of the distribution system is to deliver the required air flow with the minimum pressure drop. It has to supply an adequate amount of compressed air at the required pressure to all the locations where compressed air is needed.

Compressed air is mainly distributed through a network of pipelines, but the flow experiences friction with the sidewalls of the pipes which results in a pressure drop. Friction loss is proportional to the pipe length and inversely proportional to the pipe diameter. A pressure drop can also be affected by the type of material used to manufacture the pipe, number and type of valves, couplings and bends in the system.

Pressure drops are also caused by corrosion and other system components. It may lead to pressure drops of between 0.34 and 1.7 bar which can affect the efficiency of the system dramatically [53].

In order to prevent major pressure drops there should be thorough audits of all the compressed air users in the network. It is very difficult to determine the exact demand because it will fluctuate beyond the predetermined average demand. This is mainly affected by artificial demand.

Artificial demand is when an excess volume of compressed air is created for unregulated users. Unregulated users include the following [53]:

- All unregulated consumption, including appropriate and inappropriate production usage
- Open blowing
- Leaks
- Points of use with regulators adjusted to their maximum setting
- Tooling

It is important to select the right pipe diameter in relation to the compressed air velocity in the pipeline. The velocity must never exceed 15 m/s in any part of the system. An ideal air velocity would be 10 m/s or less in the main headers and interconnecting piping. The main reason for this is that moisture and debris will not be carried past drain legs and moisture traps into the rest of the system at velocities of less than 10m/s [54].

The distribution system is obviously an essential part of the compressed air system since it could affect the efficiency of any compressed air system.

2.2.5. Air consumers

Air consumers are the main reason for a compressed air system as it uses compressed air as its power source. Compressed air is typically used in the mining industry, as previously mentioned, for the following:

- Pneumatic underground drilling
- Mechanical ore loaders
- Carriage systems or loading boxes
- Refuge bays
- Pneumatic control systems
- Agitation
- Instrument air
- Pneumatic conveying

In all these cases compressed air is used as an alternative power source instead of other common power sources like electricity and hydraulics. In Figure 16 examples of pneumatic rock drills are given.



Figure 16: Examples of pneumatic rock drills¹

The effectiveness of air consumers also influences the efficiency of the entire compressed air system. Therefore it is important to specify the correct pneumatic tool for the required application. For example, cleaning work benches using compressed air is no longer up-to-date. However if compressed air is still being used for such tasks then it is recommended to use optimised jets which achieve the maximum cleaning effect with minimal air consumption.

2.3. Demand Side Management opportunities on mine compressed air systems

2.3.1. Preamble

The scope for DSM on mine compressed air systems is enormous when taking into account the amount of electricity that is being used by these systems. Only 4% of the initial primary

¹ Picture courtesy of: www.industrialpowertoolandrepair.com/air_tools.html

energy is converted to useable energy due to the inefficiencies of power generation by the power utility (34% efficient), transmission/distribution losses and the efficiency of the compressor and piping system [55].

This part of the chapter will discuss and compare a few control strategies that contribute to different DSM opportunities being used in several projects all over South Africa. These control strategies are already being used effectively in Peak Clipping projects as part of the Eskom DSM programme. The optimised control of compressed air systems is often divided into two main groups:

- Supply side control, and
- Demand side control.

2.3.2. Supply side control

2.3.2.1. Preamble

Supply side control refers to the optimised and purposeful control of the amount of compressed air that is being delivered into a compressed air system by the compressors.

This supply side control can be achieved in several different ways, of which the following are the most effective and commonly used control strategies:

- Guide vane control,
- Load sharing, and
- Compressor selection

2.3.2.2. Guide vane control

A compressor delivers a specific mass of compressed air at a certain pressure. When guide vane control is used, the mass flow of compressed air through a compressor varies.

Different compressors use different guide vane controllers, but the most commonly used is the Moore controller. This controller enables the compressor operator to specify a pressure profile according to the requirements of the system. When this 24-hour pressure profile is programmed into the control system the guide vane controller will adapt the compressor delivery accordingly.

There is some danger to this type of control with the phenomenon called compressor surge. Surge is when, for any given speed, guide vane angle or inlet valve position; flow in the system decreases sufficiently to cause momentary flow reversal in the compressor and results in oscillation of air flow through the compressor [50].

This phenomenon is associated with axial and centrifugal compressors and can severely damage the machine if it is not controlled properly. Although there is danger to this type of control it is becoming less of a problem with state of the art technology which prevents the compressor from passing the surge line.

2.3.2.3. Load sharing

In most compressed air systems the number and types of compressors differ, as does the layout of the system and number of end users. All these factors can cause the compressed air system to operate inefficiently. It can also nullify the advantages obtained from using guide vane control to such an extent that they become ineffective.

In order to prevent this from happening, a method called load sharing can be used. Load sharing is the process whereby compressors operating in the same system are operated to equally bear the necessary load. Various methods of establishing load sharing can be used:

- Variable speed drives in compressors.
- Management of intake volume of compressors, i.e. suction valve and the guide vane control.

2.3.2.4. Compressor selection

Compressor selection is the selection of the most efficient compressors in a compressed air system. It will be valuable to operate the most efficient compressors at any given time as they will need less electricity to supply the same amount of compressed air. This will result in the most efficient compressors operating as the base load machines and the less efficient compressors as standby machines.

2.3.3. Demand Side Control

2.3.3.1. Preamble

Demand Side Control refers to the effective control of the distribution and end use of compressed air. This is the most important part in controlling a compressed air system effectively since it is the most difficult part to actively control. The reason for this is that there are many parties involved and much air is wasted in this area of the system. Different people are responsible for the different parts of the demand side control before the air is actually delivered to the end-user.

This effective control of the demand of compressed air causes an upstream pressure build-up which in turn minimises the load on the compressors in the system. The two main techniques used to control the demand side are:

- Surface control valves, and
- Underground control valves.

2.3.3.2. Surface control valves

Surface control valves are usually air control valves in the main header just before it goes into the mine shaft (referred to as the “bank” of the shaft) controlling the amount of compressed air that flows downstream. When these control valves are gradually closed, the pressure upstream of the valves will increase.



Figure 17: Example of a surface control valve system²

² Photo taken by HVAC International Personnel

Figure 17 above shows a surface control valve system installation at Lebowa Platinum Mine in the Limpopo province. In this specific system, the main air valve (larger, bottom valve under the cover plate) is closed and a bypass control valve (smaller, top valve) is throttled to supply the necessary compressed air during mine off-peak times.

2.3.3.3. Underground control valves

Underground control valves are air control valves installed on each working level to efficiently control compressed air on each mining level. When these valves are throttled closed, air pressure will increase upstream of the valve.

This is a more efficient way of controlling the compressed air use since individual levels can be controlled, and in some cases a few of these levels can be completely shut off. This minimises air wastages more effectively than surface control valves.

The basic control of these valves is in most cases the same as the surface control valves previously described, with a main air valve and a bypass valve. During the mine's off-peak times the main air valve is isolated and the bypass valve is controlled according to the compressed air needs of the level.

This control is done via a Programmable Logic Controller (PLC) which receives inputs from pressure, mass flow and temperature measuring instruments. These instruments are installed either before or after the control valve to monitor the compressed air in that specific region of the system. It enables the controller to effectively control the compressed air flow according to the requirements for that area.

2.4. Energy Efficiency as part of the Demand Side Management programme

Energy Efficiency (EE) is a commonly used phrase but the real meaning is often misunderstood. It is therefore important to discuss how Energy Efficiency fits into the DSM programme.

Definition of efficiency: Ratio of actual output power to actual input power, expressed per unit or as a percentage.

As with other DSM interventions, Energy Efficiency is a method of ensuring electricity security. As South Africa did not have real problems with its electricity supply in the past 20 years, it was taken for granted and very little or no Energy Efficiency measures were taken. Energy Efficiency does not only help with ensuring electricity security but it has major cost benefits for the consumers of electricity.

Figure 18 shows the cost contribution of three factors of a compressed air system. It can be seen that the electricity cost is more than 75% of the total cost of a compressed air system for a system life of 10 years [55]. It should therefore be of utmost importance to any compressed air system owner/manager to lower the electricity usage of that system.

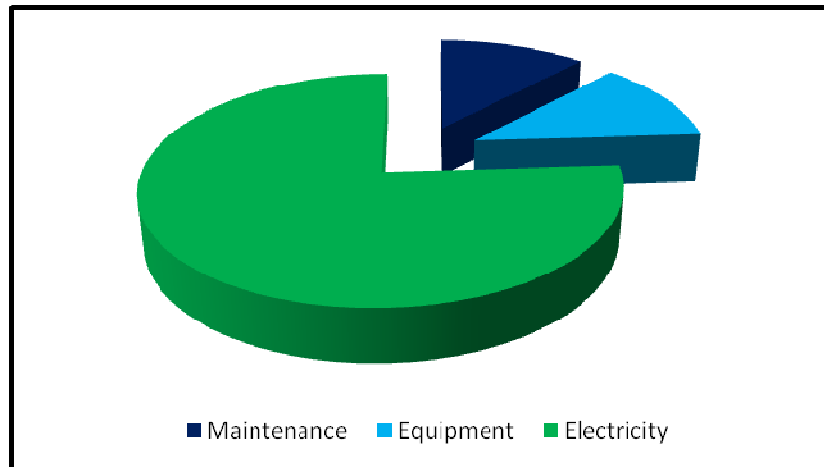


Figure 18: Cost contribution over 10 years for a compressed air system [55]

In 2005 South Africa released its first Energy Efficiency strategy. The vision is to contribute towards affordable energy for everyone, and to minimise the negative effects of energy usage on the environment and human health. The strategy set a target for an overall Energy Efficiency improvement of 12% by 2015, as indicated in Figure 19 [14].

In order to achieve this, an individual target has been set for all the major electricity consumer sectors. The target for the industry and mining sector is 15% by 2015 [14].

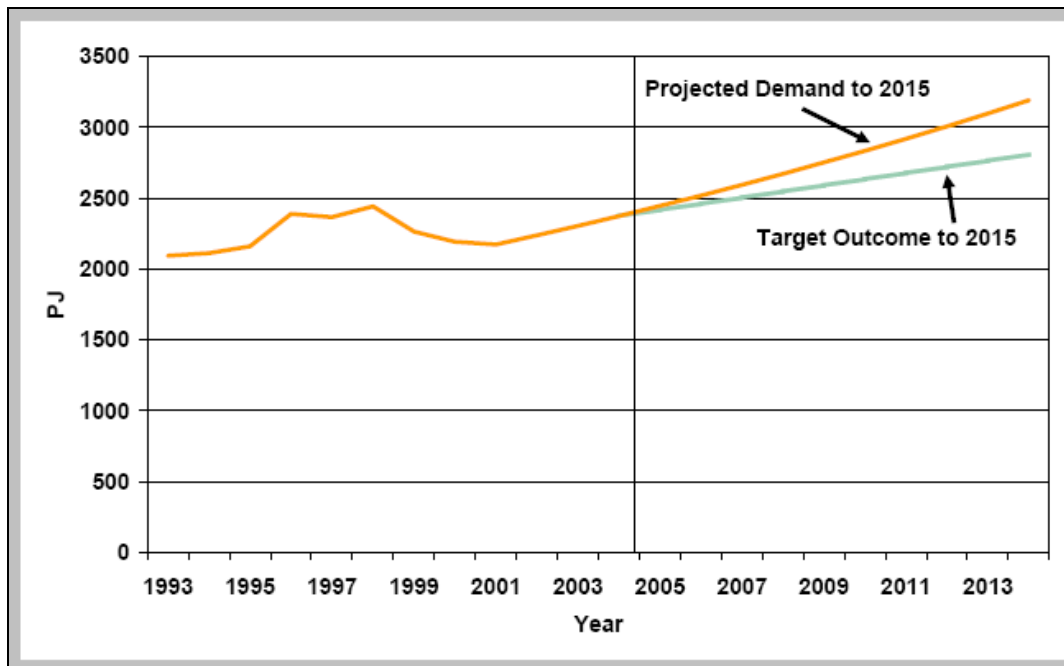


Figure 19: Final energy demand - target outcome to 2015 [14]

If Energy Efficiency is achieved it will have many advantages, including the following [14]:

- Postpone additional electricity generation capacity requirements;
- Reduce pollution levels from power stations and industry & commerce sector;
- Reduce CO₂ emissions across all sectors;
- Increase electricity supply reserves to acceptable limits in South Africa.

The main difference between traditional DSM initiatives and Energy Efficiency initiatives is that with DSM the main focus is to lower electricity demand in specific time periods by controlling or shifting the electricity loads. In the case of Energy Efficiency the aim is to lower the total electricity demand throughout the day.

This is achieved by optimising the performance of machinery and the processes the machinery is used for. In this study the main focus will be on how to optimise mine compressed air systems and how Energy Efficiency can be obtained in these systems.

2.5. Conclusion

This chapter provided a better understanding of compressed air systems and what they are used for. Further, it explained how Demand Side Management can and has already been accomplished in mine compressed air systems.

A further study is necessary to investigate how Energy Efficiency can be introduced into mine compressed air systems. This study will comprise the different strategies and the technical and economic viability of these strategies.

DESIGN AND IMPLEMENTATION OF A PRACTICAL SYSTEM



(Courtesy of www.kevinbeare.com)

This chapter will discuss the various methods to optimise mine compressed air systems and how Energy Efficiency can be introduced into these systems.

CHAPTER 3: DESIGN AND IMPLEMENTATION OF A PRACTICAL SYSTEM

3.1. Introduction

In order to achieve Energy Efficiency in mine compressed air systems there are various methods to increase the performance of the machinery and to optimise the processes in which compressed air is used. This will then eventually lead to an optimised control strategy for the specified compressed air system.

In this chapter these various methods will be identified, and an in-depth study conducted reveals the advantages and disadvantages of each of these methods. It is important to realise that the mining industry uses large amounts of compressed air and not all of these methods will eventually be viable in each of these situations.

After these methods have been identified and assessed, it will be possible to set out a control philosophy for Energy Efficiency projects in the South African Mining industry.

3.2. Techniques of obtaining Energy Efficiency on compressed air systems

3.2.1. Preamble

It is important to identify, describe and evaluate techniques to obtain Energy Efficiency on compressed air systems in order to be able to set out a control philosophy for these projects.

As discussed in previous chapters the control of compressors can be divided into two main groups, namely supply side control, and demand side control. There are different techniques

to achieve Energy Efficiency in each of these two groups and these techniques are explained in the following section.

Supply side control:

- Compressor efficiency and compressor selection
- Variable Speed Drives (VSDs)
- Inter- and aftercoolers
- Air dryers and condensate traps
- Primary air receivers
- Minimise pressure drops
- Eliminate air leaks

Demand side control:

- Surface control valves
- Underground control valves
- End-user efficiency
- Secondary air receivers
- Eliminate air leaks

3.2.2. Supply side control

3.2.2.1. Preamble

As previously mentioned, it is important to identify, describe and evaluate each of the techniques to obtain Energy Efficiency in compressed air systems. Now that those have been

identified, it is even more important to describe each technique in detail and determine if it is viable and cost effective in the mining industry.

First it is important to investigate the opportunities on the supply side of the compressed air system; therefore the major components here are the compressors, air coolers and dryers, and part of the distribution system.

3.2.2.2. Compressor efficiency and compressor selection

Compressor efficiency is the ratio between energy input and energy output. This is a good indication on how effective electricity is used and converted to kinetic energy in the form of compressed air. In some cases machines run at efficiencies of as low as 10% [56]. By improving the total compressor efficiency of the compressed air system, significant savings can be realised. This can be established by selecting the compressors with the best efficiencies to operate as the base load machines.

The following calculations can determine the theoretical Adiabatic Efficiency (η) of a compressor [57]:

$$\dot{W}_{ideal} = c_{p,avg} (T_{2s} - T_1) \quad (1)$$

$$T_{2s} = T_1 \left[\frac{P_2}{P_1} \right]^{\frac{k-1}{k}} \quad (2)$$

$$\dot{W}_{ideal} = \dot{m} \times \dot{W}_{ideal} \quad (3)$$

$$\eta = \frac{\dot{W}_{ideal}}{\dot{W}_{actual}} \quad (4)$$

Where:

\dot{W}_{ideal} = Ideal Work

T_{2s} = Exit Temperature

$c_{p,avg}$ = Constant Pressure Specific Heat

T_1 = Inlet Temperature

k = Specific Heat Ratio

P_1 = Inlet Pressure

\dot{W}_{ideal} = Ideal Power

\dot{m} = Compressed Air Delivered (kg/s)

P_2 = Absolute Delivery Pressure

\dot{W}_{actual} = Actual Input Power

With the above information available it is possible to establish which compressors in the system are theoretically the most efficient machines. This will lead to selecting the right compressors to operate in the system and the least efficient machines will only operate when it is absolutely necessary.

In practice the highest delivery for the lowest power consumption is the most important factor as it is considered the most efficient machine. It can be determined by dividing the compressor delivery volume flow by the actual power consumed when operating at full load.

This practical efficiency (η_p) calculation is shown in Equation 5.

$$\eta_p = \frac{Q_v}{\dot{W}_{actual}} \quad (5)$$

Where:

Q_v = Volume flow (m^3/h or cfm)

\dot{W}_{actual} = Actual Input Power (kW)

Compressor selection/sequencing plays a major role to get the best Energy Efficiency results that are possible within a given system without making major changes to it. Less efficient compressors consume more electrical energy to deliver the same amount of compressed air as more efficient machines.

It is therefore very important to prioritise compressors in a compressed air system in order of decreasing efficiencies to ensure that only the machines with the best efficiencies operate at all times.

Another important factor to consider when controlling a compressed air system is the system pressure. A reduction in system pressure reduces the compressed air production cost. Reducing the system pressure by 1 bar will typically save in the range 6 to 7% of the generation costs [55]. This is illustrated in Figure 20 overleaf [55].

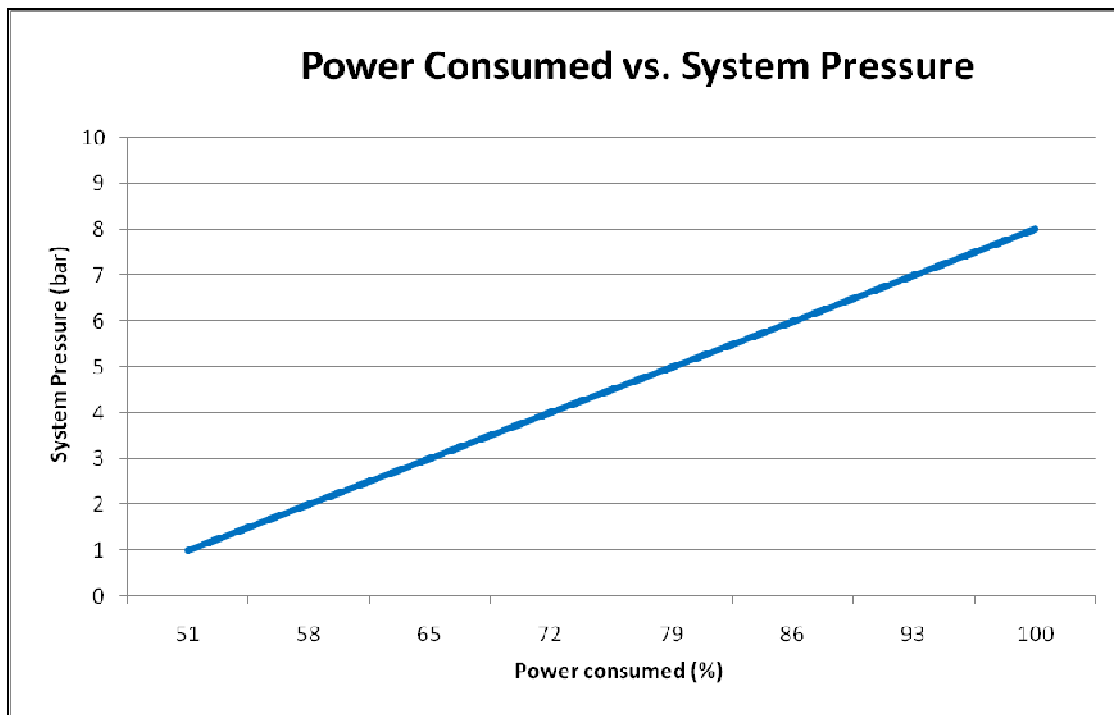


Figure 20: Graph illustrating power consumption vs. system pressure [55]

3.2.2.3. Variable speed drives

Variable speed drives (VSDs) are probably the most effective way to control the efficiency of a compressor if it cannot be switched off. This reduces the time compressors are operating in the offload condition or blowing off compressed air back into atmosphere. The speed of the compressor can be controlled to control the output of the compressor. A compressor is usually driven by a gearbox and a 4-pole motor. The variable speed drive would typically be sized for a system nominal point; in this case it would be defined at 50 Hz and 1485 rpm. The motor and the VSD are designed to reach nominal power at 1485 rpm.

The centrifugal compressor has a quadratic torque/speed characteristic (the torque is proportional to the square of the speed). This means that theoretically the power will reduce with the square of the speed when the speed is reduced below 1485 rpm [58]. This will result in considerable savings without wasting compressed air such as in the case of a guide vane control traditionally used in centrifugal compressors. The compared Life Cycle Cost (LCC) of standard compressors vs. VSD compressors is shown in Figure 21 [59]. Over the lifetime of the compressor the additional cost for the VSD drive is not that significant since the payback period is around 2 years.

In multi compressor systems it is not necessary to install VSDs on all the compressors. It is only required on one or two compressors and the rest of the compressors can be used as base load compressors.

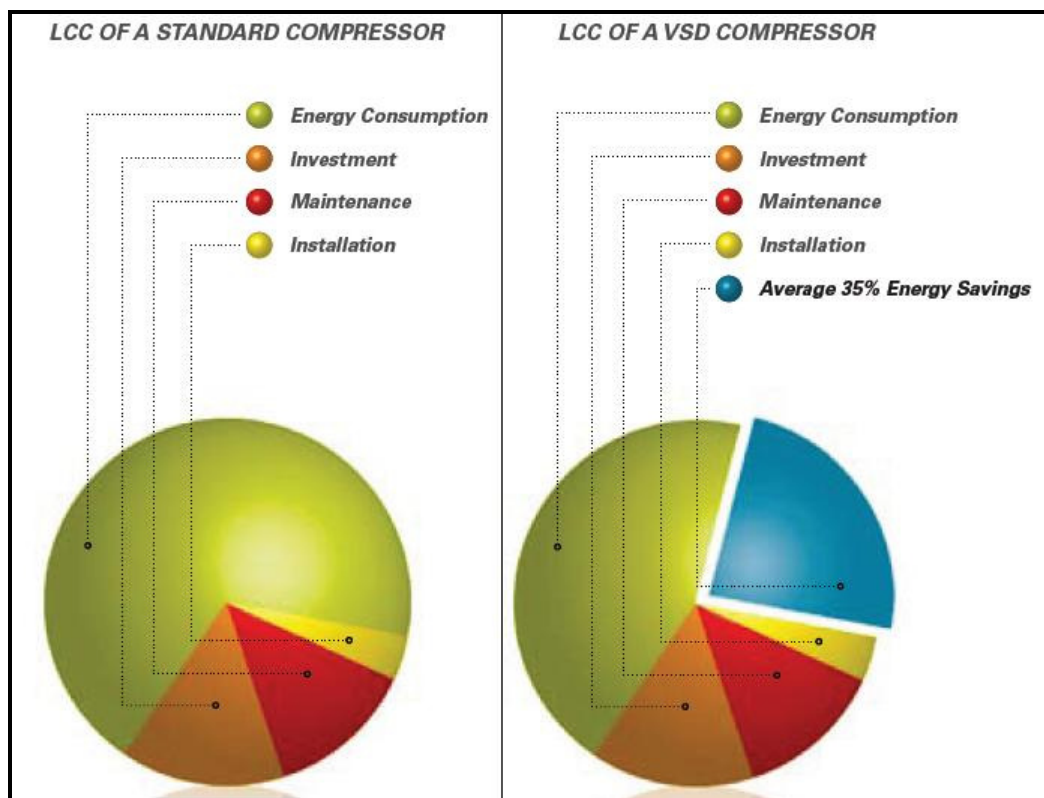


Figure 21: Life cycle cost of standard compressor vs. VSD compressor [59]

Benefits of variable speed control on compressors [60]:

- High reliability and availability
- Low maintenance cost
- High uptime and increased production hours
- Operation of the compressor the optimal speed/power range
- High efficiency
- Lower CO₂ emissions

In most cases on South African mines the existing motors and switchgear are very old technology and need considerable upgrades to install VSDs on these motors. This requires a high capital investment and it has a much longer payback period in comparison with other Energy Efficiency interventions.

3.2.2.4. Inter- and aftercoolers

The Energy Efficiency of a compressed air system can be increased by enhancing the mass flow of the system which is affected by the following three parameters [61]:

1. Increasing the pressure delivered by the system.
2. Increase the volume of the system.
3. Reducing the system temperature.

When considering which of the options will have the most viable effect, it is important to consider what type of changes to the system will be required. To increase the pressure will require major changes to the impeller or the electric motor, and it will automatically mean higher power consumption and would require a substantial capital outlay. The main reason for increased costs is because the changes need to be done on the compressor itself and increasing the compressor size will also increase the required motor size.

Increasing the volume of the system will be discussed in the section on air receivers later in this chapter, but it also has major cost implications.

Therefore it would be viable to investigate the effect that lowering the system temperature has on the Energy Efficiency of the system.

The compressor mass flow and actual cubic feet per minute (acfm) capacity at a given discharge pressure increases as the ambient temperature decreases. If air is drawn from a cool and dry source rather than a compressor house the system will operate more efficiently [62]. Investigations have shown that using cooler outside air rather than hot compressor house air can save as much as 6% compressor power [62]. The energy saving can be calculated using Equation 6 [62].

$$\text{EnergySaving}(kWh) = \frac{1\% \times P \times T}{3} \times t \quad (6)$$

Where:

P = kW Rating of the compressor

T = Inlet Temperature reduction (°C)

t = Operating hours per year

The simplest way to establish an inlet temperature reduction (T) is by using outside air rather than hot compressor house air at the suction of the compressor. The second way of achieving this inlet temperature reduction is to make use of intercoolers between compressor stages.

In most cases in the mining industry only multistage compressors are being used which automatically lead to a requirement of inter cooling. After each stage of compression, before the air enters the next stage, it is first cooled down. When compressed air is cooled down before entering the next stages of compression the quality of the compressed air delivered by the machine is increased. In Chapter 2 some other advantages of air cooling were discussed in detail.

3.2.2.5. Air dryers or condensate traps

In a compressor much heat is generated due to the friction between the compressor itself and the mechanical energy being added to the air. The outlet temperature of a centrifugal compressor is about 107°C, as can be seen in Table 3 in Chapter 2.

This air will form some condensate when it is cooled down for the last time by the after cooler. It is important to remove this condensate to protect the system from erosion and corrosion.

The relative vapour pressure, more commonly known as relative humidity, is used to describe the moisture content of the air. When air is compressed the volume is decreased and the amount of moisture in the air is lower and will drop out as liquid condensate. The temperature at which the moisture would condensate at a pressure greater than atmosphere is called the pressure dew point.

Most equipment specifies a required working pressure dew point like some of the examples in Table 4 in Chapter 2. When selecting an air dryer it necessary to investigate the requirements of the system to prevent drying the air below the required pressure dew point. This will only lead to unnecessary energy and initial costs.

There are different types of air dryers namely [49]; [52]:

- Refrigerant dryers
- Regenerative-desiccant-type dryers
- Deliquescent-type dryers
- Heat-of-compression dryers
- Membrane technology dryers

In order to remove the condensate liquid from the system it is necessary to install condensate traps. Condensate traps are installed in the compressed air system after moisture separators, intercoolers, refrigerated dryers and filters.

Automatic condensate traps are used to conserve energy by preventing the loss of air through open valves. In manual condensate drains, the valves need to be opened by operators themselves and are often left open to continuously drain condensate thus allowing compressed air to continually escape out of the system. Poorly maintained traps waste a lot of compressed air in the long run. There are four ways to drain condensate liquids from the system:

- Manual
- Level-operated mechanical traps
- Electrically operated solenoid valves
- Zero air-loss traps with reservoirs

Therefore it is very important to install automatic condensate traps to prevent any unnecessary compressed air losses and damage to the entire system.

3.2.2.6. Primary air receivers

A common definition for an air receiver is a tank that serves to store compressed air for large demands in excess of compressor capacity. An air receiver acts as a buffer and a storage medium between compressors and the air consumption system [63].

Primary air receivers are usually installed close to the compressors and act as extra capacity during high demand time periods to comply with the system demand. This makes air receivers a potential good contributor to electricity saving and the energy efficient operation of compressors.

Compressors do not operate outside the design parameters and it operates close to its “Best Efficiency Point” (BEP) whether the demand is high or low. When the demand is low, the compressors will pressurise the air receivers, and when the demand is high the air receiver will assist the compressor to deliver the compressed air needed.

Unfortunately this is an expensive alternative in the mining industry as large volume air receivers are required. These types of air receivers will take up much space and are costly to manufacture and erect. These are not used on the large compressed air systems in the mining industry³.

3.2.2.7. Minimise pressure drops

Pressure drop is a term used to describe the reduction in air pressure from the compressor discharge to the actual end user. This was described in more detail in the preceding chapter. Excessive pressure drops lead to poor system performance and high electricity consumption. Pressure drops should be minimised right from the start with the design of the system and with regular maintenance. Air treatment equipment such as intercoolers, dryers, separators, filters, etc. should be selected to ensure the lowest possible pressure drop at maximum system operating conditions. A well designed system will have a pressure drop of far less than 10% [64]. Thereafter, regular maintenance of this equipment and interconnecting pipelines should be done to ensure that the pressure drop does not increase over the lifetime of the system.

³ Cassie Wesolowski – Harmony. Tel: (011) 411 2000.

There are a few additional ways to minimise pressure drops: [64]:

- Proper design of the distribution system during system set up.
- Operation and maintenance of air filters and dryers to reduce the effects of moisture in the system, such as corrosion.
- Minimise the distance that air travels in the distribution system.
- Specify pressure regulators, lubricators, hoses, and connections that have the best performance characteristics with the lowest possible pressure losses.

3.2.2.8. Eliminate air leaks

Air leaks are one of the biggest sources of wasted energy in compressed air systems. This source is the most difficult to track since leakage can come from any part of the system. The most common problem areas are:

- Couplings, hoses, tubes, and fittings.
- Pressure regulators.
- Open condensate traps and shut-off valves.
- Pipe joints, disconnects, and thread sealants.

In semi-automated systems where the compressors have start/stop or load/unload controls it is possible to determine the amount of leakage in the system. It is important to do this test when there are no demands on the system (all the end-use equipment is turned off). Leaks will cause the compressors to cycle because of the pressure drops in the system as air escapes through the leaks.

Using Equation 7 below and a number of measurements of the time a compressor is running loaded and unloaded during a period of time; the leakage percentage can be determined [49].

$$\text{Leakage (\%)} = [(T \times 100)/(T + t)] \quad (7)$$

Where:

T = On-load Time (minutes)

t = Off-load Time (minutes)

Leakages will be expressed as a percentage of the compressor capacity lost. It is important that this percentage is kept below 10%, but in some systems it can be as poor as 20 or 30% [49].

In Table 5 the electricity losses and equivalent cost of compressed air leaks at 700 kPa is shown [49], [62]. The annual cost of leaks is calculated using an average electricity cost of 10.8c/kWh in the low demand season and 26c/kWh in the high demand season.

From Figure 22 it can be seen that the air leak sizes result in a significant increase in electricity costs. In the South African mining industry air leaks accounts for the highest percentage of the air wastages in their systems.

Table 5: Electricity wastages and equivalent cost for compressed air leakages at 700 kPa [49]

Equivalent Hole Diameter (mm)	Quantity of Air Lost in Leaks (l/s)	Annual Electricity Waste (kWh)	Annual Costs of Leaks
1.6	3.2	2,128	R 310.70
3.2	12.8	8,512	R 1,242.75
6.4	51.2	34,040	R 4,969.84
12.7	204.8	136,192	R 19,844.03

It is clear that in a poorly maintained system it will also be financially beneficial to the electricity consumer to set out a leak prevention programme. The cost of fixing holes in comparison to the cost of energy wasted annually is incomparable.

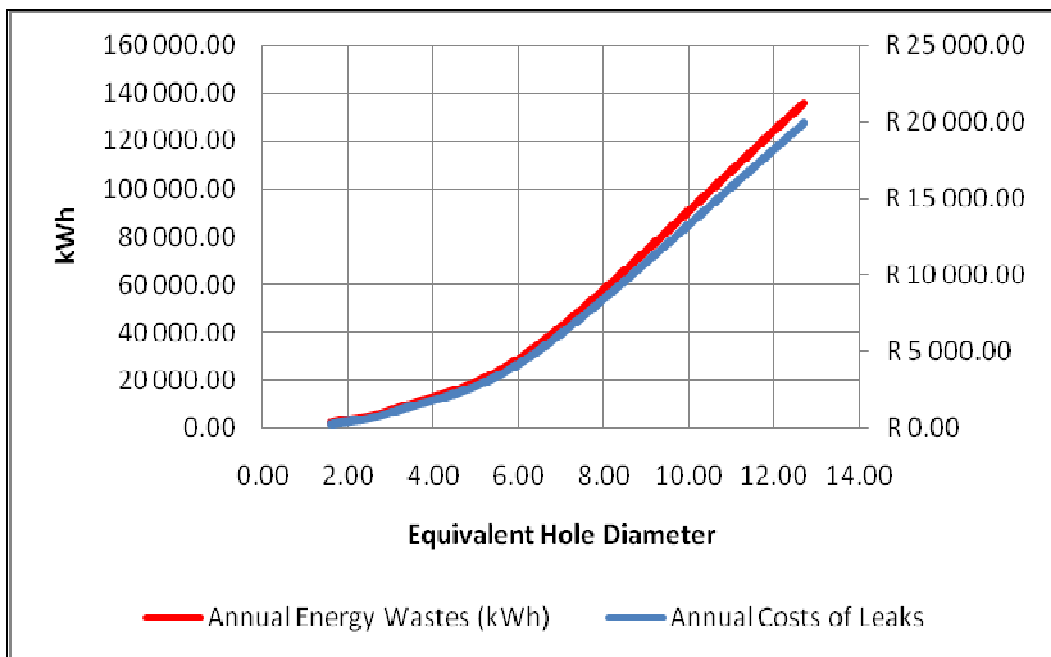


Figure 22: Graphical illustration of electricity wastages and equivalent cost for compressed air leakages

When establishing a leak prevention programme there are two ways to go about it, the Seek and Repair programme, and the Leak Tag programme. The Seek and Repair programme is the easiest as leaks are repaired as soon as they are detected. In the case of the Leak Tag programme the leaks are logged and identified by a tag to be repaired at a later stage.

The most important thing about a leak prevention programme is not the type of programme used but to ensure that the following key elements are included [49]:

- Set up a baseline for compressed air usage.
- Determine the losses in the system caused by the air leaks.
- Calculate the cost of air leaks.

- Identify new air leaks.
- Capture or document air leaks.
- Prioritise the repair of leaks.
- Adjust the compressor controls.
- Document all repairs for future reference.
- Compare the baseline with baseline before leaks prevention programme.
- Restart the programme.

The advantage of a good compressed air leak repair programme is that it maintains the efficiency, reliability, stability and cost effectiveness of the compressed air system.

3.2.3. Demand side control

3.2.3.1. Preamble

The major part of the compressed air system that is considered part of the demand side includes the final part of the distribution system to each point of use, and finally the air end users.

3.2.3.2. Surface control valves (SCV)

Surface control valves are used to control the amount of compressed air distributed to a specific shaft. These valves are installed on the main header supplying the shaft with compressed air.

The valves are used to control the downstream mass flow of compressed air causing an upstream pressure build up if the compressor control system does not respond to the changes in the system. The control system would reduce the IGVs on the compressors to reduce the

delivery of compressed air into the system. This pressure build up reduces the compressed air demand which may result in compressors switching to stand-by mode or even switching off when a point is reached where the IGVs are closed to the minimum position.

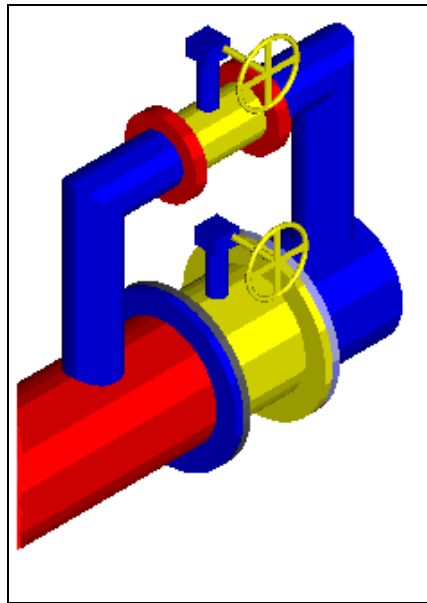


Figure 23: Standard surface control valve assembly⁴

Figure 23 is an illustration of the most regularly used arrangement for surface control valve assembly. A valve is installed in the main compressed air header with a smaller bypass line and control valve. The bypass valve is mainly used because of the higher cost of the larger valves installed in the main header. If the valve is constantly opened/closed to control the air pressure it could also cause mechanical failure of the valve. Mechanical failure to a valve in the main header feeding the shaft with compressed air will result in system downtime to replace the main valve.

⁴ Courtesy of Casper Vos

This valve assembly is used to control the supply of air according to the individual compressed air requirements at each mining level. It is in most cases in the range of 350 to 450 kPa. When the required air pressure of the shaft becomes less, the main valve is throttled to the minimum possible position to regulate the air pressure. From this point the smaller bypass valve takes over and fine controls the downstream pressure. This control in turn causes an upstream pressure in the system. Upstream pressure allows the compressors in the system to cut back on their power consumption. The compressors achieve this either by guide vane control, switching to standby mode (offload) or switching off. The compressors are usually controlled at pressures of between 550 – 650 kPa.

In order for this intervention to work according to the design parameters it needs to have automatically controlled valves to effectively control the system. Due to the higher demand for compressed air during certain hours of the day, the set points for these valves will differ throughout the day. This control will be explained in the underground control valve section.

3.2.3.3. Underground control valves

Underground control valves (UCVs) are used for exactly the same reasons as the surface control valves. These valves are installed on every working level of the shaft. On non-working levels it is not necessary to install control valves, as the level can be permanently shutoff either by blanking of the specific header or installing a manual valve. The principle of controlling these valves is exactly the same as with the SCV system.

This control technique is much more effective than the SCV technique as it gives much more effective control. The valve at each level can be controlled separately without affecting the rest of the levels. Compressed air can be closed off at levels that do not require air at certain times of the day. With only SCVs the whole shaft must be supplied with more air if the demand in one level increases.

Another important difference, compared with the SCV technique, is that the bypass valve is not used in the UCV technique. This is mainly because the costs involved when installing double the amount of valves on each level and not only on the surface level. And with the smaller diameter headers feeding the individual levels the fine control is already part of the system. These valves are usually only opened or closed depending on the activity on the level.



Figure 24: Typical butterfly valve used for underground control valves²

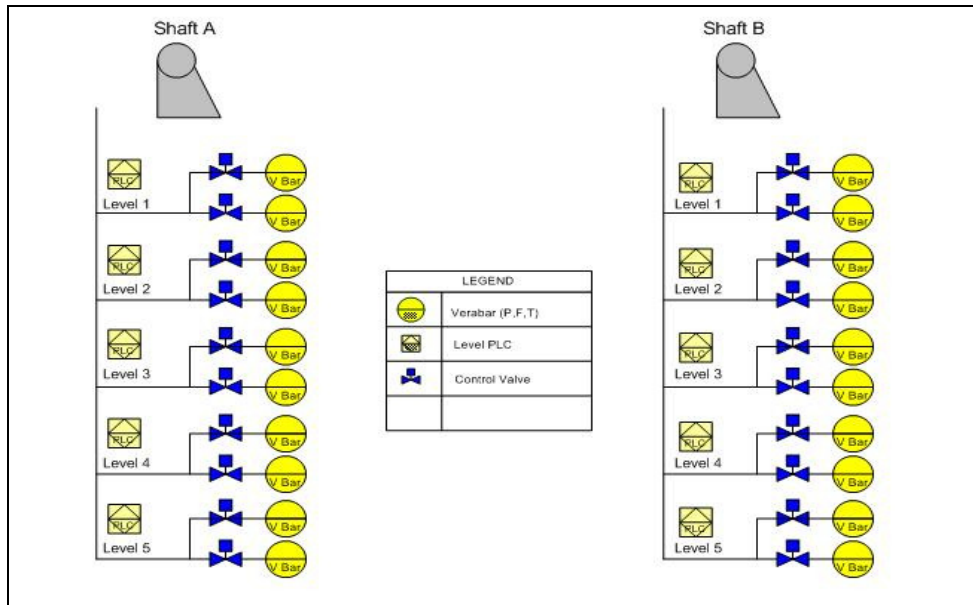


Figure 25: P&ID for an underground control valve system at Modikwa Platinum Mine

Figure 25 is a process and instrumentation diagram (P&ID) of the underground control valve system installed at Modikwa Platinum Mine in the Limpopo province. It indicates the equipment needed to effectively control the valves underground. The type of valve used in these applications is a butterfly valve and there is a picture of this valve and its actuator shown in Figure 24.

In order to effectively control the valves it is necessary to combine the control of the compressors and the valves in the system. This is achieved by a backbone operations' system, commonly referred to as supervisory control and data acquisition (SCADA). A SCADA system is software used to monitor and control all electrical, industrial components and processes from one central control room (CCR) [65]. The SCADA controls a piece of equipment via a communication network and a programmable logic controller (PLC). The communication network is usually an existing LAN (Local Area Network) or an optic fibre/copper cable network.

The PLC is programmed to control equipment according to a certain control philosophy and various inputs from the SCADA and field instruments. How the control is applied to the

system will be discussed in the ‘control philosophy for Energy Efficiency projects’ section below.

3.2.3.4. End-user efficiency

End-user efficiency is a very important contributor to achieving Energy Efficiency on compressed air system. A system can be highly efficient, from the generation of compressed air right through the distribution system. However if the end-users waste air it can drastically affect the efficiency of the total system.

Compressed air is often chosen as an energy source for applications where other sources could be much more economical. A few applications where it is considered as a bad energy source are as follows:

- Used for cooling or air conditioning.
- Used for aspirating, agitating, mixing or to inflate packaging.
- Used for cleaning and removing debris.
- Used for vacuum – using compressed air venturi methods.

As previously mentioned, the excess volume of compressed air needed by unregulated end uses is known as artificial demand. It results in the supply of a higher pressure than necessary for end user applications [66]. The maximum end-of-use pressure must be limited just prior to the end-user tool by installing a pressure regulator [67]. If this is not done the tool uses the full system pressure, and a lot of air is wasted this way, which results in increased electricity use. Higher pressure can also be the reason for excessive equipment deterioration which will result in higher maintenance costs [67].

In the mining environment abandoned equipment is one of the major reasons for inefficiency of end users. When it is time for shift changes, the miners leave the point of work without ensuring that compressed air tapping points are closed off.

Thus it is very important to take control of this part of the system, and in most cases wastages occur due to human error. Miners should be motivated to save as much compressed air as possible.

3.2.3.5. Secondary air receivers

In many industrial and some mining plants, there could be one or more applications with an irregular demand of compressed air of a relatively high volume. This can cause fluctuations of the dynamic pressure in the whole system, affecting essential points of use. By installing a secondary air receiver close to this point of high demand, this fluctuation can be prevented. The definition and workings of an air receiver are explained in the section above on 'primary air receivers'.

Secondary air receivers act as extra capacity during the high volume demand periods. This maintains the necessary pressure in the system and avoids a situation where an extra compressor is loaded or switched on. It saves much electricity due to fewer fluctuations of compressors stopping and starting, as well as on the high electricity currents necessary to start the motors of the compressors.

As with the primary air receivers this is an expensive alternative in the mining industry as large volume air receivers are needed because of the system size. In the mining sector normally the system is very complex and there are a lot of applications that could benefit from a secondary air receiver. These air receivers do take up a lot space and will necessitate a high capital investment to manufacture and erect.

3.2.3.6. Eliminate air leaks

This section has been covered in great deal by the previous section on 'eliminate air leaks' on the supply side of the system. Therefore this section is only mentioned because it does have a great effect on the Energy Efficiency of the system on the demand side.

In South African mines, on the demand side of the system, a major contributor to air leaks is miners punching air distribution pipes to cool down the workplace. This is mostly due to bad cooling and ventilation underground which causes unbearable working conditions.

Substantial savings are achievable if air leaks can be minimised in the whole of the demand side of a compressed air system.

3.3. Control philosophy for Energy Efficiency projects

3.3.1. Preamble

By now it is established that there is a considerable savings potential on mine compressed air systems from an Energy Efficiency point of view. It is now important to look at the best possible control philosophy of such an Energy Efficiency project.

It is important to look at the process control variables for controlling the system effectively without impairing the efficiency of other system components. The main control variable that needs to be considered is the required pressure in the system. This varies according to the time of day. It is important to control the pressure according to the needs of the shaft/mine. If this is not done it will affect the amount of electricity used by the compressed air system. In turn, if it is not controlled correctly, some equipment may not have sufficient pressure to operate to its best performance.

In Figure 26 the typical mining activities are shown; this is an illustration of when the main activities occur on average during various times of the day. In most mines which use a lot of compressed air the drilling shift consumes most compressed air. It is during this shift that higher pressures are required to use the pneumatic rock drills, and to prevent damage to this equipment.



Figure 26: Typical daily shift roster for mining activities

The other shifts can get by with using less compressed air and at lower pressures without influencing the production of the mine and/or damaging equipment. This can be considered as the single most important aspect to take into account when optimising the control of any compressed air system in the mining industry.

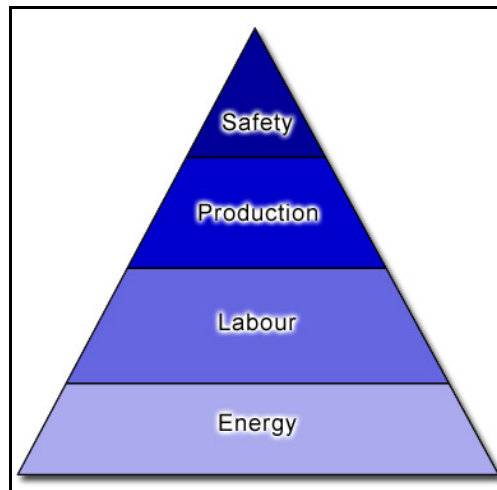


Figure 27: Decision hierarchy of South African mines⁵

On any mine the priorities are safety and production, and this is indicated in Figure 27. If these two factors are negatively influenced the mine will not commit to electricity savings on

⁵ Courtesy of HVAC International

compressed air systems as it is right at the bottom of the hierarchy. Any mine would take their losses in electricity savings if it affects the production statistics of the mine.

In order to effectively manage electricity usage the following four steps to effectively manage energy usage need to be considered:

- Identify all the opportunities.
- Prioritise all actions rationally.
- Implement the activities successfully.
- Ensure that the activities are sustainable.

In order to effectively control a compressed air system, there are three main controls to integrate:

- Central Control Room (CCR).
- Compressor selection and control.
- Pressure control.

3.3.2. Central control room

All is well in implementing the discussed methods for Energy Efficiency into a compressed air system, but if it is not controlled from a central point it cannot be implemented successfully.

A central control room is the central point of the compressed air system from where the whole system can be monitored and controlled. It is visually illustrated in Figure 28. The advantages of a central control room (CCR) are:

- Centralised compressed air system monitoring and control.
-

- Historic data of the system is at one central point.
- Changes in the system can be detected and rectified e.g. increase air leakages.
- Unnecessary electricity wastages can be minimised.

The advantages of having a central point of monitoring and control are clearly overwhelming. This is made possible by various field instruments that are connected to a central PLC and SCADA system. The importance of a CCR cannot be over emphasised when energy control and savings are being considered. It is the only way that any sort of control can be implemented on a vast system as used by the South African Mining Industry.

In order to achieve electricity savings the total system should be examined, and creating a CCR is thus the first objective to be achieved. Most compressed air systems do have dedicated compressors for all the shafts (main users), and this increases the necessity to be able to monitor the whole system.

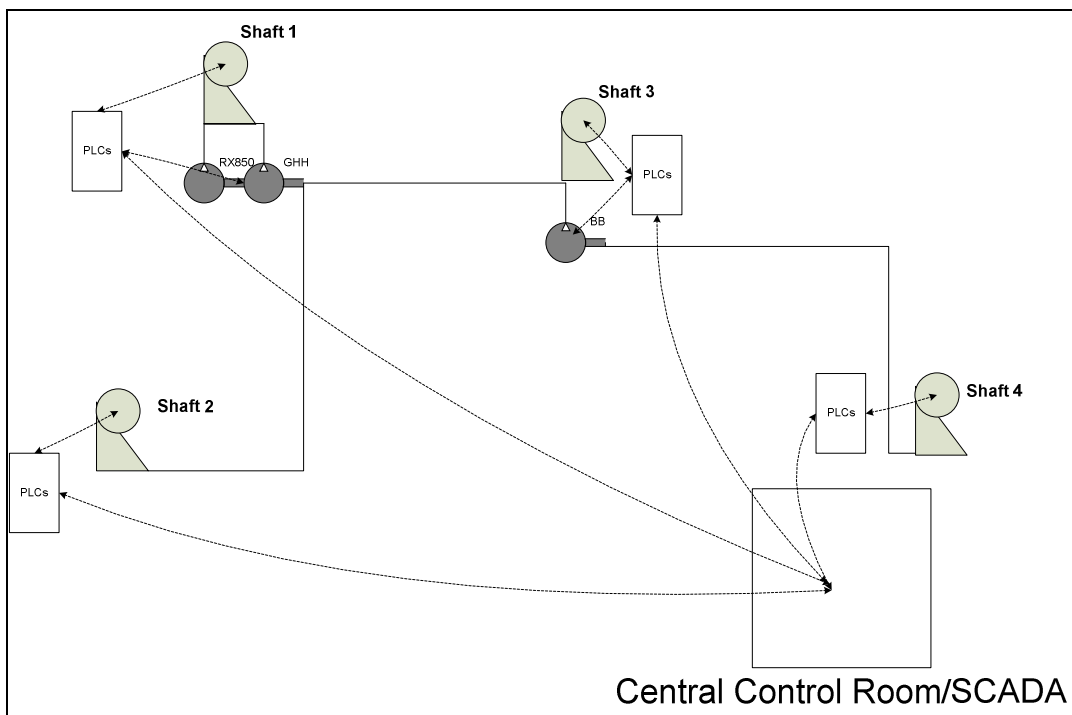


Figure 28: Demonstration of a central control room (CCR)⁵

The Central Control Room is something that is in most cases non-existent on the older South African mines. This makes it the most capital consuming part of most projects and very little capital can be set aside to do other upgrades on the system. But because of its importance it should be the first part of the project.

3.3.3. Compressor selection and control

Compressor selection and control include the selection of the most efficient compressors and optimising the specific number of compressors operating at a given time. It also includes optimising the compressor operations individually.

The selection of the most efficient compressors can be done by first determining which of the compressors are the most effective. The control software can determine this by calculating the efficiency of each compressor, as described in more detail in Section 3.2.2.2 on compressor efficiency. This important function can be done by creating a compressor scheduler; either automatic or manual.

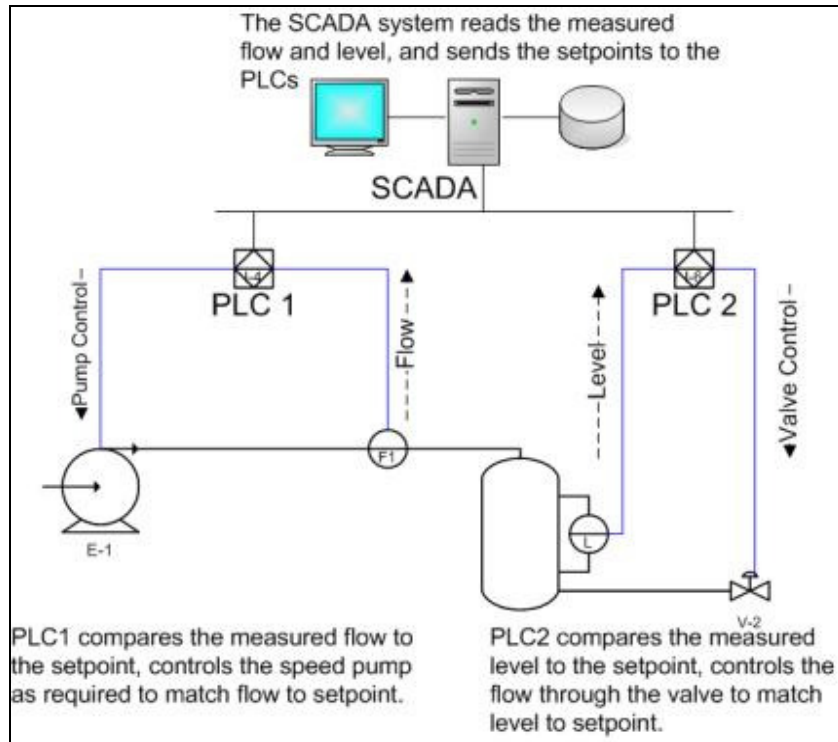


Figure 29: Overview of a simple system with SCADA control⁵

Efficient control can be established by making use of intelligent software through a SCADA system. In Figure 29 an illustration is shown of how a SCADA system integrates with the rest of the plant. It is important to notice that it is connected to the rest of the field equipment through a PLC. The PLC is programmed to control the components in the system according to specific inputs from various field instruments as required by the process.

If the compressor is used as an example, for instance, the PLC receives continuous information from other instruments such as the guide vane position, delivery pressure, and blow off valve position, just to name the critical information for system control. This is illustrated by the diagram in Figure 29.

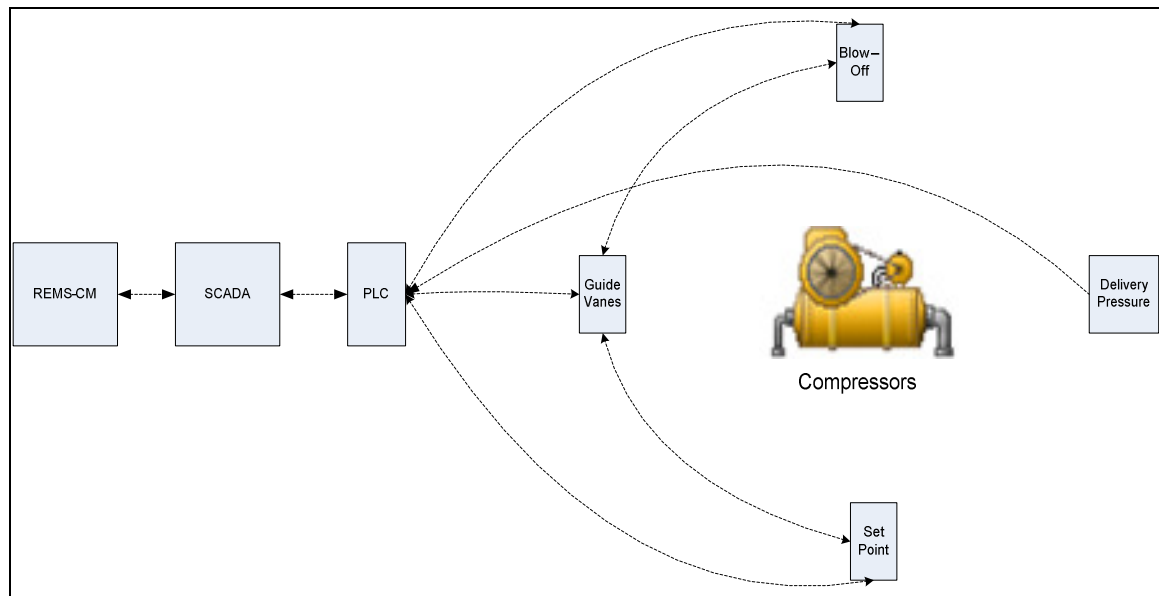


Figure 30: Control of a compressor⁵

Set points for the compressor can either be programmed into the PLC, or the PLC can call for the set point from the SCADA. This makes it possible for an operator or the control software to alter the set point as needed by the system requirements. The pressure profiles for each of the main compressed air users over a 24 hour period can be altered by the control software.

A compressor scheduler that forms part of the control software uses various inputs from different field instruments to schedule the compressors for the order and amount of compressors operating. The order of operation of the compressors is mainly influenced by the efficiency of the compressors.

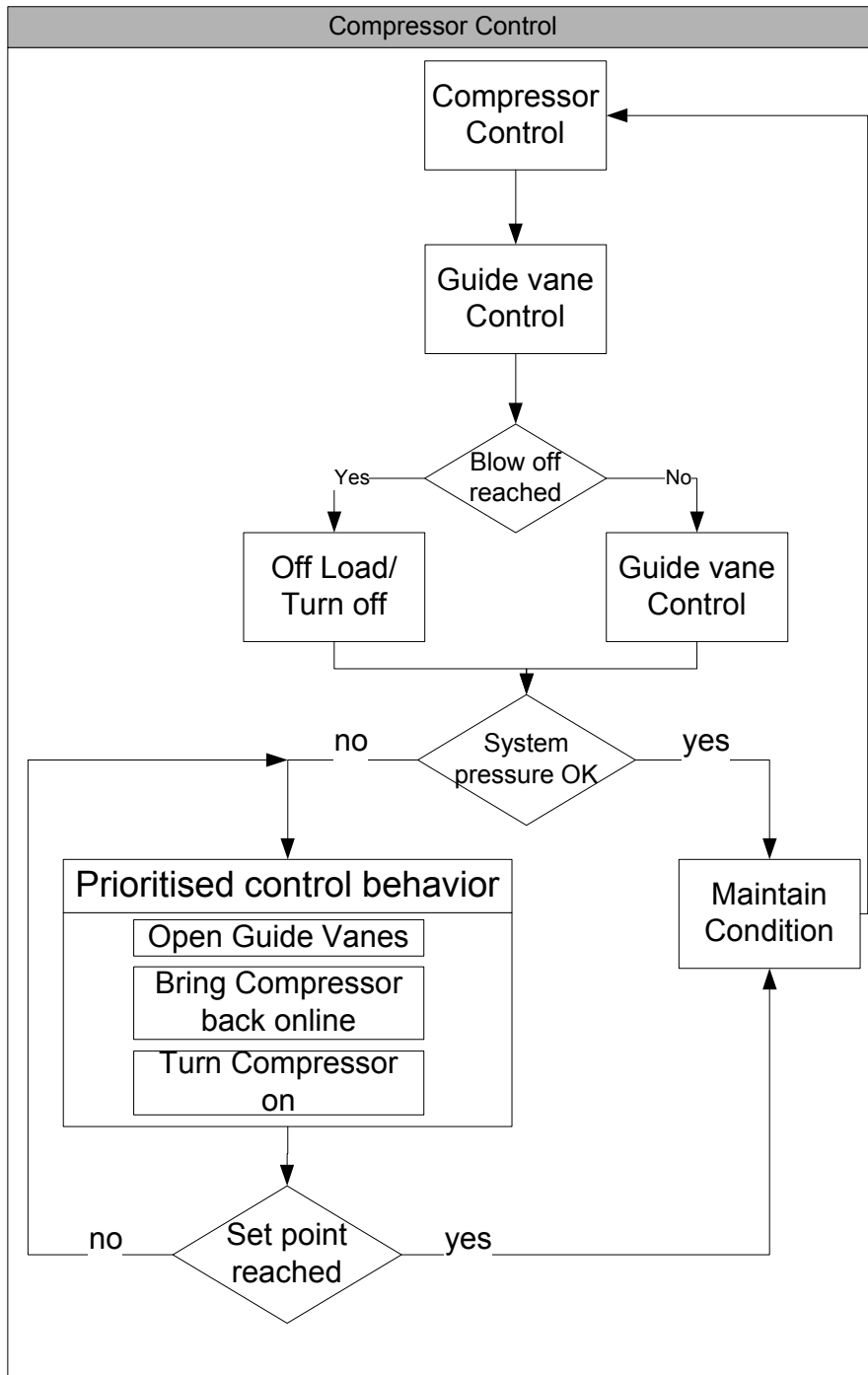


Figure 31: Compressor control functional diagram

The compressor control philosophy is illustrated in the flow diagram in Figure 31. This control procedure is implemented on the compressors when the most efficient compressors

are selected and operating at any given stage. The system pressure is continuously monitored and adjusted to comply with the required pressure set points.

A compressor will be switched to offload if all the compressors that are operating in the system are running on-load with the guide vanes in the minimum positions and the pressure set point is maintained. When a compressor operates in the offload condition and continuous to operate in that condition for a predetermined timeframe it will be switched off.

When the pressure drops more than 10% below the pressure set point the most efficient, switched off compressor will be switched on again. This will only happen when the operating compressors are running at full load (guide vanes completely open). It entails that the supply of compressed air is not enough to meet the demand of the system and more compressors must be brought online to meet the demand.

In the functional diagram the priority of behaviour when an increase in demand is experienced is clearly stated and is as follows. Firstly, the closed guide vanes are open to the fully open position. Secondly, any compressor that is operating in the off-load status will be brought back online. And finally, if the demand is still not met, the most efficient remaining compressor will be switched on.

The order of control and the type of action to execute in a compressor system is of utmost importance.

3.3.4. Pressure control

Pressure control is a very important part on the control of the compressed air system; it ultimately influences the amount of electricity savings possible in a system. The better the pressure control, the higher the possible electricity savings. The control philosophy of a surface control valve system is illustrated in the functional diagram in Figure 32.

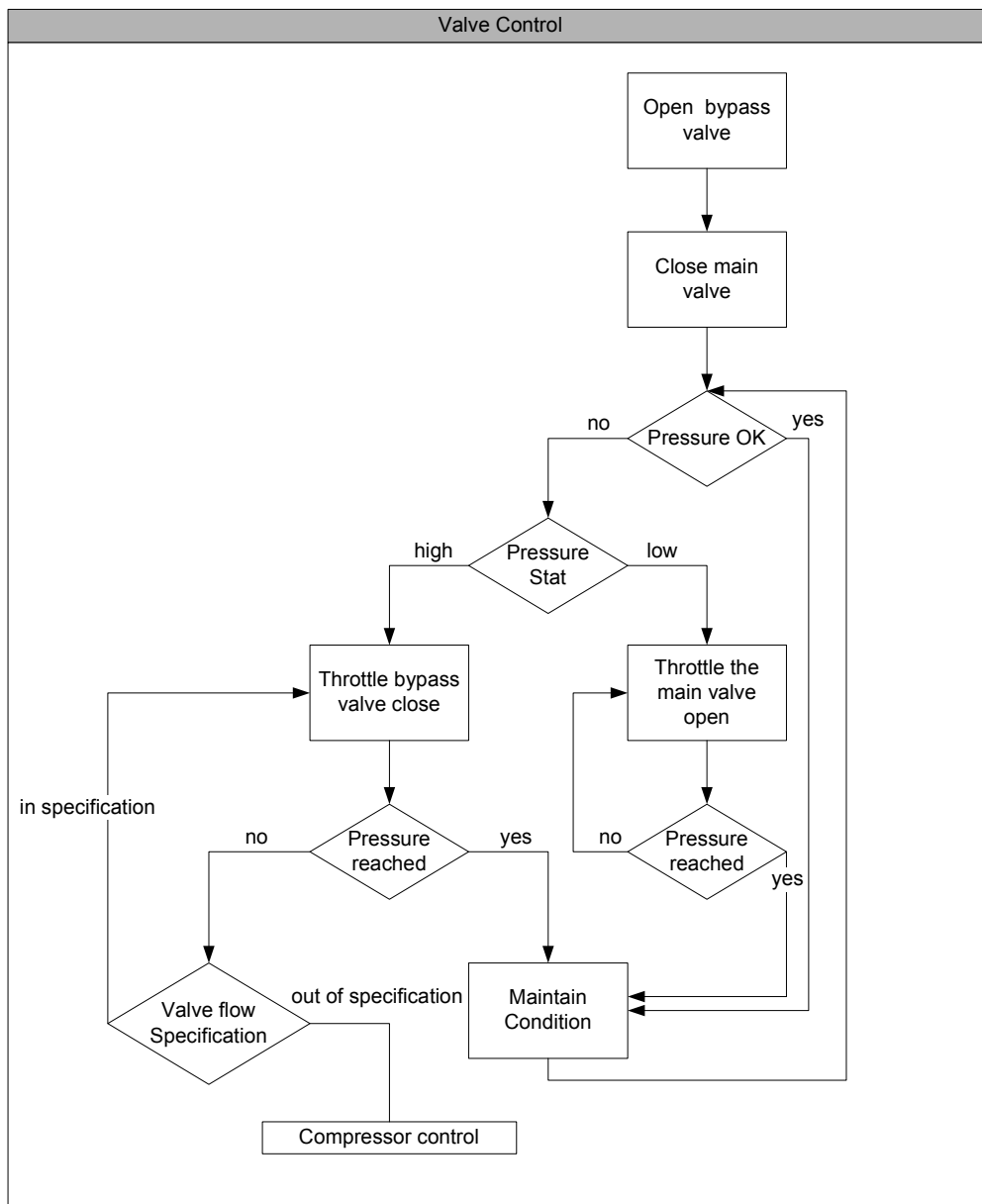


Figure 32: Pressure control functional diagram

The flow diagram is set out for a surface control valve system since none of the case studies in Chapter 4 will include underground valves. The principles for underground valve control does not deviate at all from this, except for the fact that there is no bypass valve and the inline valve will be controlled at the correct opening to maintain the desired set point pressure of the specific level.

The first step in the control of a surface valve arrangement is to open the bypass valve fully and close the main valve completely. The system pressure on the downstream side of the valve arrangement, which is the control parameter for this type of control, is continuously monitored.

If the pressure is sustained well above the pressure set point required for efficient control at the specific air user, the controller will throttle the bypass valve closed in small increments. This is done while still monitoring the pressure in comparison with the pressure set point. The process of controlling the system pressure is a continuous process since the demand for compressed air can vary so much throughout the day.

In case of the pressure dropping to below the set point when the bypass valve is fully open and the main valve is fully closed, the main valve will be opened gradually. This is also done while monitoring the system pressure. This is very important in order to achieve the maximum compressed air savings.

During the peak drilling shift all valves are opened and no control of downstream pressure is done unless it is permitted by the mine. Most mines believe that the control of compressed air will influence their production.

3.4. Simulation of Energy Efficiency projects

3.4.1. Preamble

In order to design and implement practical electricity saving projects, or more precisely, Energy Efficiency projects, it is important to do the necessary feasibility studies. This feasibility study involves identifying possible projects, investigating the possible electricity savings, and researching the existing and required infrastructure to implement the project.

When investigating the possible electricity savings it is important to simulate the compressed air system. In the following section more background information will be given regarding the software used to simulate the compressed air systems.

3.4.2. REMS3 as simulation tool

A sister company of HVAC International Pty (Ltd), TEMMI Pty (Ltd), developed a simulation, monitoring and control program especially for the mining industry called Real Time Energy Management System (REMS3). This is a unique, proprietary and patented control system, consisting of the following products; Compressor Manager® (REMS3 CM) and REMS Optimisation of Air Networks® (REMS3 OAN).

This system is used to optimise the control of compressed air systems. Production and operating constraints that were taken into account are the following:

- Maximum number of equipment active daily.
- Minimum and maximum allowable air pressures.
- Minimum and maximum flow rates.
- Daily underground compressed air usage at the different sites.
- Safety constraints.

- Maintenance constraints.
- Allowable on/off switch periods for all elements.

In Figure 33 the basic platform of REMS3 is illustrated; this is where the basic layout of the program is illustrated. It is on this platform that the compressed air system can be built from all the components in that specific system and the simulation parameters can be defined. An example of an illustrated system build in REMS3 is shown in Figure 34.

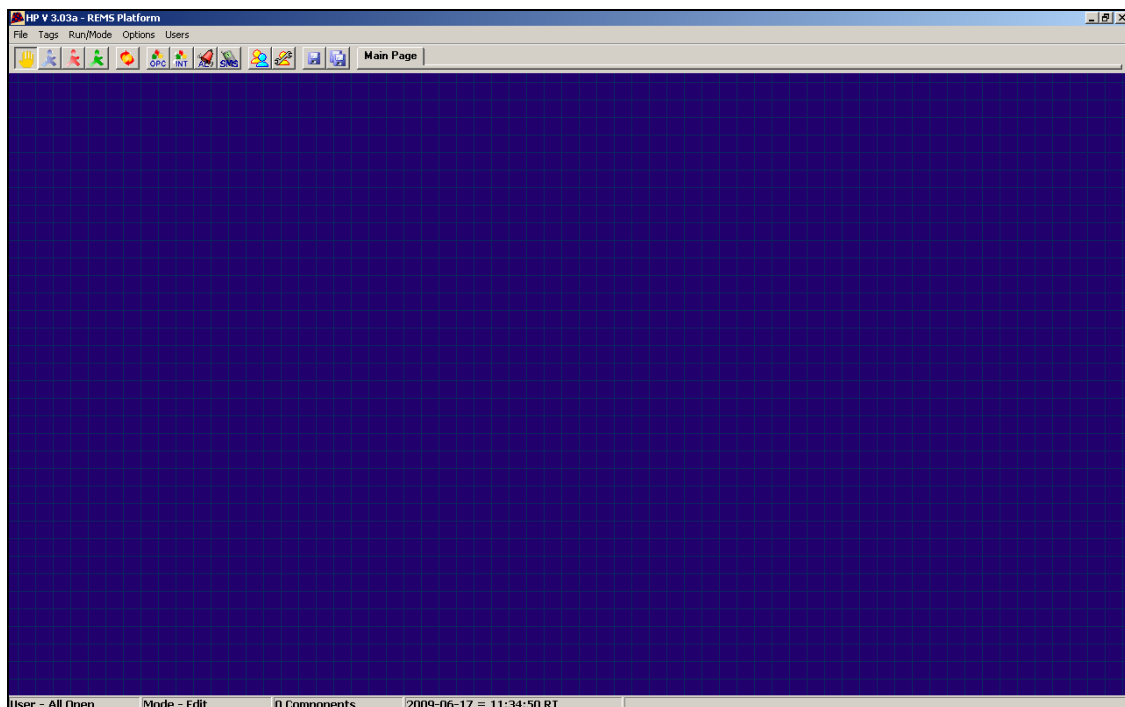


Figure 33: REMS3 platform⁵

It is from this screen that the program's control mode can be set to either "edit-", "idle-", "manual-" or "automatic-mode". Basic settings can be set, including system alarms, OPC settings and user-login settings. The main function for "control mode" or "simulation mode" is also set here in the main platform. All of these settings can be done without building any part of the system which means that it is not necessarily unique to a specific compressed air system that is simulated or controlled. This means that these are general settings for using the program.

In the user-login section the administrator of REMS3 can give certain login rights to certain users. This implies that operators can be given certain capabilities that differ from the capabilities of an administrator. These users are identified by a username and password. This ensures that operators cannot change the control parameters of the system.

When using the simulation mode, the time intervals can be varied to accelerate the time for efficient simulation. This results in simulating real-time in shorter durations which speed up the simulation process, and real-time results are available without waiting for days to actually pass. This enables the user to predict savings and provide the client with a report in a shorter time period and reduce the exhaustion of valuable resources with days of simulations.

As the goal of this study is not to educate the reader on the procedure to use this simulation and control platform, a short overview with screenshots from the software will be given in the following section.

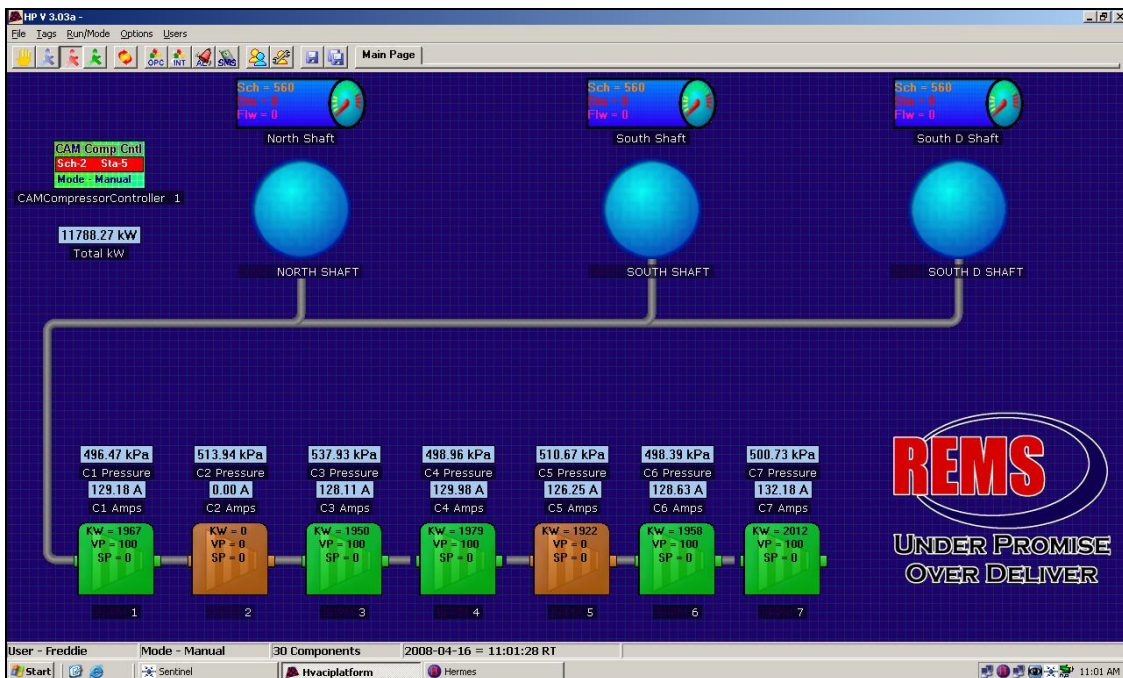


Figure 34: Example layout of a compressed air system⁵

The first controllable part of any compressed air system is the compressor itself. This discussion will therefore begin with the Compressor Information window and the Compressor Controller window. These two windows are respectively indicated in Figure 35 and Figure 36.

In the Compressor Information window (Figure 35) the information of each individual compressor is added. Particular information includes control parameters, physical properties, simulation options and tags. This effectively means that there should be a Compressor Information window for each compressor that forms part of the system.

The Compressor Controller window (Figure 36) is the controller of all the compressors in the system as a whole. The top right section is where the compressors that will be controlled by the software are added to the system controller. This is also the heart of the control where all the continuous system calculations are done during simulation and/or control.

Figure 35: Compressor information window⁵

The priority of the compressors is also manually selected here when setting up this controller by selecting the “Priorities” tab. The compressor which is required to operate the greater part of the day (this will be the most efficient machine) is added at the top of the list and the compressors that are usually the standby machines (less efficient machines) are listed at the bottom. The compressor operational priority can be changed, as required, on this screen.

At the bottom right is the “Pressure Control Nodes” section; this is where the main air users which need to be considered are added, each of which have individually set pressure profiles used to control the compressors in the system. The individual pressure control nodes are setup in the “Pressure Control Node Editor” window, shown in Figure 37.

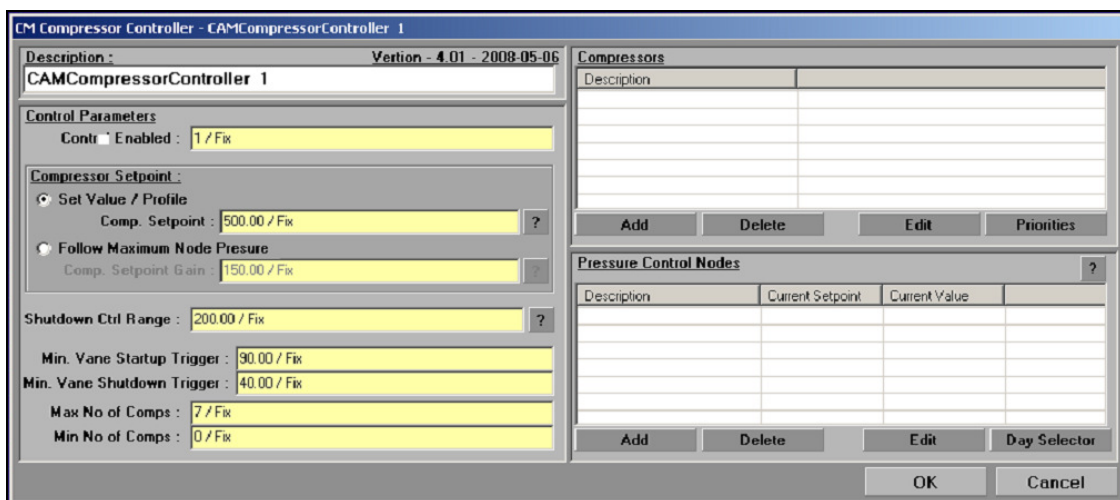


Figure 36: Compressor controller window⁵

Each shaft that forms part of the simulated/controlled compressed air system needs to be added to the controller otherwise its compressed air requirements will not be taken into account by the system controller. In order to add it to the controller the required pressure profile for that shaft needs to be specified in the “Pressure Control Node Editor”. This is then added to the system controller as a pressure control node, as described in the preceding paragraphs.

Logger” in the REMS platform and is shown in Figure 38. The “Generic Data Logger” logs by default the date, time and control mode. There is also an option of logging 24 hours a day or only a specific part of the day, and the logging interval can also be predetermined in the “Generic Data Logger”.

The power consumption of each compressor is the most important information that needs to be logged because it is used to determine actual electricity savings. The pressures of all the main electricity users can also be logged to determine whether or not the pressure control is effective. It can log any information that is available on the SCADA that the mine feels they need logged.

Heading	Comment	Tag
Date	Current Date - Real or Simulated	
Time	Current Time - Real or Simulated	
Control Mode	Current Platform Mode	

Figure 38: REMS3 generic data logger⁵

REMS3 is therefore a very important tool; firstly to simulate each system to determine the possible savings available in a given compressed air system. When the system is identified as an Energy Efficiency project and the project is actually implemented it is also used to control the system.

At this stage it is important to note the effects of the Energy Efficiency by determining the amount of savings achieved. Figure 39 is a flow diagram indicating the information and extra features of the REMS3 system. Sentinel is a program developed to generate an automatic savings report with data sent from the REMS system.

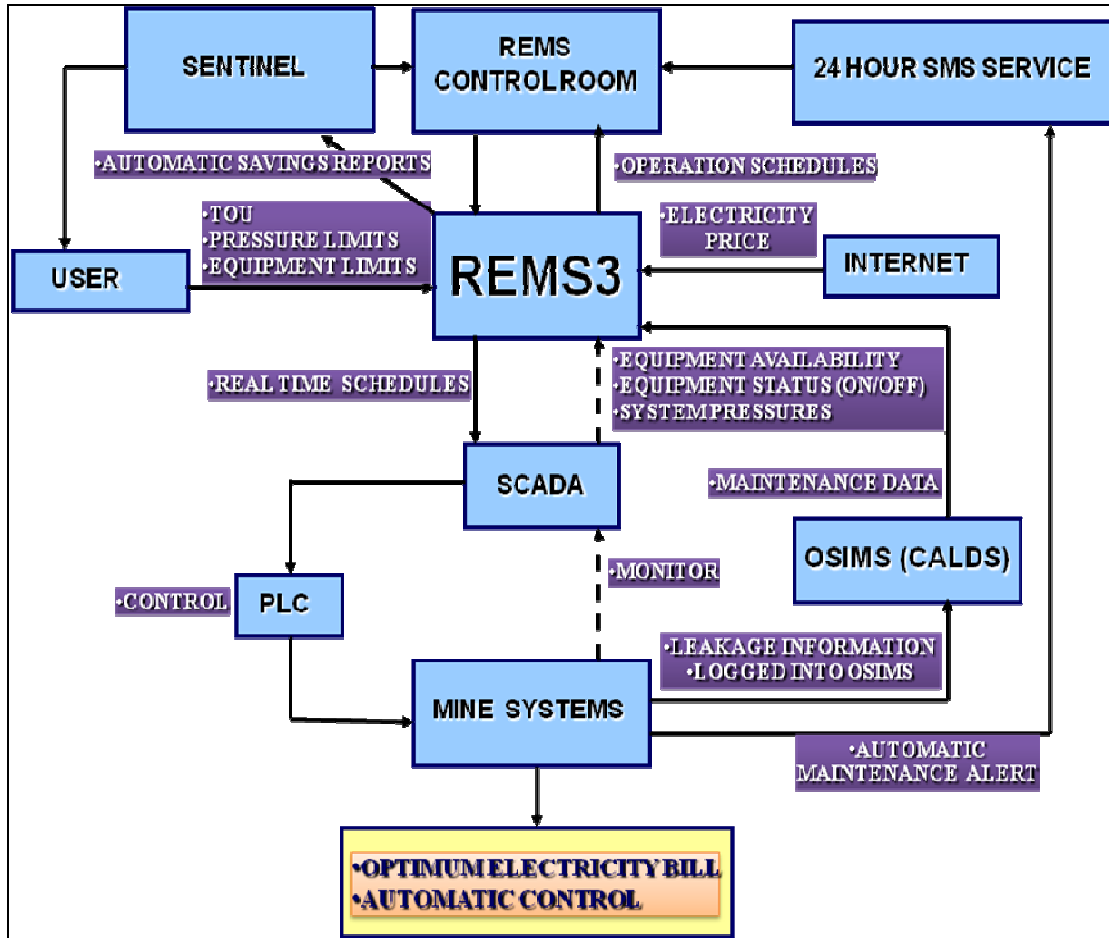


Figure 39: REMS3 added features⁵

3.4.3. Baseline and savings achieved in a system

In order to determine the final savings of the implemented or simulated system it is firstly important to establish a baseline of the electricity usage before any Energy Efficiency strategies can be implemented. In the following paragraphs the concept of determining the

baseline will be explained in more detail. After that, the savings can be noted by also calculating the new baseline after the Energy Efficiency strategies have been implemented.

Definition: Baseline – Imaginary line or standard by which things are measured or compared.

This is an important line to establish at the start of any investigation into a project when identifying Energy Efficiency projects. In terms of an electrical definition it should be an average power usage line (kW/MW) over a 24 hour period. To determine the baseline of a system it is necessary to have historic data of the compressor electricity usage on the project. Some mines are more developed and have SCADA systems that log this data, in other cases the compressor operators' manually log the data, and in the worst cases nothing is logged on the compressor system.

When the last scenario is the situation, one can install electrical loggers on the compressors that form part of the project. It is important to take the measurements over 3 to 4 months to get an accurate baseline of the average use of electricity by the compressed air system. This data can be logged at predetermined intervals; the only important part is that it is converted back to kW over a 24 hour period.

Figure 40 is a typical example of a baseline in the form of a graph for a weekday, Saturday and Sunday. The reason for the different baselines is because of reduced production on mines during weekends. Power consumption of the compressed air system can be read from the graph for any hour of the day.

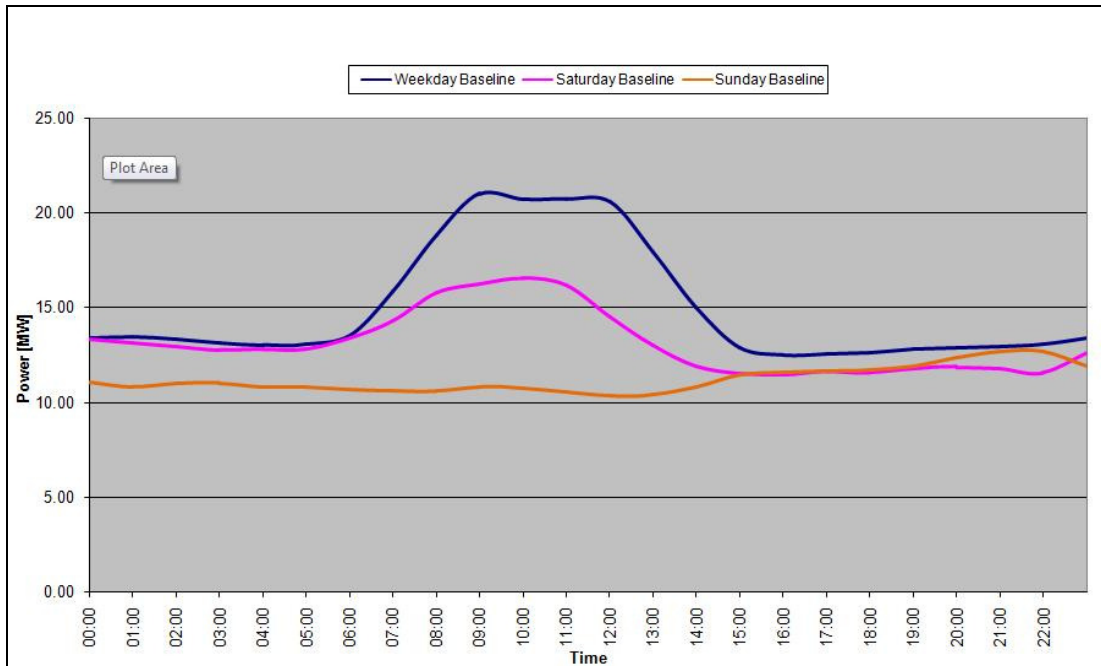


Figure 40: Example of a typical baseline

The set up of the baseline in the early stages of any investigation is really important to determine the real effect of any Energy Efficiency project. It is also the only way to determine the savings that will be achieved by the Energy Efficiency initiative. This will include the actual electricity savings for Eskom and the financial savings for the client only on the cost of electricity.

It will not be the client's only saving, as there will be considerable other advantages where savings would be made. These savings may include lower maintenance costs, less man hours because fewer operators are required, and better system's monitoring from a central point. Compressed air baselines can be used to identify any increase in compressed air consumption, which can lead to further investigations to find and solve the reason for the increase.

3.3.5. Compressed Air Leak Documentation System

Another software package that was developed by TEMMI Pty (Ltd) is Compressed Air Leak Documentation System (CALDS). This software is used to establish a compressed air leak management system customised to the client's compressed air system.

CALDS is a mobile information capturing tool that allows the user to log data onto a handheld device and export the data into a database on a local computer for future use.

The logging data fields are divided into the location of the leak, the leakage size, the date and time the leak was logged onto the system, and any notes. This is illustrated in Figure 41 below. Some clients choose to customise the system with a Global Positioning System (GPS) integrated into the system in order to have exact coordinates for surface leaks.

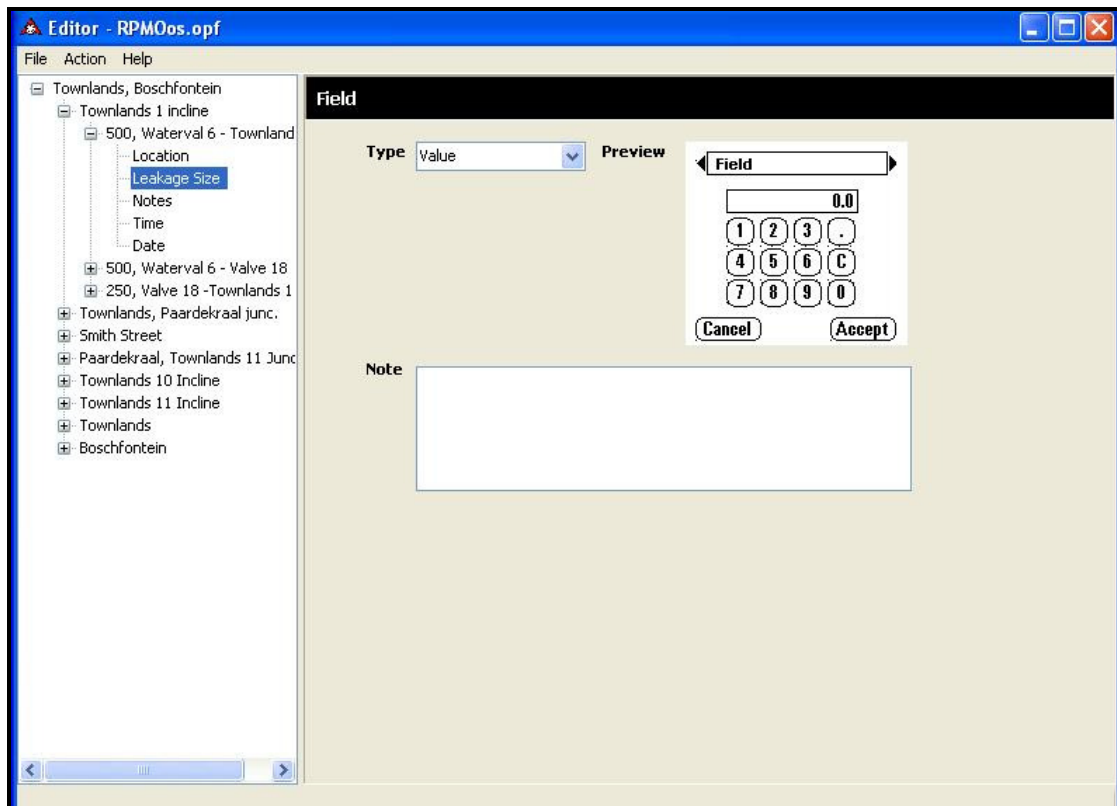


Figure 41: CALDS database structure⁵

The data on the computer can be accessed and viewed, printed, and used in documents or reports. The computer software is customised to develop maintenance reports for shutdown periods for maintenance personnel to attend to them in the shortest possible time. In some cases the client may select to appoint a surveyor to attend only to leaks in the compressed air system where CALDS is used as a handy tool.

All the major pipes and valves are already added in the logging structure for fast and easy access to the part of the piping system in use. This ensures a quick and direct approach to all the pipes in the compressed air system and keeps the data in a logical order.

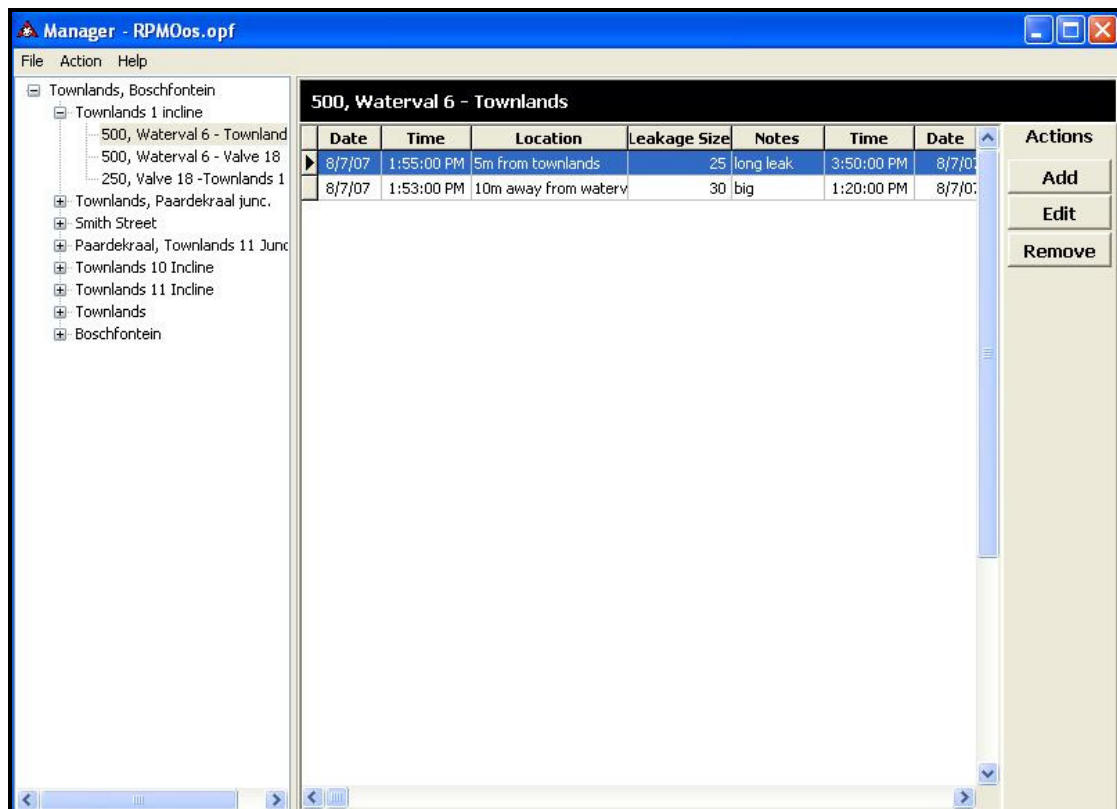


Figure 42: CALDS summary window⁵

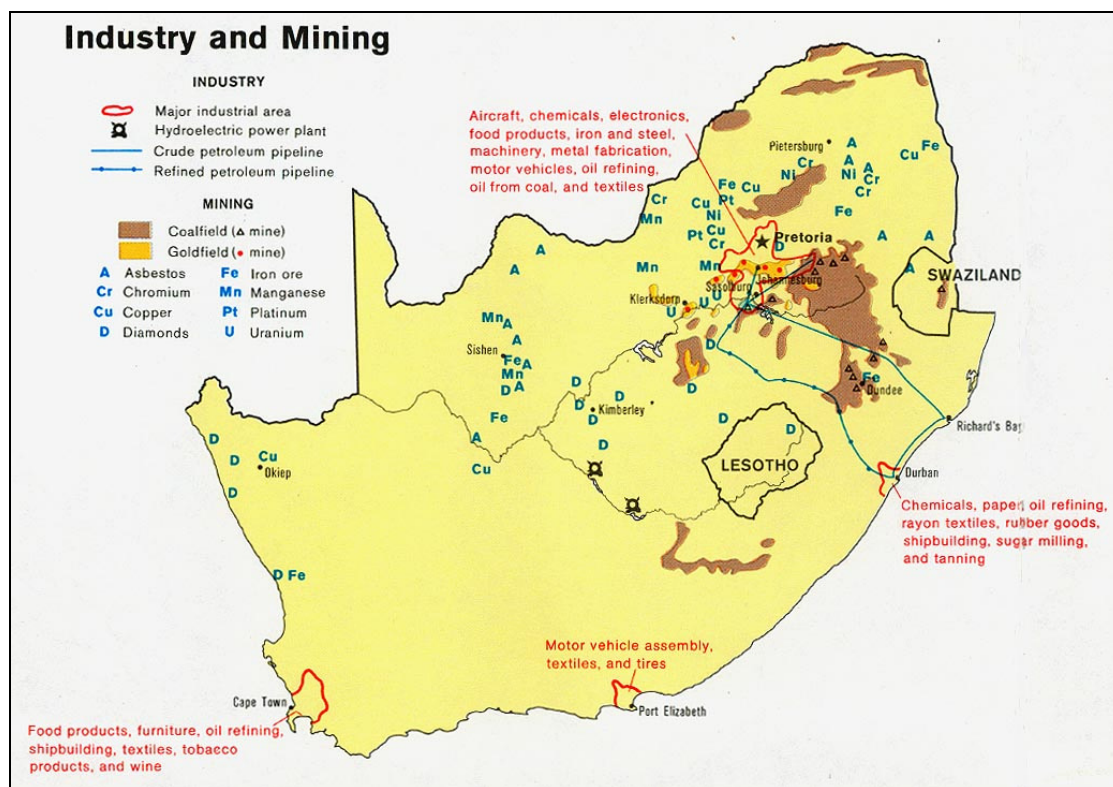
In Figure 42 the CALDS summary window is indicated where all the detected and logged leakages are listed with short descriptive summaries. It is clear that this is a handy tool when managing compressed air leaks.

3.5. Conclusion

The scope for Energy Efficiency on South African mine compressed air systems is immense because of the large electricity consumption of compressors on South African mines. In the light of Energy Efficiency it is therefore critical to identify mines for case studies.

Therefore, in the following chapters various case studies will be explained to determine the real effect of Energy Efficiency. It is important to relate the theory to the practical side and determine if its actual effect will realise significant benefits to Eskom and the mines.

CASE STUDIES OF ENERGY EFFICIENCY



(Map courtesy of <http://www.lib.utexas.edu>)

This chapter will discuss the results from the various case studies undertaken in order to illustrate the successful implementation of Energy Efficiency projects on South African Mines.

CHAPTER 4: CASE STUDIES OF ENERGY EFFICIENCY

4.1. Introduction

This chapter will discuss the identified case studies that formed the basis of this thesis. The success of various projects where Energy Efficiency (EE) strategies have been implemented on South African mines will be investigated. In all these projects different strategies have been implemented and proven to be successful.

4.2. Rustenburg Platinum Mine – Rustenburg Section

4.2.1. Background

Rustenburg Section is part of the Rustenburg Platinum Mine (RPM), which consists of four major sections; Rustenburg, Union, Amandelbult and Bafokeng Rasimone. RPM is part of the Anglo Platinum Group and is situated in the Bushveld Complex of North West and Northern provinces [68].

The Rustenburg Section has eight production shafts which have high compressed air consumptions, as illustrated in Figure 43 [69]. These shafts are:

- Bleskop Shaft
- Boschfontein Incline Shaft
- Brakspruit Shaft
- Frank Shaft
- Frank 2 Shaft

- Paardekraal
- Townlands Shaft
- Turffontein Shaft



Figure 43: Map of the Rustenburg section of Anglo Platinum [69]

4.2.2. Compressed air system layout and background

The Rustenburg Section was identified in 2005 as a potential DSM and EE project during a research and development study conducted on platinum mines in South Africa. There are eight shafts, as discussed in the background section, which results in the Rustenburg Section being a high compressed air consuming mine.

The system consist of a large ring of shafts and compressors which is divided into two parts but it is still interconnected with only a valve separating the two systems. This valve is only opened in an emergency situation where one of the two parts cannot supply its own compressed air. These two parts will be referred to as Rustenburg Platinum Mine – East

(RPM-E) and Rustenburg Platinum Mine – West (RPM-W). The shaft separation of these two sections is indicated in Table 6.

Table 6: RPM-W and RPM-E Split of the Rustenburg section shafts

Shaft	RPM-W	RPM-E
Bleskop	X	
Boschfontein		X
Brakspruit	X	
Frank	X	
Frank 2	X	
Paardekraal		X
Townlands		X
Turffontein	X	

As this compressed air system is a ring of various shafts and compressors it is not necessary for each shaft to have its own compressors. In Table 7 all the compressors included in this ring are listed, the shaft where it is positioned, and the power rating of each compressor.

The Rustenburg Section has a total of 56.4 MW compressor installed power in its compressed air system. West 10 is not an actual production shaft but a compressor house with four compressors at a central point to boost the compressed air system during high demand hours of the day.

The scope of EE is massive with the amount of installed capacity of the compressors on this mine in particular. Only a 10% saving in electricity on the installed capacity can make a 5.64 MW difference.

Table 7: Rustenburg section compressor summary

Shaft	Compressor	Power [MW]	Split	Total Power [MW]
Boschfontein	RX 800	4.3	RPM-E	21.40
	RX 850	4.3		
Townlands	RX 850	4.3		
	GHH	4.3		
Paardekraal	BB Sulzer	4.3		
Frank 2	VK 40	3.7	RPM-W	35.00
West 10	GHH 6	4.3		
	GHH 7	4.3		
	GEC	3.3		
	VK 28	2.8		
Turffontein	GHH	4.3		
	VK 125	12.3		

The infrastructure on the compressors before implementing the project was very old and outdated. The mine did not even have a SCADA system to monitor the compressed air system. Implementing any sort of control on this project would have been costly from the start because of the outdated infrastructure.

Another situation that makes this a costly project is the fact that the individual shafts are far from each other, and installing any sort of cable communication would mean kilometres of cable.

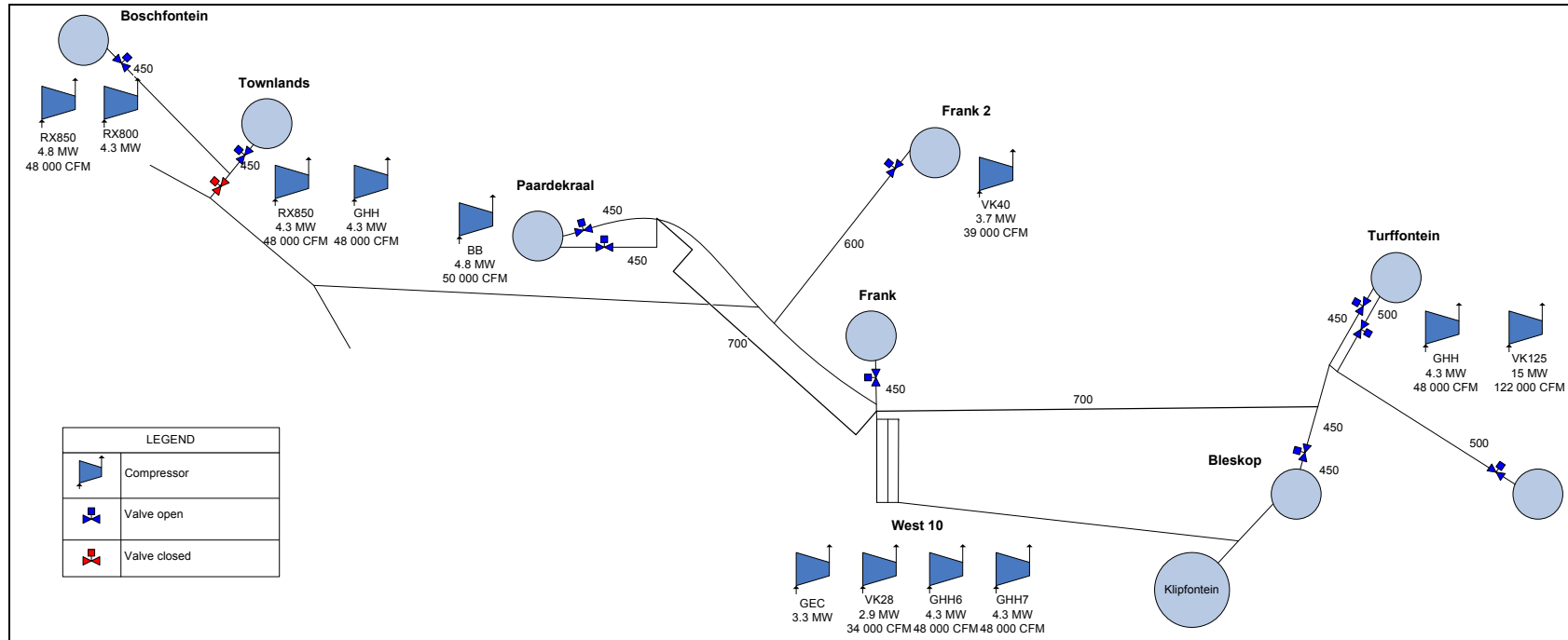


Figure 44: Rustenburg section compressed air system layout⁵

4.2.3. Compressed air baseline and Energy Efficiency intervention

The graph in Figure 45 shows the developed and Eskom approved (via a MV Entity) baseline for the Rustenburg Section. It is clear that there are different baselines for Weekdays (Blue line), Saturdays (Red line) and Sundays (Green line). This is mainly because the regular usage of compressed air over weekends is drastically reduced because most mines do not have production shifts over weekends. Secondly, Eskom has different tariff structures for each of these time periods. The baselines for Saturdays and Sundays should not intersect each other in theory, but due to bad compressor management this intersection does exist. It is also important to note that these are averages for the daily power consumption.

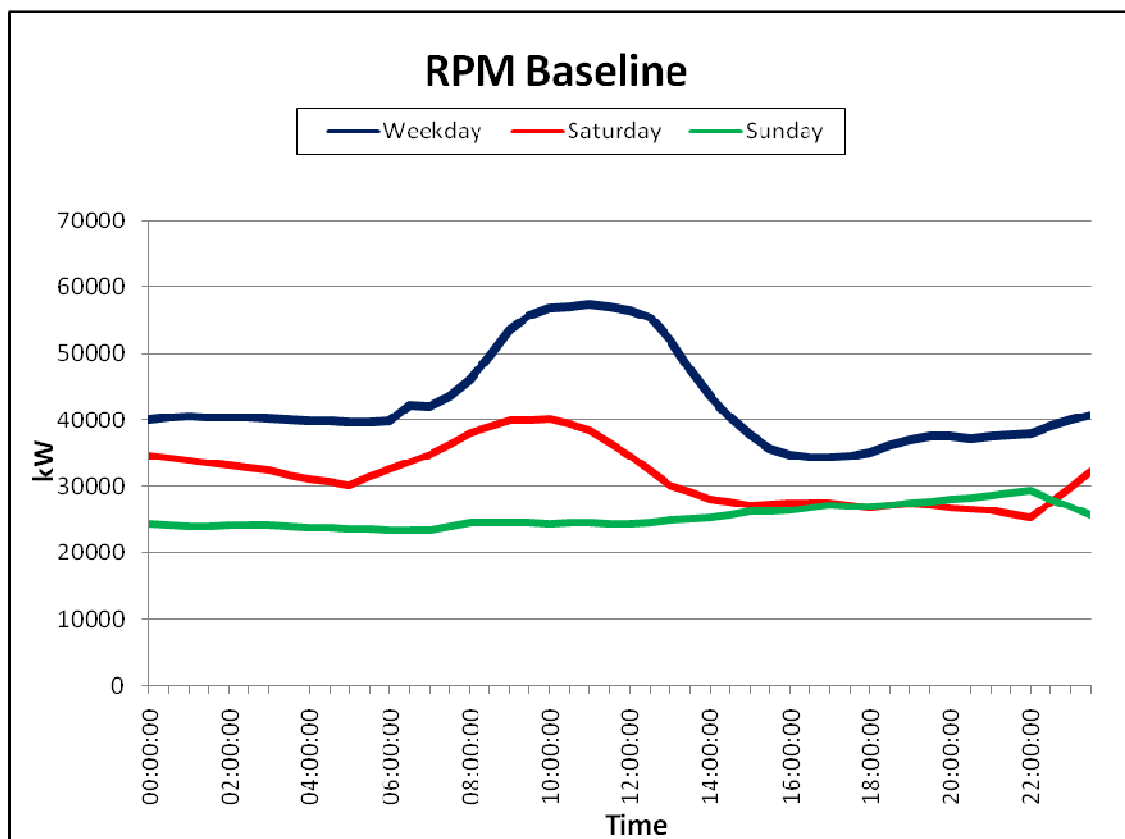


Figure 45: Rustenburg section compressed air baseline

During the simulation stage of the project where the research and development studies were conducted, REMS3 was used to predict the possible savings achievable. The estimated

savings with optimised control and the lowering of the total system pressure were calculated as indicated in Table 8 below.

Table 8: Simulated Energy Efficiency demand savings for RPM

Energy Efficiency Strategy	Total (MW)
Optimised Compressor Control and System Pressure Drop	8.00
Eliminating Compressed Air Leaks	3.96
Total Energy Efficiency Demand Saving	11.96
Total Energy Efficiency as Percentage	20.82 %
Maximum Achievable R/c Savings per Year	R 35 880 000.00
Savings Promised to Eskom by the ESCo	12.00

As part of the EE intervention implemented on this compressed air project, the following strategies were implemented to achieve the above mentioned savings:

- Central Control Room.
 - Compressed air system monitoring.
 - Compressor control on selected compressors.
- System pressure delivery reduction during off-peak time periods.
- Leak detection and management by mine personnel with the assistance of the CALDS system.

As previously mentioned, the out of date infrastructure on this project had substantial cost effects on this project. Therefore only certain peak demand compressors were automated and controlled from the CCR. Compressors used as the base load compressors have not been automated since there is not a lot of controlling done with these machines. Although only certain compressors can be controlled, not all of them can be monitored from the CCR. The possible savings that can be achieved by fixing leaks in the system is quite substantial in comparison with other case studies. The reason for this is poor maintenance over the lifetime of the system with one specific shaft, Turffontein, being responsible for the majority of the

air wastage. Miners punch holes into the compressed air headers to help with ventilation which is not what the compressed air system is design for.

One of the major cost implications was the fibre optic network communication system that was installed between all the shafts that formed part of the compressed air system and the CCR. At the end of the project there were 55 kilometres of fibre optic cable installed on RPM to connect all the shafts.

4.2.4. Results and conclusion

When looking at the results of these EE projects it is important to look at the overall savings established for the client and the electricity provider (Eskom). The client would like to see a reduction in the monthly electricity cost and Eskom desperately needs reductions in the electricity demand in South Africa.

Firstly, the savings for the client are analysed; the savings for three consecutive summer months are shown in Table 9 below. This does look like an enormous saving but when taking into account that the monthly electricity account of RPM is in excess of R20 million, further savings would be highly appreciated [48].

Table 9: Energy Efficiency results on RPM for the client

	Energy Efficiency Savings (R/c)		
	RPM-E	RPM-W	RPM
Month 1	R 398 938.98	R 1 124 152.49	R 1 523 091.47
Month 2	R 380 805.39	R 1 073 054.65	R 1 453 860.04
Month 3	R 417 072.57	R 1 175 250.34	R 1 592 322.91
Total Saving	R 1 196 816.95	R 3 372 457.48	R 4 569 274.43

Secondly, and possibly the most important, is the savings for Eskom. This is primarily to the advantage of Eskom and secondarily to the advantage of every electricity user in South

Africa. In Table 10 and Figure 46 are the savings made on RPM through EE strategies implemented on the mine compressed air system for the three consecutive summer months.

Table 10: Energy Efficiency results on RPM for Eskom

	Energy Efficiency Demand Savings (MW)		
	RPM-E	RPM-W	RPM
Month 1	1.99	11.04	13.03
Month 2	3.88	11.23	15.11
Month 3	3.66	11.09	14.75
Average Demand Saving	3.18	11.12	14.30
Total Energy Efficiency as Percentage			24.90 %

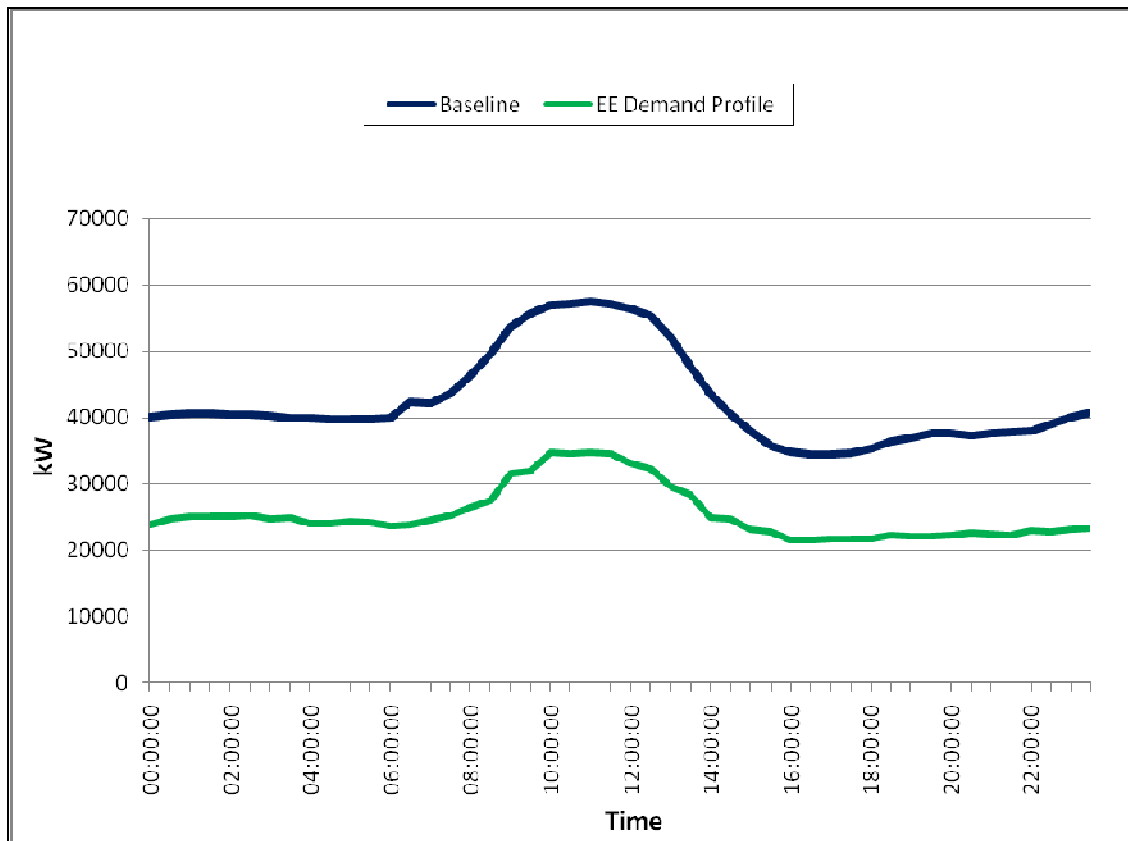


Figure 46: RPM Energy Efficiency demand savings

All of the above results in a yearly saving of 106 GWh which is an equivalent energy saving of 383 780 GJ per year. An added benefit will be the 106 000 ton reduction in CO₂ emissions.

In conclusion, the EE strategies implemented on RPM have shown considerable savings to the client and Eskom, and even exceeded the projected savings.

4.3. West Wits Complex

4.3.1. Background

The West Wits Complex is wholly owned by the Anglo Ashanti Group in South Africa, and is situated near the town of Carletonville on the border between the Gauteng and North West provinces. It comprises three individual mines:

- Mponeng
- TauTona
- Savuka

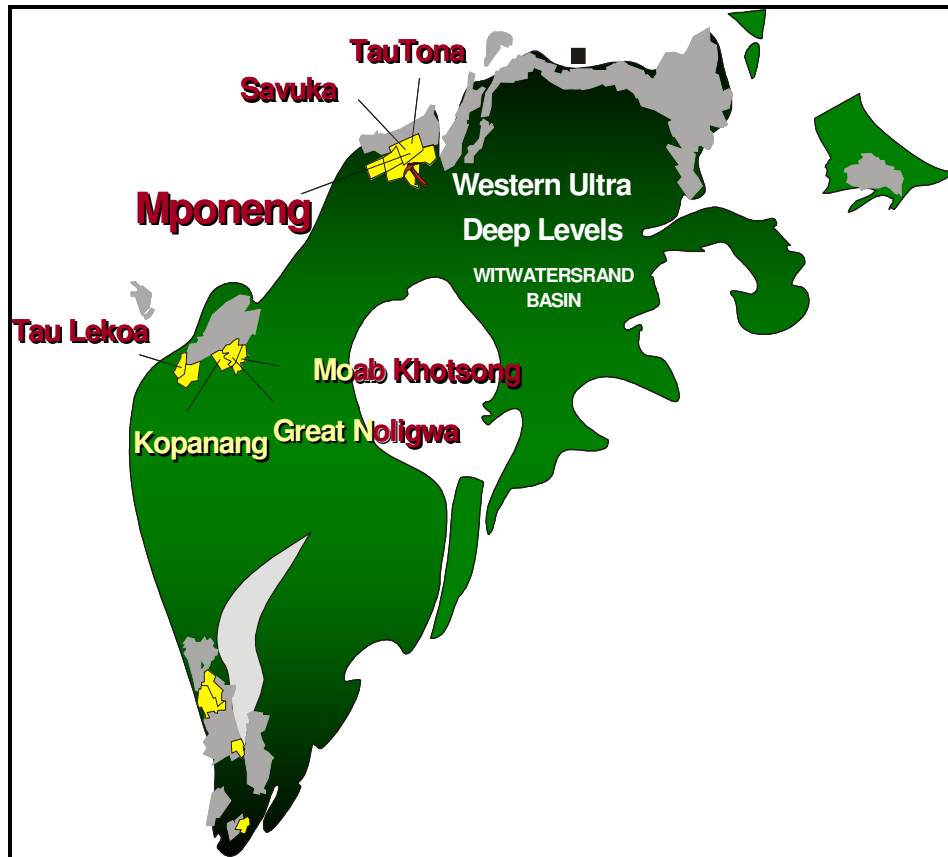


Figure 47: Map of the West Wits complex [70]

Mponeng has a gold processing plant of its own, and TauTona and Savuka share a processing plant. In Figure 47 these Anglo Ashanti owned mines are shown on a map of the Witwatersrand Basin [70].

West Wits and the rest of the mining industry have been threatened by the inability of Eskom to provide electricity for the full power load required for safe operations as from 2007 [71]. This is something that Anglo Ashanti has acknowledged and the company is planning to engage in any electricity savings where ever possible.

4.3.2. Compressed air system layout and background

The West Wits Complex was also identified as an EE project in 2005 and submitted to Eskom for approval. West Wits has an interconnected compressed air ring system between the three mining operations with an isolation valve in the main system header separating Mponeng from TauTona and Savuka.

The basic layout of the total compressed air system is shown in Figure 48; the system has a total compressor installed power of 63.222 MW. In Table 11 below is a summary of all the compressors that form part of the West Wits Complex and the shafts where they are located.

Table 11: West Wits complex compressor summary

Mine	Compressor	Power [kW]	Total Power [MW]
Mponeng	Sulzer 1	5400	27.00
	Sulzer 2	5400	
	Sulzer 3	5400	
	Sulzer 4	5400	
	Sulzer 5	5400	
TauTona	Sulzer 1	5900	11.80
	Sulzer 2	5900	
Savuka	BTH1	3766	24.42
	BTH2	3766	
	BB1	4030	
	BB2	4030	
	BB3	4030	
	Sulzer	4800	

The isolation valve between Mponeng and TauTona is opened in the peak production hours of the mine from 07:00 to 14:00, and is closed during the rest of the day to minimise air leaks

and pressure drops in the main header. This assists in controlling the system pressure to the maximum required pressure on the ring system.

The communication backbone on West Wits is much better developed and the available capital can be utilised to upgrade compressors for optimal control.

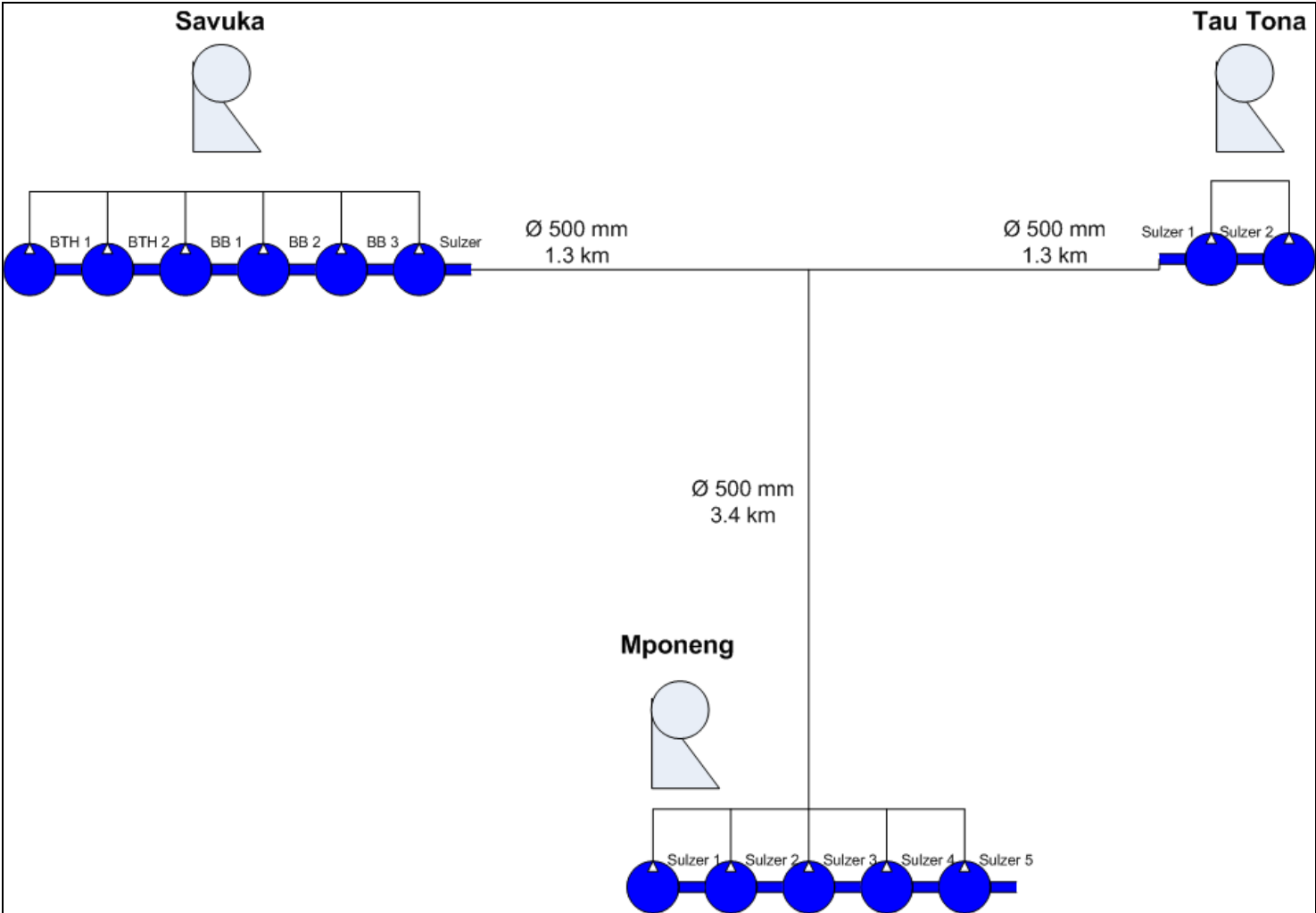


Figure 48: West Wits compressed air system layout⁵

4.3.3. Compressed air baseline and Energy Efficiency intervention

The baseline was set up and approved in 2005 and is illustrated in Figure 49 below. The Weekday, Saturday and Sunday baselines are once again separated. This is only because of the different compressed air requirements over weekends and the Eskom tariff structures.

The power baseline shown in Figure 49 shows that there is only a small peak between 07:00 and 14:00. This either means that there is “continuous mining” or the off-peak shifts have high potential for EE savings. Continuous mining is when there are no dedicated shifts and the work is continuously finished as soon as the requirements of the previous shifts are finished. In the case of continuous mining it is important to have compressed air available at all times.

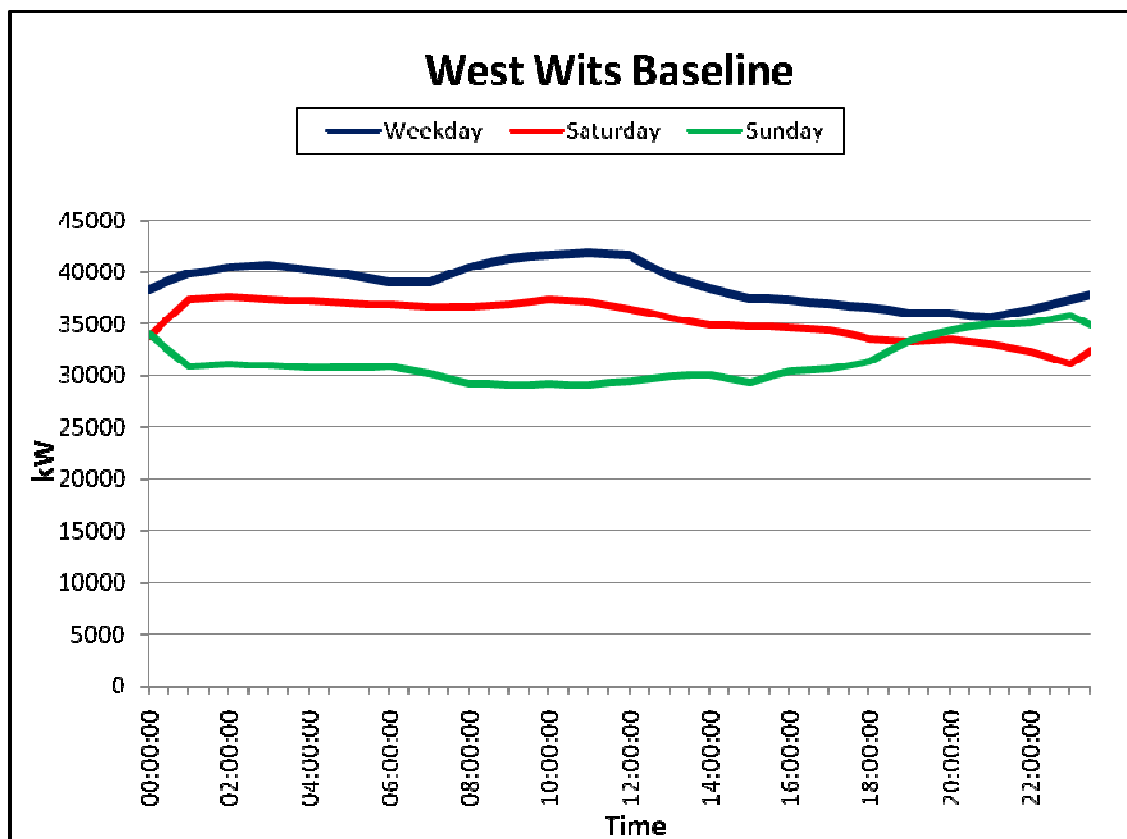


Figure 49: West Wits compressed air baseline

During the Research and Development (R&D) stage of this project it was verified that West Wits was not on any continuous mining schedule and rather had fixed shifts throughout the day. In simulating the compressed air system it was assumed that the mine had a peak compressed air period from 07:00 to 14:00.

The simulation software, REMS3, was once again used to predict the possible savings achievable on this project. The estimated savings with optimised control and the control of the total system pressure at each shaft/station were calculated as indicated in Table 12 below.

Table 12: Simulated Energy Efficiency demand savings for West Wits

Energy Efficiency Strategy	Total (MW)
Optimised Compressor Control and System Pressure Control	11.25
Eliminating Compressed Air Leaks	1.20
Total Energy Efficiency Demand Saving	12.45
Total Energy Efficiency as Percentage	29.68 %
Maximum Achievable R/c Savings per Year	R 37 350 000.00
Savings Promised to Eskom by the ESCo	13.00

As part of the EE intervention implemented on this compressed air project the following strategies were implemented to achieve the above mentioned savings:

- Central Control Room.
 - Compressor control on compressors – mainly guide vane control.
 - Compressed air system monitoring.
- System Pressure Control.
 - SCVs at the main shafts/stations.
 - Total system pressure reduction during off-peak periods.
- Leak detection and management by mine personnel with the assistance of the CALD system.

The main focus of this project was to control the different shaft/station pressures according to the demand of the specific station. Different stations require different pressures at different time periods. The gold plants needs, for example, 0.5 – 1 bar lower pressure than the shafts. SCVs (pressure sustaining valves) were installed at the main shafts to control the downstream pressure by delivering the exact set point pressure at the individual stations or shafts.

In conjunction with the SCVs the compressor guide vanes are controlled to reduce the delivery of compressed air according to the system demand. The pressure build up caused by the SCVs on the upstream side of the valves results in optimised compressor control through the following:

- Guide vane control.
- Compressor selection.

This is all controlled from a CCR and the final result is substantial power savings.

4.3.4. Results and conclusion

Firstly the researcher examined the savings for the client. The savings for three consecutive summer months are shown in Table 13 below.

Table 13: Energy Efficiency results on West Wits for the client

	Energy Efficiency Savings (R/c)
Month 1	R 1 447 228.93
Month 2	R 1 516 144.60
Month 3	R 1 516 144.60
Total Saving	R 4 479 518.12

Secondly, and most possibly the most important, is the savings for Eskom because this is the main reason why Eskom funds EE projects. In Table 14 and Figure 50 are the savings made

on West Wits through EE strategies implemented on the mine compressed air system for the three consecutive summer months.

Table 14: Energy Efficiency results on West Wits for Eskom

	Energy Efficiency Demand Savings (MW)
Month 1	15.28
Month 2	14.62
Month 3	15.65
Average Demand Saving	15.18
Total Energy Efficiency as Percentage	36.19 %

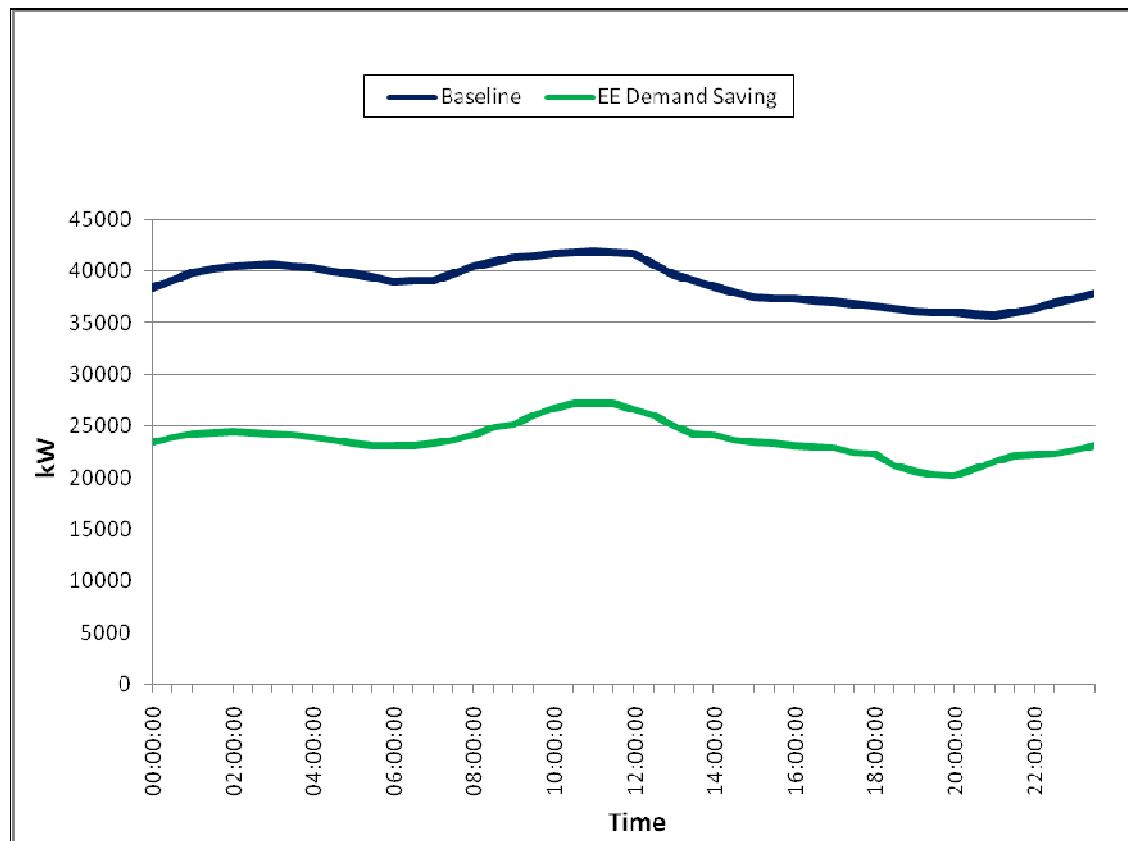


Figure 50: West Wits Energy Efficiency demand savings

All of the above results in a yearly saving of 95 GWh which is an equivalent energy saving of 341 070 GJ per year. An added benefit will be the 95 000 ton reduction in CO₂ emissions.

In conclusion, the EE strategies implemented on West Wits have shown considerable savings for the client and Eskom.

4.4. Vaal River Operations

4.4.1. Background

The Vaal River Operations is also part of the Anglo Gold Ashanti group and consists of four major operations. It is situated near the towns of Klerksdorp and Orkney in the North West and Free State provinces. The Vaal River Complex has four gold plants, one uranium plant and one sulphuric acid plant.

The four major operations at the Vaal River Complex are:

- Great Noligwa
- Kopanang
- Moab Khotsong
- Tau Lekoa

These four operations that form the Vaal River operations are also indicated on the map in Figure 47.

4.4.2. Compressed air system layout and background

The Vaal River Operations was identified as an EE project in 2005 and submitted to Eskom for approval, as with the previous case studies. Vaal River is an intricate compressed air system with 10 interconnected shafts:

- 1#, 2#, 3#, 4#, 5#, 6#, 7#,
- Great Nologwa
- Kopanang
- Moab Khotsong

The basic layout of the total compressed air system is shown in Figure 51 and the system has a total compressor installed power of 93.917 MW. This is one of the largest compressed air systems when looking at the installed capacities of the compressors. In Table 15 below is a summary of all the compressors that form part of the West Wits Complex and the shafts where they are located.

Table 15: Vaal River operations compressor summary

Mine/Shaft	Compressor	Power [kW]	Total Power [MW]
1#	BB Sulzer	4030	15.13
	B.T.H.	3767	
	GHH	3600	
	BGE	3730	
2#	Sulzer	4800	4.80
4#	Sulzer	4800	4.80
7#	Demag	3730	3.73
Great Nologwa	Sulzer	5900	17.70
	Sulzer	5900	
	Sulzer	5900	

Mine/Shaft	Compressor	Power [kW]	Total Power [MW]
Kopanang	Sulzer	15000	30.00
	Sulzer	15000	
Moab Khotsong	Demag	3730	7.46
	Demag	3730	
Moab Khotsong (Tau Leko)	Demag	10300	10.30

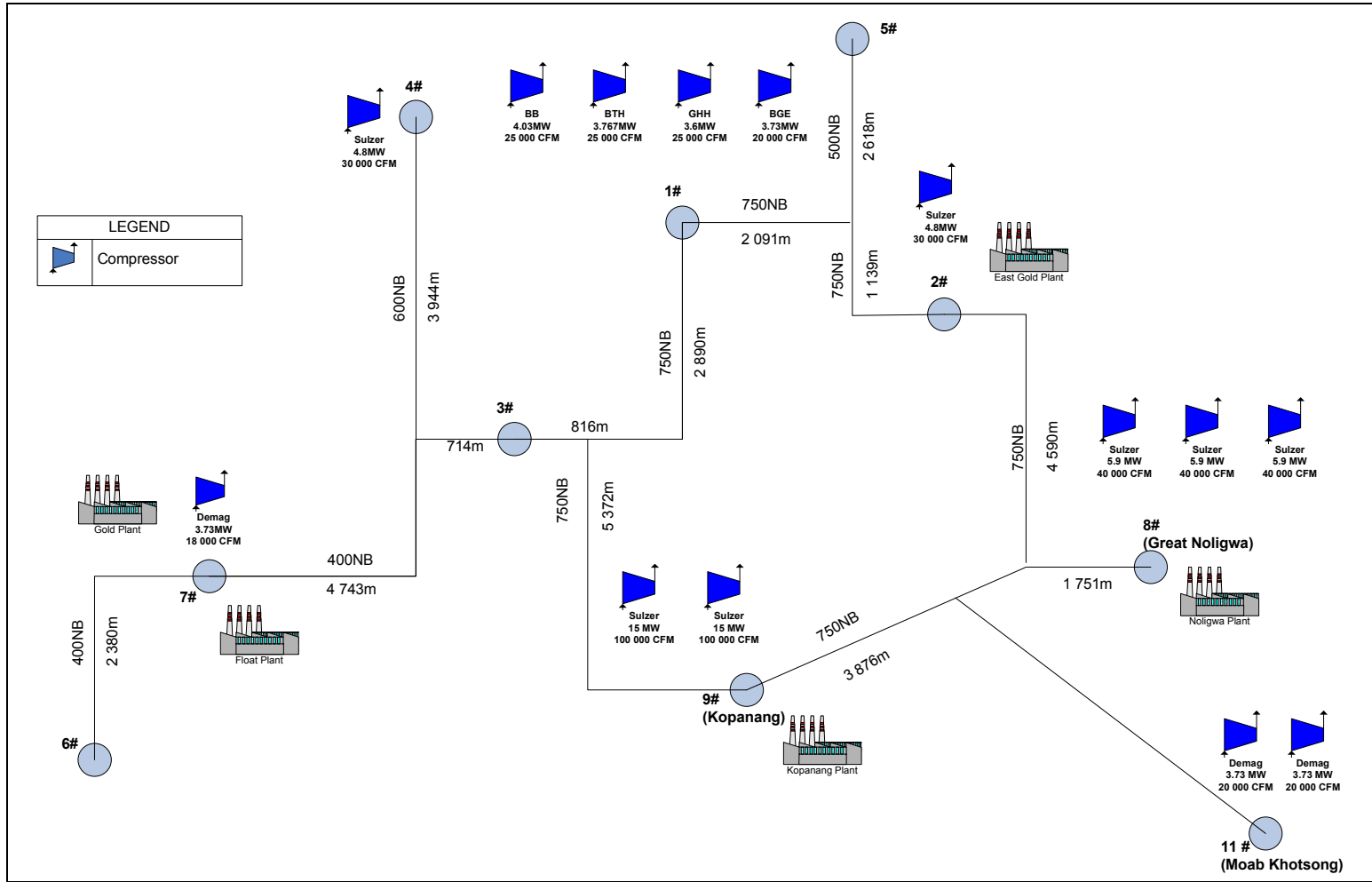


Figure 51: Vaal River compressed air system layout⁵

4.4.3. Compressed air baseline and Energy Efficiency intervention

In Figure 52 the baseline for the Vaal River operations is illustrated for Weekdays, Saturdays and Sundays. It is clear that Vaal River has a peak period in compressed air consumption from 07:00 to 14:00, usually referred to as the drill shift. The off peak power consumption is not much lower than the peak power consumption. This means that there is still massive scope for lowering the power consumption during off peak hours of the day.

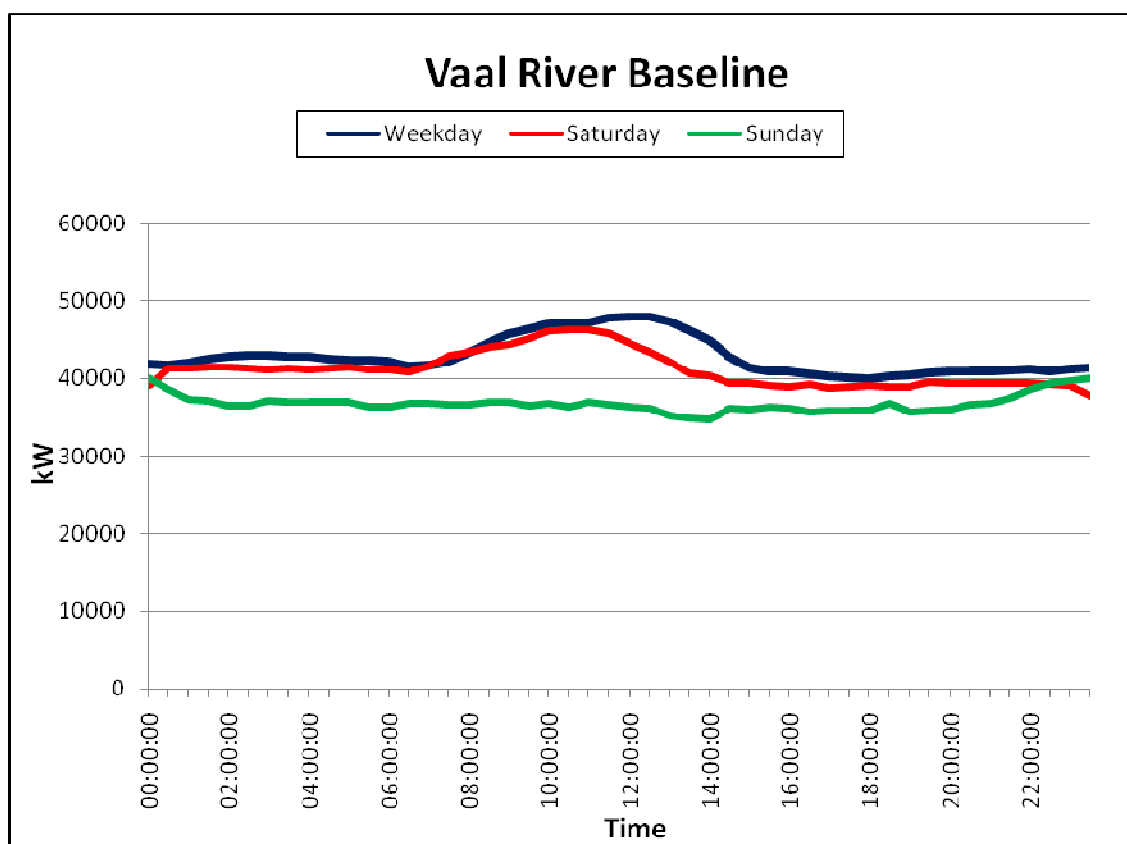


Figure 52: Vaal River compressed air baseline

During the Research and Development (R&D) stages of this project it was determined that the power consumption during the peak hours was being used effectively since the delivered compressed air was just sufficient to supply the demand of the Vaal River Operations. This results in lower Energy Efficiency savings on this project and is the result of the mine trying to save electricity wherever possible.

Therefore the possible EE savings on this project were not as high as could be expected from the installed capacities of the compressors. The scope for Peak Clipping/Load Reduction on this project is better than EE projects. The reason for the vast difference in system demand and the installed compressor capacity is due to the downscaling of production on some of the shafts in the compressed air ring. This does not really affect the control philosophy of the system as the most efficient compressors are operated and the excess compressors are used as standby machines.

The simulation software, REMS3, was once again used to predict the possible savings achievable. The estimated savings with optimised control and the control of the total system pressure at each shaft/station were calculated, as indicated in Table 16 below.

Table 16: Simulated Energy Efficiency demand savings for Vaal River

Energy Efficiency Strategy	Total (MW)
Optimised Compressor Control and System Pressure Control	6.20
Eliminating Compressed Air Leaks	1.00
Total Energy Efficiency Demand Saving	7.20
Total Energy Efficiency as Percentage	14.99 %
Maximum Achievable R/c Savings per Year	R 21 600 000.00
Savings Promised to Eskom by the ESCo	7.00

As part of the EE intervention implemented on this compressed air project, the following strategies were implemented to achieve the above mentioned savings:

- Central Control Room.
 - Compressor control on compressors – guide vane control.
 - Compressed air system monitoring.
- System Pressure Control.
 - SCVs at the main shafts/stations and isolation valves.
- Leak detection and management by mine personnel with the assistance of the CALD system.

The main focus on this project was to control the different shaft/station pressures according to the demand of the specific station. SCVs were installed at the main shafts to control the downstream pressure by delivering the exact set point pressure at the individual stations or shafts.

In conjunction with the SCVs the compressor guide vanes are controlled to cut back on the delivery of compressed air as is needed by the system. The pressure build up caused by the SCVs on the upstream side of the valves results in optimised compressor control through the following:

- Guide vane control.
- Optimal compressor selection.

The compressors were upgraded in order to be optimally controlled; the main upgrades included:

- PLCs.
- Control instrumentation.
- Condition monitoring instrumentation.
- Guide vane controllers (Moore).

This is all controlled from a CCR with the aid of servers, a SCADA platform and the REMS3 control infrastructure. The final result of these interventions is substantial power savings.

4.4.4. Results and conclusion

The cost savings for the client, over three consecutive summer months, is shown in Table 17 below.

Table 17: Energy Efficiency results on Vaal River for the client

	Energy Efficiency Savings (R/c)
Month 1	R 686 242.44
Month 2	R 626 569.18
Month 3	R 656 405.81
Total Saving	R 1 969 217.43

Secondly, and most possibly the most important, is the savings for Eskom because this is the main reason why Eskom funds EE projects. In Table 18 and Figure 53 below are the savings made on Vaal River through EE strategies implemented on the mine compressed air system for the three consecutive summer months.

Table 18: Energy Efficiency results on Vaal River for Eskom

	Energy Efficiency Demand Savings (MW)
Month 1	7.54
Month 2	6.07
Month 3	6.08
Average Demand Saving	6.56
Total Energy Efficiency as Percentage	13.66 %

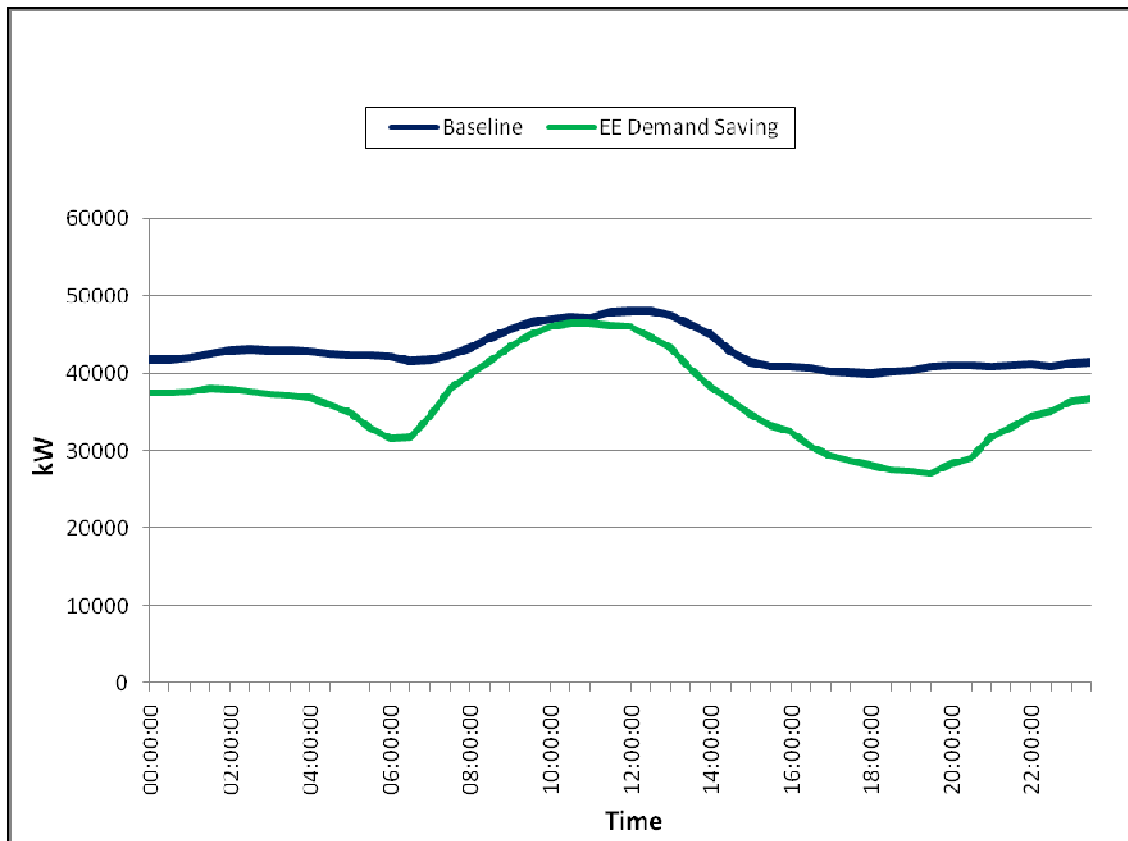


Figure 53: Vaal River Energy Efficiency demand savings

All of the above results in a yearly saving of 41 GWh which is an equivalent energy saving of 147 444 GJ per year. An added benefit will be the 41 000 ton reduction in CO₂ emissions.

In conclusion, the EE strategies implemented on Vaal River have shown considerable savings for the client and Eskom. The only reason that the predicted savings were not achieved is because the leak detection program was not implemented successfully by the client. During month 1 the overall demand on the mine was lower due to Eskom instructions to all their mining clients.

4.5. Conclusion

In conclusion it is important to examine which sections of the identified EE strategies were implemented for these clients, and why they were chosen in preference to other strategies. Most of the workable strategies have been set aside because they would require substantial infrastructure capital to implement.

The following strategies were identified as the most cost effective for the amount of capital available for Eskom EE projects:

- Central Control Room (Optimised Compressor Selection and Control).
- System Pressure Control mainly through SCVs.
- Leak detection and management programs.

There are many more savings strategies/methods identified in this study that can contribute to the efficiency drive in South Africa. These strategies are important to consider in the design of new compressed air system as they can be implemented at a reduced capital cost if they form part of the initial design.

The implementation of these strategies, as part of the EE drive in South Africa, can lead to savings of 10% to 35% of the maximum demand of the compressed air system. It can save the mines discussed in this research up to R108 million per year should the maximum possible energy efficiency be realised every day, according to the Eskom rates at the end of 2009.

CONCLUSION AND RECOMMENDATIONS



(Courtesy of <http://www.smcinvestment.com>)

This chapter will conclude the research and provide recommendations for any other further studies on this subject.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The constantly growing demand for electricity in South Africa and poor planning by the country's major electricity supplier has left much of South Africans in the dark for several hours. This has forced Eskom to implement various short and long term solutions to establish a safety margin of available electricity for days when unforeseen circumstances reduce the available electricity in the Eskom grid.

Typical examples of Eskom's long term solutions are to build new coal fired, base load power stations, and the extensive research into nuclear power and renewable energy alternatives. Short term solutions to their short supply situation have been the re-commissioning of power stations that were mothballed in the 1980s, and the implementation of Demand Side Management (DSM) projects.

DSM has been implemented in various projects in South Africa through different methods that include load reduction and Energy Efficiency. Through load reduction projects implemented by various ESCOs in South Africa, DSM has become a proven strategy in South Africa. Energy Efficiency has become more dominant over the past several years, especially in lighting and water heating projects. In comparison to building a complete new power station, DSM projects can be implemented at a fraction of the cost and the time that would be necessary to build a new power station.

The implementation of DSM projects has been to great advantage of the electricity user and Eskom. Eskom is in real need of the reduction of the load on their electricity grid more than

the direct financial savings. It is therefore important that any DSM project be implemented successfully for the life of the project.

Energy Efficiency projects on mine compressed air systems have not been high priority for Eskom as their first focus was the high peak hours of the day from 07:00 to 10:00 in the morning and 18:00 to 20:00 at night. In recent years Energy Efficiency has become more important and Eskom has funded more and more projects.

In this study opportunities were identified as to how Energy Efficiency could be achieved in compressed air systems, and more specifically, in the mining industry of South Africa. Various opportunities that were identified required too much capital input to achieve the potential savings on existing mine compressed air systems. However, these strategies will work exceptionally well on newly designed compressed air systems and should be taken into account during the design phase.

Identified strategies that could be achievable within the available budget received from Eskom were implemented on various mine systems, of which three were used as case studies in this research. These case studies have common Energy Efficiency strategies implemented on their compressed air systems because of the success of these strategies.

The identified strategies in this research with the best success and best return on investment include (and should not be limited to) the following:

- Central system control via a control room:
 - Optimal compressor control through guide vane control.
 - Optimal compressor selection – highest efficiency at all times.
- System pressure control:
 - Lowering the total system pressure within acceptable limits.
 - Controlling pressure of main air users by means of surface control valves.
- Detection and management of compressed air leaks.

Not only did Eskom receive substantial reductions on the grid power demand through these Energy Efficiency projects, but they also had far reaching financial savings for the end-user/client. Additional savings included savings on labour costs and maintenance costs which was not investigated in this study.

This study was successful in identifying Energy Efficiency opportunities on mine compressed air systems. In the case studies that formed part of this research, some of these opportunities/strategies were proven to be successful and sustainable. Savings of 10% of the maximum demand of the system can be achieved and these savings can increase to as much as 35% of the system maximum demand. The mines used in the case studies can have combined total savings of R108 million per year due to the Energy Efficiency strategies implemented.

When these types of projects are identified it is very important that the production and safety is not affected in any way as this will decrease the cooperation from the client in making these projects a success. All these projects were identified and implemented during a time in which the NERSA placed unofficial pressure on the mining industry to save on electricity consumption. It is therefore important to motivate the electricity user by achieving high savings without affecting their production and safety records.

Electricity savings will become the norm in the coming years with Eskom's increased cost of electricity in order to generate capital to increase the capacity of the power utility. Eskom will need to build up a safe margin of available generation capacity.

5.2. Recommendations

Further studies in this area of research will always be of great value with the ever changing technology and the technological advances made in this century. Identifying ways to save electricity will always be regarded as valuable studies.

Recommended areas of research include the strategies that were identified in this research but could not be verified as they did not form part of the planning of the project. These include designing the distribution system for minimum pressure drops and at the ideal flow velocity. Two subjects that should have great impact on the Energy Efficiency of a system are using Variable Speed Drives (VSDs) and Underground Control Valves (UCVs). Most of these were influenced by the high capital cost necessary to implement. They can be implemented on the mines and form case studies as Phase 2 of the project if Eskom agrees to finance further electricity savings.

An in-depth study should also be conducted as to how the automation of the compressors affects the maintenance necessary on these compressors, and how it affects the Total Cost of Ownership (TCO) for the client.

A valuable study from the Eskom perspective would be to investigate the costs involved to realise electricity demand savings through DSM in comparison to providing new power station capacity. This can also include the time difference as Eskom would need the best solution in the shortest possible time but this could change in future. Another important factor is the sustainability of DSM savings where additional power station capacity would be readily available and sustainable.

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