
***Implementing energy efficiency measures
on the compressed air network of old
South African mines***

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Abstract

Title: Implementing energy efficiency measures on the compressed air network of old South African mines

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In South Africa, the energy supply constraint has been in force since 2003. Eskom introduced the Demand Side Management (DSM) programme to help reduce the load on the electrical network. The mining industry is one of the major electricity consumers, thus offering potentially significant load efficiency strategies. This will benefit both Eskom and the mines. Less electricity will need to be generated by Eskom and the mining industry will benefit through financial savings.

The DSM programme was successfully implemented at various mines in South Africa. In this study an investigation was done on implementing DSM strategies on an old South African mine. The focus of this dissertation is on the compressed air network of the mine, where compressors are one of the major electrical consumers.

The compressed air network can be divided into the supply- and demand side. By focusing on both of these, effective control was implemented at a specific mine. The implementation entailed thorough research on the compressed air systems at mines and the concept of energy efficiency. Further research on the challenges associated with implementing the energy efficiency demand-side management (EE/DSM) strategies at an old mine was conducted. Older mines use outdated infrastructure and energy-intensive mining methods, making them good candidates for energy savings.

A simulation was done to indicate the effect of underground valve control in a compressed air network. The simulation presents the effect of increased pressure by active compressed air control on each of the mining levels. A decrease in pressure will result in lowered operation of the compressors.

The implementation of EE/DSM was successfully completed for this case study, which resulted in an average saving of 1.80 MW (91.6% of the target savings) for the three performance assessment months. To achieve this savings the Real-time Energy Management System (REMS) was installed to ensure automatic control on the newly installed infrastructure for the compressed air network. Due to the successful implementation of the project, the client benefitted from large financial savings. Furthermore, it was demonstrated that EE/DSM strategies could be successfully implemented on the compressed air systems of old gold mines.

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Abbreviations

BB – Brown, Boveri and Company
BOP – Blow-off Percentage
CAC – Compressed Air Challenge
CRCED – Centre for Research and Continued Engineering
DME – Department of Minerals and Energy
DSM – Demand Side Management
FY – Financial Year
EE – Energy Efficiency
EE/DSM – Energy Efficiency for Demand Side Management
EMS – Energy Management System
ESCO – Energy Services Company
FP – Fridge Plant
GDP – Gross Domestic Product
HT – High Tension
kW – Kilowatt
kWh – Kilowatt-hour
M&V – Measurement and Verification
MD – Maximum Demand
MI – Megalitre
MW – Megawatt
NERSA – The National Energy Regulator of South Africa
OAN – Optimised Air Network
OLE – Object Linking and Embedding
OPC – OLE for Process Control
PGM – Platinum Group Metals
PLC – Programmable Logic Controller
REMS – Real-time Energy Management System
SCADA – Supervisory Control and Data Acquisition
UPS – Uninterrupted Power Supply

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Chapter 1: INTRODUCTION AND BACKGROUND



This chapter gives the background of the mining industry in old South African gold mines and the problems associated with implementing a demand-side management project on a compressed air network. Where the mining industry is outlined as big electrical consumers a reduction of the electrical load will lessen the stress of the South African energy crisis (Van Der Merwe, 2007).

1.1 South African gold mining industry

Mining in South Africa started in 1867 after the discovery of the first diamond on the banks of the Orange River by Erasmus Jacobus. A couple of years later diamond mining began at Kimberly, fundamentally changing the South African economy and signalling the start of the mining industry in South Africa (Projects IQ, 2011a). It later became known that South Africa has the richest mining reserves in the world. South Africa ranked first in aluminosilicates (andalusite), chromite, ferrochrome, gold, manganese, PGM, vanadium, and vermiculite, and second in production of titanium minerals – chiefly ilmenite – and zirconium (USGS, 2005). South Africa produced more than Russia, Australia and the United States of America. In 1994, the United States of America (USA) became the second largest producer (Ramos, 2010).

For more than 130 years the mining industry created positive growth and development opportunities for numerous other industries – energy, financial services, water services, engineering services, specialist seismic, geological and metallurgical services – for using its products or supplying the mining industry (SouthAfrica.info, 2011).

South Africa's gold resources represent about 40% of the total of the world reserves. Figure 1 represents the respective countries' contribution to the world gold production, while Table 1 reflects each country's gold production and revenue gained from 1997 to 2006 (Conradie, 2008).

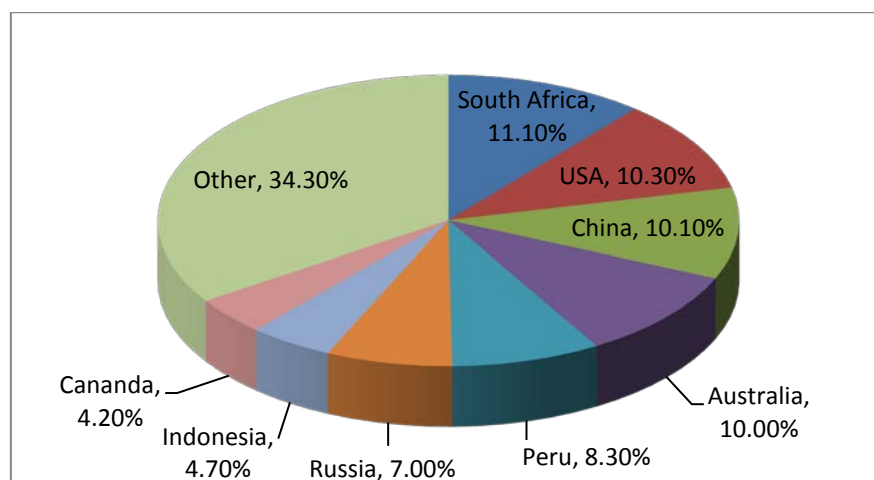


Figure 1: World gold production in 2006 (Conradie, 2008)

Table 1: World gold resources (Conradie, 2008)

Country	Reserve base		
	Tons (t)	Percentage (%)	Rank
South Africa	36 000	40.1	1
Australia	6 000	6.7	2
China	4 100	4.6	3
Peru	4 100	4.6	3
USA	3 700	4.1	5
Canada	3 500	3.9	6
Russia	3 500	3.9	6
Indonesia	2 800	3.1	8
Other	26 000	29	-
TOTAL	89 700	100	

Table 1 indicates that South Africa was the largest producer of gold resources in 2006. Since 1970, a number of challenges arose due to significant consolidation, escalating cost of mining below 3 000m and worsening ore grades of gold. Therefore, in the South African mining industry more energy is required to produce each ton of gold (Conradie, 2008; DME, 2002; Van Der Merwe, 2007).

In the 30 years leading up to 2000 this caused a decline in the gold production. The situation continued between 2002 and mid-2005, because of the mining cost and the low rand-per-kilogram (R/kg) gold price (Davenport, 2011).

In 2007, South Africa was known as the world's largest producer of gold according to the Chamber of Mines (CM, 2011). This position has been held for over a century, before China took over as the world's biggest gold producer towards the end of 2007 (Nkosi, 2008).

In South Africa, gold mining typically involves methods such as panning, sluicing, dredging, hard-rock mining and by-product mining. The most effective method used for gold mining is hard-rock mining, since gold reserves are typically fully encased in rock deep underground. For deep-mining techniques industrial air cooling- and air quality control systems were developed for mines to reach unprecedented depths – the deepest being 3 900 metres (Projects IQ, 2011b).

Table 2 lists gold mining companies in South Africa. For each mining company the number of mine shafts and the number of shafts in production is indicated (24hGold, 2011).

Table 2: Gold mine companies (24hGold, 2011)

	Gold mine company	Mine shafts	In production
1	Harmony Gold	47	42
2	Gold Fields	6	6
3	Wits Gold	7	0
4	AngloGold	10	9
5	Lonmin	7	5
6	DRDGOLD	5	5
7	Central Rand Gold	1	1
8	First Uranium	2	2
9	Great Basin Gold	1	1
10	Uranium One	1	0
11	Vantage Goldfields	4	1
12	Franco-Nevada	3	3
13	Gold One	5	2
14	Pan African Resources	2	1
15	Mintails	2	2
16	Eastern Goldfields	7	1
17	Galaxy Gold	1	1
18	Metorex	2	1
19	West Wits Mining	1	0
20	African Rainbow Minerals	1	1
21	Implats	3	2
22	New Dawn Mining	1	0

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Out of the 119 gold mine shafts, 72.27% of the shafts are in production. The other mines are in the developing phase and have not yet reached production (24hGold, 2011). In South Africa, most of these mines can be seen as old gold mines when they are compared to the high percentage of mines in production. To bring a new gold mine into production takes between 8 to 13 years from inception, with the average lifespan of a mine between 10 to 35 years, depending on the gold deposits (Virgin Gold Mining Corporation, 2011).

Due to the prolonged operating years of mines it is a difficult task to determine the age of South African mines. During a mine's lifetime over decades, it could have changed ownership several times. In South Africa, a mine's age is estimated through investigation of the mine's compressors. Table 3 lists various mines, showing the installed capacities, the age of the compressors and the mines' statuses.

Table 3: Installed compressor at different mine shafts

#	Mine	Compr. #	Type	Size (MW)	Year	Age	Status
1	Tshepong	1	Sulzer	4.8 MW	1985	26	Mining
		2	Sulzer	4.8 MW	1985	26	
		3	Sulzer	4.8 MW	1985	26	
		4	Sulzer	4.8 MW	1985	26	
2	Nyala	1	Sulzer	3.95 MW	1974	37	No mining, compressors feed to Phakisa mine
		2	Sulzer	3.95 MW	1977	34	
		3	Sulzer	4.8 MW	1980	31	
		4	Hitachi	4.8 MW	1983	28	
3	Beatrix 4	5,6	Siemens	5.1 MW	1988	23	Mining
4	Bambanani	1	BB	3.0 MW	1962	49	Shaft pillar mining, 12 years left
		2	GHH	3.95 MW	1974	37	
		3	Sulzer	4.8 MW	1981	30	
5	Masimong 2	1	Martninusen & Routts	3 MW	1950	61	No mining, used for gold plant
6	Masimong 3	1	Sulzer	3.95 MW	1974	37	No mining, used for 5#
7	Masimong 4	1	Hitachi	4.8 MW	1981	30	Minimum Mining, backup for 4#
8	Masimong 5	1	Sulzer	4.33 MW	1985	26	Mining
		2	Sulzer	4.8 MW	1985	26	
9	Amandalbult - Dishaba	1	BB - Sulzer	4.8 MW	1973	38	Mining
		2	BB - Sulzer	4.8 MW	1973	38	
10	Amandalbult - Tumela	1	Centac	4.8 MW	1989	22	Mining
		2	Centac	4.8 MW	1989	22	

Compressors need to be installed on a gold mine shaft for production to take place. Therefore, the age of the compressors were used as an estimate for the age of the mines. Over the years the compressors might have been upgraded, or replaced with newer compressors, thus influencing the age of the mine. In some cases a compressor could have been moved from one mining site to another.

The information in Table 3 was gathered by examining the compressors and doing interviews with the mining personnel at the mines. Acknowledgement is given to the people who were involved with the investigation. From the collected data in Table 3 the following can be observed:

- 50% of the mines are still in production, which the exception of the shaft pillar mining at Bambanani.
- 48% of the installed compressors are 20 to 29 years old and are still mining, with the exception of Dishaba, with compressors with an age of 38 years.
- 43% of the installed compressors are 30 to 39 years old and minimum mining takes place, except at Dishaba as mentioned above.
- 10% of the compressors are more than 40 years old; of the two mines one has been closed and the other is in the process of shutting down.

The information gathered gives an indication of the typical age of the gold mines. From Table 3 it can be seen that all the mines have been in production for more than 20 years; approximately another 10 years can be added for the mine to reach the production phase. From the ten mine shafts visited, most of them are considered to be old South African mines.

With most of the mines more than 30 years old, and the deep-mining techniques used, it can be concluded that these old mines of South Africa are very energy intensive.

1.2 Energy usage in South African and the mining sector

1.2.1 Overview

South Africa is the main producer of electricity on the African continent. In 2007, South Africa generated 43% of the total electricity of Africa. About 92% of the electricity produced by the national electricity provider, Eskom, is generated from coal, 5% from nuclear energy and 3% from other resources (Inglesi-Lotz & Blignaut, 2011).

The requirement for sustainable energy supply has become a worldwide challenge because of the rapid increase in the world population as well as economic development. In both developed and developing countries there is an increase in the demand for energy. An increase in demand was also experienced in South Africa (DME, 2008). Between 2006 and 2030, the world's primary energy needs is estimated to increase by 45% (IEA, 2010), (Mandil, 2005). This is equivalent to an annual compounded increase of 1.56% in world energy demand over a 24-year period (DME, 2005). The expected increase in demand for energy is shown in Figure 2.

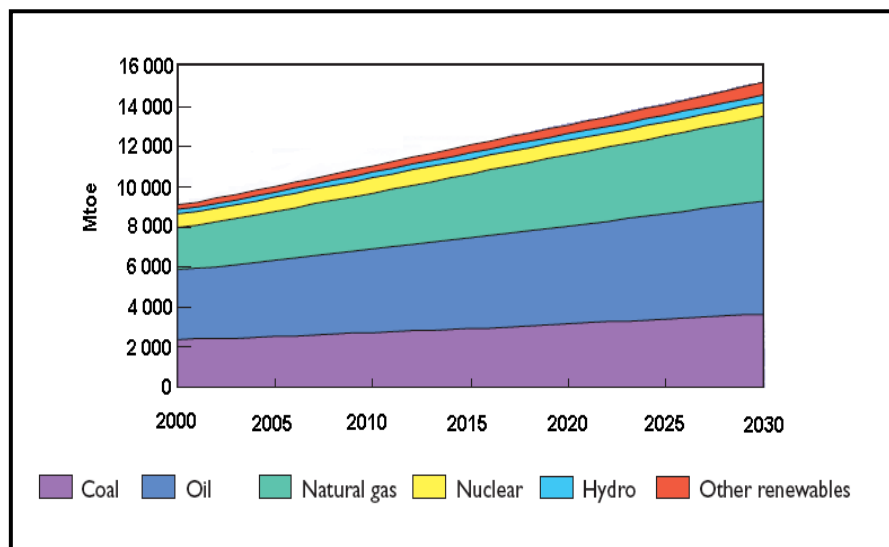


Figure 2: Increasing demand for energy in the world (Mandil, 2005)

In developing countries such as South Africa, the maximum supply capacity of electricity to meet the demand is being approached. The availability of energy supply became a global concern and there is worldwide need to conserve energy. The historical and the projected energy consumptions are shown in Figure 3.

Figure 3 shows that worldwide the total energy consumption increased from 299×10^9 GJ in 1980 to 498×10^9 GJ in 2006 (EIA, 2009). During the 26 years there has been an increase of 60% in the world energy consumption. A further increase of 70% in world energy consumption is forecasted from 2009, for the next 21 years (EIA, 2009).

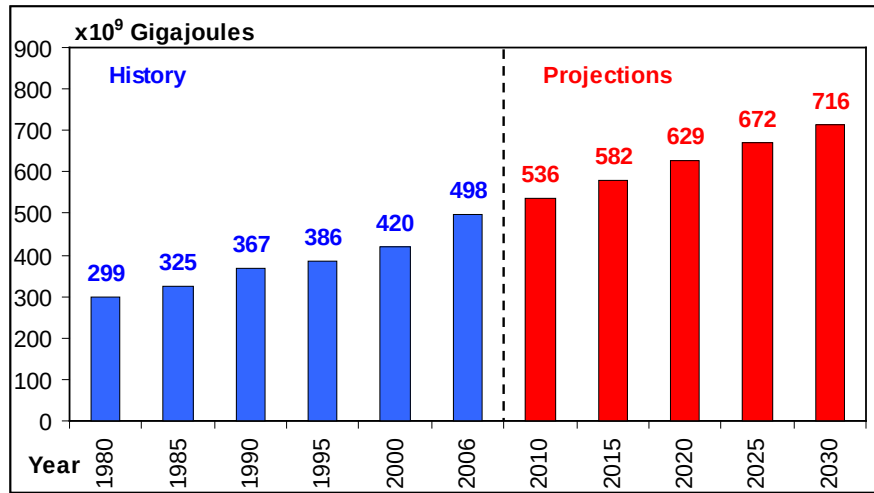


Figure 3: World historical and projected energy consumption by 2030 (EIA, 2009)

Figure 4 shows the trend and the supply capacity of Eskom (Surtees, 2001). The significant growth in electricity in South Africa resulted in load-shedding during 2008 (DME, 2008). In 2007, the maximum forecast was exceeded by the maximum demand for electricity.

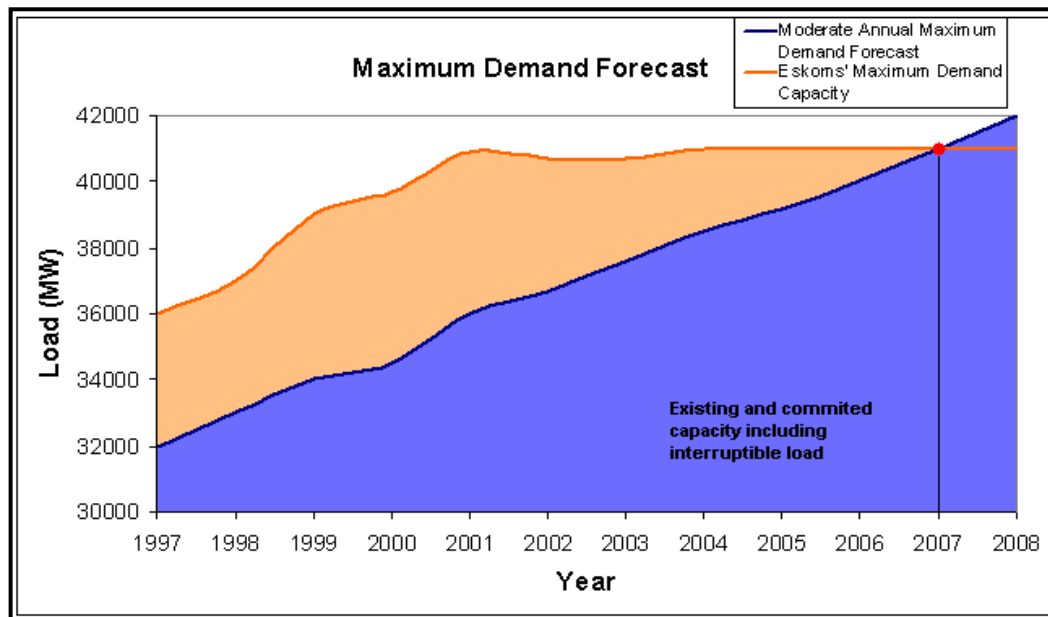


Figure 4: Eskom capacity status and maximum demand forecast (Surtees, 2001)

With the ever-growing electricity demand, the national load profile in South Africa became a huge concern. The morning and the evening peaks in the national demand profile became problematic (Pieters, 2003). It is possible that, in the near future, the country will run out of generation capacity

during these peak periods. To avoid running out of capacity, and to lower the problematic energy morning and evening peaks, demand-side management became more important and was introduced (Pieters, 2003), (CM, 2008).

The South African demand profile is indicated in Figure 5, which shows the morning and the evening peak for a typical summer day (1 February – 15 April 2008 and 1 October – 15 December 2008), a typical winter day (15 May – 15 August 2008) and a peak-demand day (14 July 2008) for the year 2008.

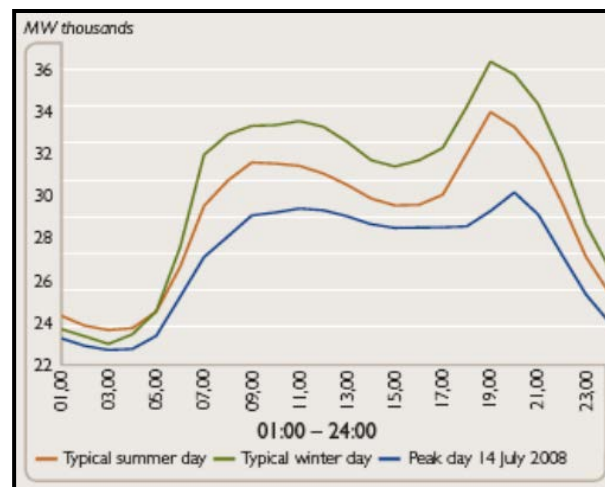


Figure 5: Weekday electricity demand profile for South Africa (CM, 2008)

Demand-side management overview

Demand-side management is a well-known method to solve a country's problem of rapid increase for the demand of electricity, and to increase the electricity supply reserves. Demand-side management is the term used for the planning and implementation of activities used for altering or manipulating the energy load profile or load shape at the end-user's side (Eskom, 2004).

The DSM initiatives used to reduce the electricity demand is equivalent to the electricity that Eskom would have generated. This saved energy – as a result of DSM programmes – can be seen as virtual power stations. Additional capacity is freed up by reducing demand. Eskom announced high electricity tariff increases starting with 31.3% from 1 July 2009 (De Bruyn, 2009), with future increases of 24.8% as from April 2010, and subsequent increases of 25.8% for 2011/12 and 25.9% for 2012/13, approved by the National Energy Regulator of South Africa (NERSA) (Creamer, 2010). Thus, it is financially important to implement DSM strategies, especially in the mining industry. The most

commonly applied DSM interventions are: peak-clipping, valley-filling, load-shifting, and energy efficiency (ESRU, 2001). In this case study energy efficiency was implemented on a compressed air network of an old gold mine.

The DSM intervention - peak-clipping - reduces the electricity consumption during Eskom's peak demand, while the rest of the day's consumption remains unchanged. Valley-filling boosts off-peak loads, which may be particularly desirable to a utility for those times of the year, or day, when the average price of electricity is cheaper. Concentrating operational times to the lower priced off-peak periods will decrease the average electricity cost to customers

The energy efficiency principle

The energy efficiency principle (also known as strategic conservation) reduces the load curve over a 24-hour period. The EE/DSM was introduced in 2005 by the Department of Minerals and Energy (DME, 2005).

Energy efficiency technologies will lead to energy demand reduction and to less greenhouse gas emissions (CIPEC, 2002). South Africa remains one of the highest emitters of the greenhouse gas CO₂ per capita in the world (DME, 2005). Other benefits include reduced maintenance and equipment replacement costs due to reduced operations. Fewer risks associated with generation, such as low energy demand and fluctuating interest rates and fuel prices, are also beneficial (Kruger, 2006).

The principle of EE/DSM is represented in Figure 6, where consumers are encouraged to reduce their electricity consumption, or baseline, for the overall system over a 24-hour period in a continuous and sustainable way (ESRU, 2001).

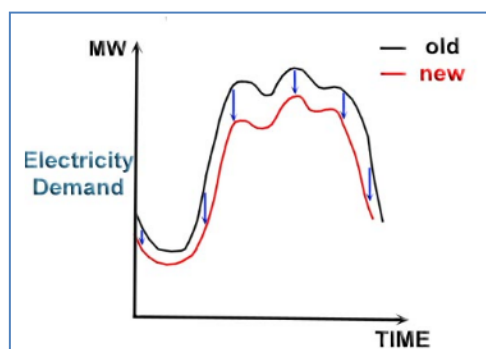


Figure 6: DSM by means of the energy efficiency principle

1.2.2 Electricity usage in the mining sector

The mining industry is one of the major energy consumers in South Africa, consuming approximately 23% of the total power generated (DME, 2002).

The South African mining is the foundation upon which the country's economy is built (CM, 2009), where the manufacturing and agricultural sectors benefitted from the mining industry and showed positive growth (Eskom, 2010). Therefore, the growing mining industry and their requirement for electrical energy drove the need of the electricity supply in the first years of the twentieth century (Davidson & Winkler, 2003), (Winkler, 2006).

In 2007, the mining and the industrial/manufacturing sectors were responsible for 53% of the total energy consumed (CM, 2009). To apply EE/DSM interventions to the mining and the industrial/manufacturing sectors will result in significant impacts on the national energy demand profile. As seen in Figure 7, in 2010 the electrical sales to the mining industry – the third biggest consumer of electricity – consisted of 14.5%.

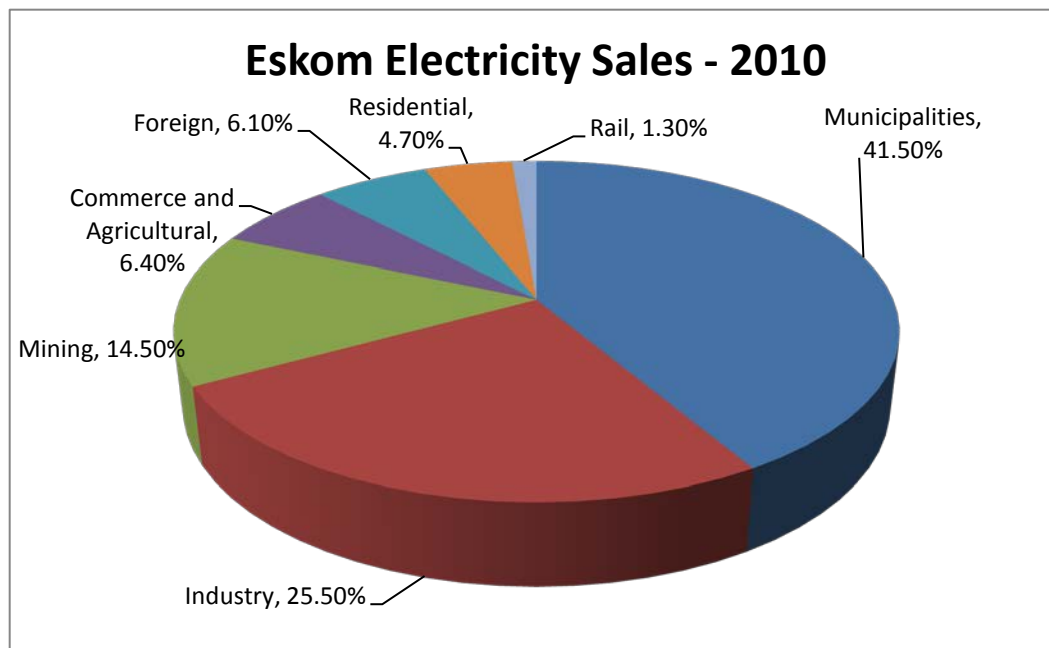


Figure 7: Eskom electricity sales for 2010 (CM, 2009)

By realising the need for DSM to reduce the electricity demand, several projects have been completed by Energy Savings Companies (ESCOs). Projects, such as the following, were done on high electrical consumers of the mine:

- Water circulation (pump projects)
- Refrigeration system (fridge plant projects)
- Rock/man winders (winder projects)
- Compressed air optimisation (compressor projects)

Eskom's variable time-of-use pricing structure

In order to encourage the large industrial consumers to lower their electricity usage during certain times, Eskom introduced the time-of-use (TOU) pricing structure. The electricity tariff in the high peak periods was increased, while the electricity tariff in the off-peak periods was lowered. This new tariff scheme encouraged clients to examine their energy profiles and to develop an energy-conscious community (Eskom, 2011).

A complex TOU structure is shown in Figure 8. The figure design shows a peak period, a few intermediate peak periods, and an off-peak period. The Eskom Miniflex, Ruraflex and Megaflex tariffs use this tariff structure (Cousins, 2008). The Megaflex tariff is mostly used for urban, industrial and the mining industries (Eskom, 2011).

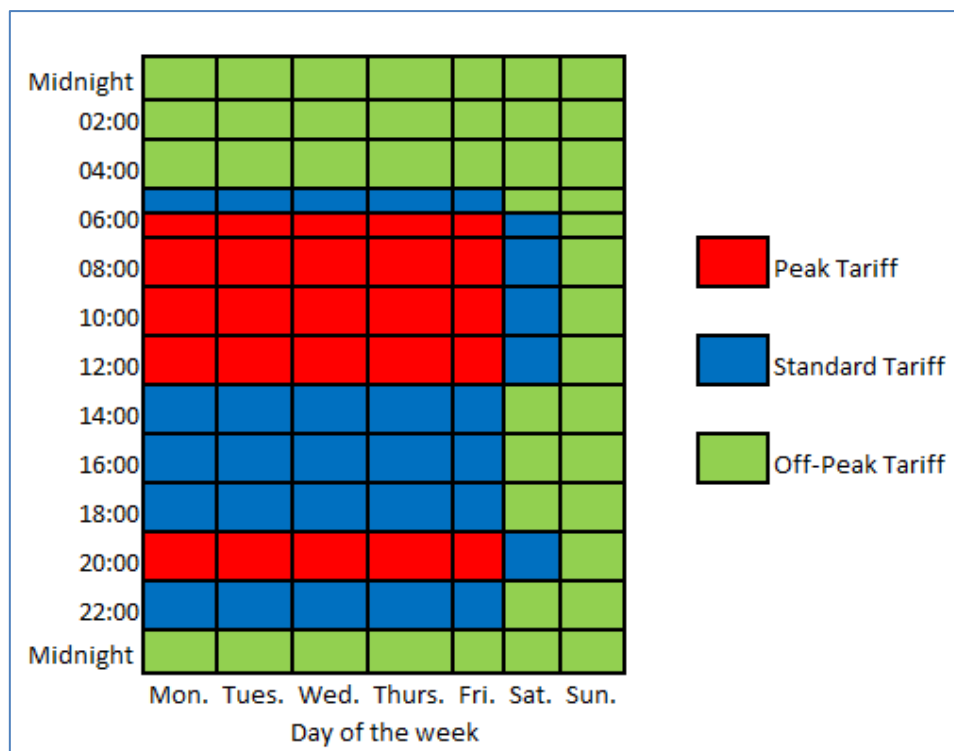


Figure 8: TOU Tariff (Cousins, 2008)

1.3 Problem statement and objectives of this study

In this study the possibility of implementing load efficiency strategies on the compressed air system of an old gold mine in South Africa is investigated. Research was done to determine the following:

- a. The demand-side management potential at an old gold mine of South Africa.
- b. Development of sustainable DSM energy strategies on old gold mines.
- c. Highlight the challenges presented during implementation of DSM energy savings strategies on old gold mines.
- d. Establish the feasibility and financial impact of the DSM strategies on old gold mines.

A single gold mine was used during this case study, which yielded various challenges related to a typical old South African gold mine.

1.4 Synopsis of this dissertation

Chapter 1 gives an introduction to the dissertation. The energy usage of mines is laid out and the DSM principle introduced to establish energy savings in the mining industry. Thereafter, implementation of energy efficiency on the compressed air system of such an old mine is suggested.

In **Chapter 2** the theory of investigating the DSM potential in an old South African gold mine is discussed. An overview of a typical compressed air layout is presented and the need for compressed air is outlined. Thereafter, the possibilities and the calculations for electrical energy savings are discussed for a specific old gold mine. Lastly, the challenges associated with implementing of these strategies are laid out.

In **Chapter 3** the specific mine for the case study is presented as the potential DSM candidate. The case study conformed to the criteria of being an old gold mine, with all the challenges that arose during the implementing of the DSM strategies. The process discussed in Chapter 2 is used to analyse the load efficiency of the compressed air system on this old gold mine.

In **Chapter 4** the results of the real-time load efficiency strategies is discussed. Thereafter, all the challenges associated with implementation and the DSM initiative in old mining environments are presented. The results are compared to the proposed savings found in the previous chapter.

Chapter 5 concludes this dissertation by summarising the feasibility of implementing a DSM initiative on the old gold mines in South Africa.

1.5 Conclusion

In South Africa, the generation and the use of electricity became a huge concern, as in several other countries in the world. Therefore, DSM projects present opportunities for electrical energy savings in the mining industry; in which the mining/industrial industry is a large consumer of electricity.

Over the years, DSM principles implemented on compressed air networks in the mining industry proved to be very successful. In this study, the implementation of a compressed air system of a specific old mine was investigated to see the feasibility of compressed air optimisation projects in old mines. The feasibility of DSM initiatives and the consequences resulting from this intervention were investigated and will follow in the next chapter.

Chapter 2: COMPRESSED AIR NETWORKS IN OLD GOLD MINES



This chapter gives a brief discussion of compressor usage in old South African mines. A basic description of the compressed air system, compressor operation and control is given. This is essential for implementing a compressed air control strategy that will reduce electrical energy consumption in old mines.

2.1 Introduction to compressed air usage in the mining industry

Compressed air represents one of the most essential components in many process and production environments (Foss, 2005). In the mining industry – especially gold and platinum mining – compressors are of the main electricity consumers. The purpose of compressed air usage will generally vary from one mine to another, and usually consists of many complex subsystems.

Compressed air is used to supply energy to the underground mining equipment and to create a safe working environment. Thus, it is one of the most important production components in the mining industry. Unfortunately, the generation of compressed air is very expensive and the least efficient utility in the mining industry (De La Vergne, 2003).

Air can be compressed by using one of two basic principles: the displacement principle or dynamic compression. See Appendix A, Figure 47 for the two basic compressor principles.

Displacement principle

The positive displacement piston compressor consists of a cylinder with inlet and outlet valves through which air is drawn in, compressed and then discharged through the outlet (exhaust) valve. The reciprocating (linear) movement of the heavy piston that moves at a relatively high speed means that large acceleration forces are experienced. This type of compressor is able to compress air to a very high pressure. Depending on the number of cylinders, compressed air will be delivered in a series of pulses. Piston compressors and the different types of rotary compressors are among displacement compressors. Displacement compressors are the most common compressors used in most countries (Lindeberg, 1998).

Dynamic compression

Dynamic compressors, categorised as either axial flow or radial flow compressors, are the most common type of compressor used in the industry (Brown, 1997). The great advantage of this type of compressor is in its relatively simple construction. The axial flow compressor consists of a series of rotating compressor blades. The radial flow compressor consists of single or multiple impellers. Because of the higher compression ratios obtainable from radial flow compressors, they are preferred by the mining industry.

The radial type compressor draws air into a rapidly rotating impeller where the air is compressed and accelerated to a high speed in a radial direction. This air then passes through a diffuser where the dynamic pressure is reduced and the static pressure increased (Lindeberg, 1998). A compressed air system can be divided into two types of systems:

Low-pressure system

Low-pressure compressed air is supplied by a blower and a typical system ranges between 50 kPa and 200 kPa. This type of system is mainly used in the mining industry for ventilation, flotation cells and in pressure tanks.

High-pressure system

In the mines the pressure is raised to approximately to 700 kPa in a high-pressure system, although this varies from mine to mine depending on their specific demand. Centrifugal compressors have proved to be the most popular type of compressor used in the mining environment (Brown, 1997). High-pressure systems are used extensively to supply compressed air to operational equipment and other production purposes in the mining industry.

2.2 Compressed air systems in the South African mining industry

2.2.1 Typical compressed air layout

Compressed air systems consist of a supply- and a demand side. The supply side includes the compressor and air-treatment systems, while the demand side includes distribution and storage systems as well as end-user equipment. A well-managed supply side will deliver stable, clean and dry air in a cost-effective manner at appropriate pressures; while the demand side minimises waste air and uses compressed air for appropriate applications. Addressing both the supply- and demand side – and how these interact with each other – is required to improve and maintain peak compressed air system performance (EERE, 2003).

A compressed air system usually consists of the following components (demonstrated in Figure 9) (UNEP, 2006), (EERE, 2003):

- Intake air filters:
The intake air filter prevents dust and small particles from entering the compressor which could result in malfunctioning valves, scoured cylinders and excessive wear.
- Compressor.
- Inter-stage coolers:
The inter-stage coolers reduce the air temperature before it enters the next stage. Cooling the air reduces the work of compression and increases efficiency. The coolers are normally water-cooled.
- After-coolers:
In the after-coolers the moisture in the air is removed by reducing the temperature in a water-cooled heat exchanger.
- Air dryers:
The air required for instrumentation and pneumatic equipment has to be relatively free of any moisture. The remaining traces of moisture are removed in the air dryers. Adsorbents - such as silica gel/activated carbon, refrigerant dryers, or heat of compression dryers - are used to remove the moisture.
- Moisture drain traps:
These drain traps are used in the compressed air lines for removal of moisture in the compressed air. The different kinds of traps used are manual drain cocks, timer-based/automatic drain valves, and so forth.

The typical compressed air layout of a mine is shown in Figure 9.

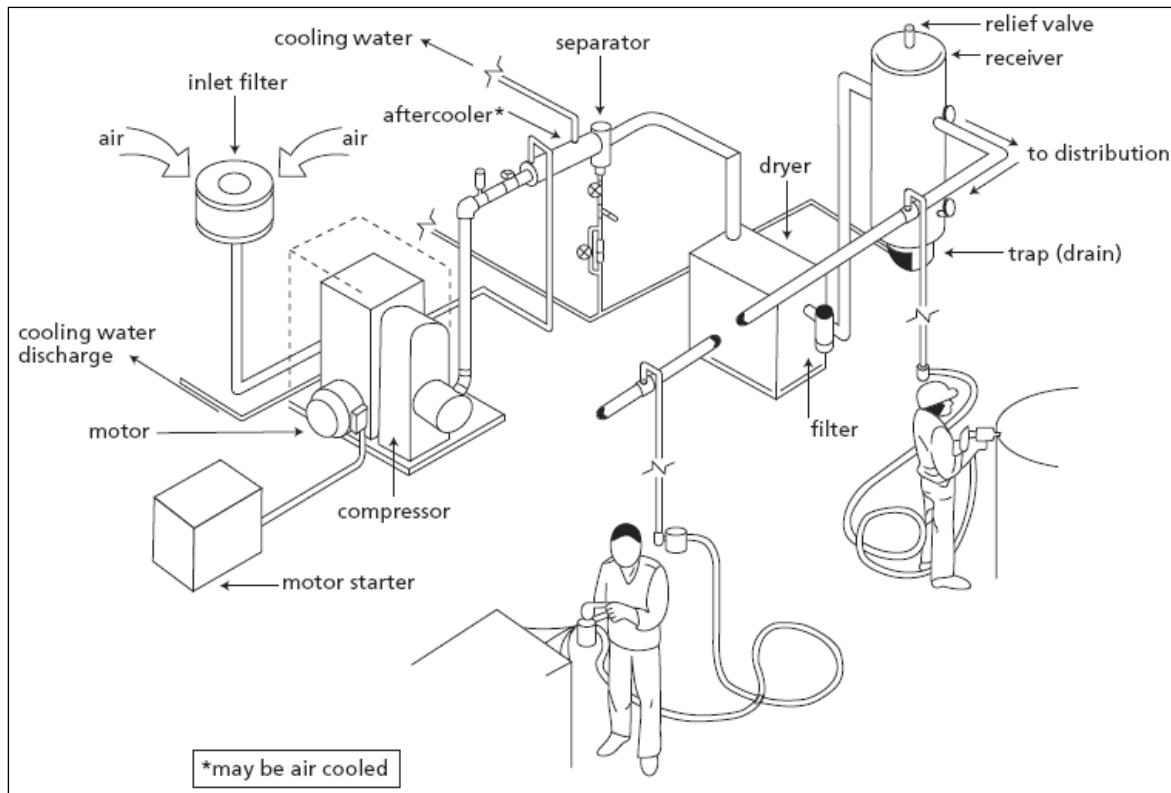


Figure 9: Layout of a compressed air system (De La Vergne, 2003)

The purpose of compressed air (demand side) will vary from mine to mine, but the most common uses for compressed air are as follows (De La Vergne, 2003):

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

To ensure an efficient compressed air network, regular maintenance and audits of all the compressed air users in the network should be done.

The compressed air demand is mainly affected by artificial demand, where compressed air is used for unregulated users. Unregulated users include (eCompressedAir, 2011):

- All unregulated consumption, including appropriate and inappropriate production usage
- Open blowing (open-end, usually done to cool down the miners)
- Leaks
- Points of use with regulators adjusted to their maximum setting

A detailed investigation into a mine's compressed air network is required to optimise operational schedules and ensure electrical energy cost savings.

2.2.2 Surge protection

Under certain conditions, centrifugal compressors are subject to surge. A compressor will usually encounter a surge condition when the outlet pressure is high and the mass airflow is low (DeltaV, 2007). If the surge is not controlled it can cause serious damage and even totally destroy the compressor (DeltaV, 2007), (Gravdahl, Egeland, & Vatland, 2002). It is essential to implement anti-surge protection on compressors so that compressors do not operate in the surge region.

In Figure 10, a characteristic curve of pressure ratio (P_d/P_s) – as a function of mass flow rate for various rotational speeds of a typical centrifugal compressor – is presented. During this study all the compressors at the mine ran at a constant speed, so that the 100% rpm line in Figure 10 is a more accurate representation of the surge description that follows.

The compressor will be running under normal operational conditions, in a region situated to the right of the red surge line. A small reduction in mass flow will result in a lower delivery pressure. The pressure of the downstream air is still at a higher pressure and will tend to reverse its direction. A decrease in the downstream pressure will eventually occur and the normal flow direction is again possible. This cycle is repeated at a high frequency, resulting in unstable airflow and extremely high compressor blade stresses (GMRC, 2008).

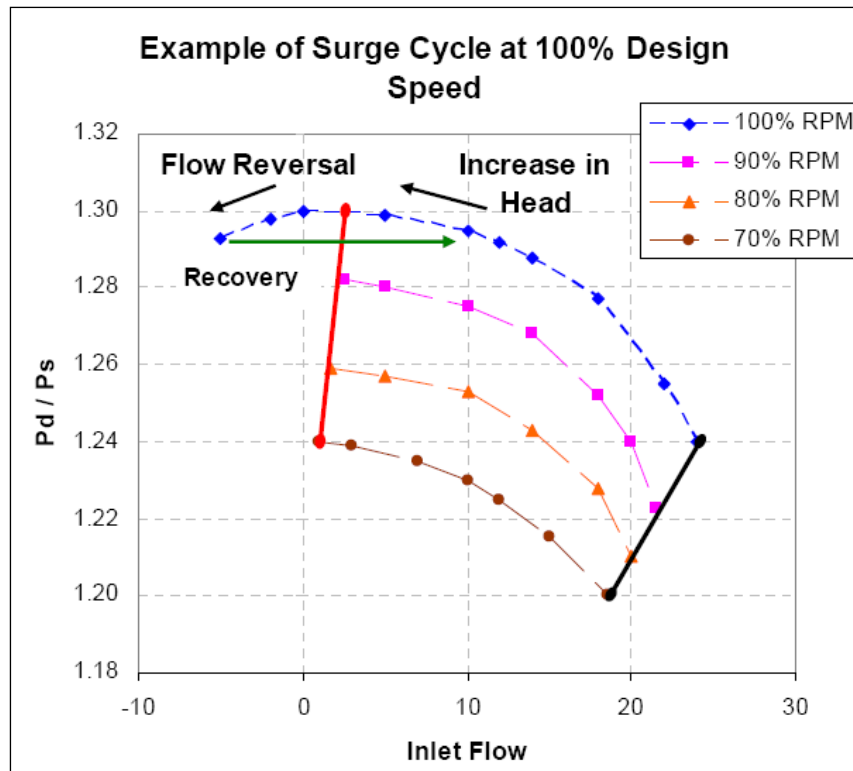


Figure 10: Typical compressor surge line and performance map (GMRC, 2008)

The typical methods employed for surge protection are as follows:

- Blow-off control into the atmosphere (DeltaV, 2007), (Siemens, 2005)
- Recirculation from the outlet to the inlet of the compressor (DeltaV, 2007), (Siemens, 2005)
- Compressor inlet vane control

An anti-surge surge control strategy is integrated with the compressor load control strategy.

2.2.3 Pressure drop in pipelines

In the mining industry the operational production areas are often spread out over long distances. It is not unusual to find pipelines of 40 km (and more) that are required to deliver high-pressure compressed air to the various work areas. Large pressure losses are experienced in these long delivery pipelines. Especially in old gold mines, the working area moved to new production levels when older levels are mined out. The compressed air pipeline is not necessarily removed from these worked-out sections and these can cause additional pressure losses if not properly sealed.

The pressure drop in a pipeline is dependent on (CII, 2000):

- Quantity of the airflow
- Diameter of the pipeline
- Pipe length
- Pipe geometry, i.e. the bends in the pipelines

Ideally, the pipe network should be designed with the minimum number of joints, bends and fittings. Welded joints are far more effective than flexible or screwed joints. A well-designed and installed pipeline will keep pressure losses and leakages to a minimum (CII, 2000).

2.2.4 Leak-detection

In an industrial compressed air system, leaks can cause a major impact on the efficiency of the system sometimes wasting between 20% and 30% of the compressor output (EERE 2003). A plant – or any system that uses compressed air – which is not well-maintained, can have a leak of 20% of the compressed air production capacity. Good maintenance and proper leak-detection and repair schedules can reduce leaks to less than 10% of the compressor output (EERE 2003).

In the case study represented in this dissertation, leak-detection becomes an important aspect to achieve financial savings. For example, an open-end leak can have a significant impact on the efficiency of the compressed air system. These results are presented and discussed in Chapter 4.

Leaks in any plant of the mining industry can contribute to operating losses. Large pressure losses will often cause pneumatically operated equipment to function improperly, decreasing the lifespan of the equipment and even the compressors. Furthermore, leaks will cause the equipment to be operated more often, increasing maintenance requirements and resulting in increased unscheduled downtime (EERE, 2003).

The most common problems areas are (CAC, 2011):

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

2.3 DSM opportunities in an old gold mine

DSM principles, and the implementation thereof, have become a common practice in South Africa, especially in the mining industry. These control strategies are being implemented as part of Eskom's nationwide DSM programme. The optimised control of compressed air is divided into two main categories:

- Supply-side control, and
- Demand-side control.

2.3.1 Supply-side control

The supply side refers to the optimised and controlled amount of compressed air that is delivered to the underground levels by the compressors.

Control of the compressors can be accomplished in various ways, of which the following are the most commonly used in old South African mines:

Start/stop

Start/stop, is one of the simplest compressor control methods and can be used on either reciprocating or rotary screw compressors (EERE, 2003). The motor driving the compressor is switched on and off by a simple pressure switch located on the control panel on the compressor house, as seen in Figure 11.

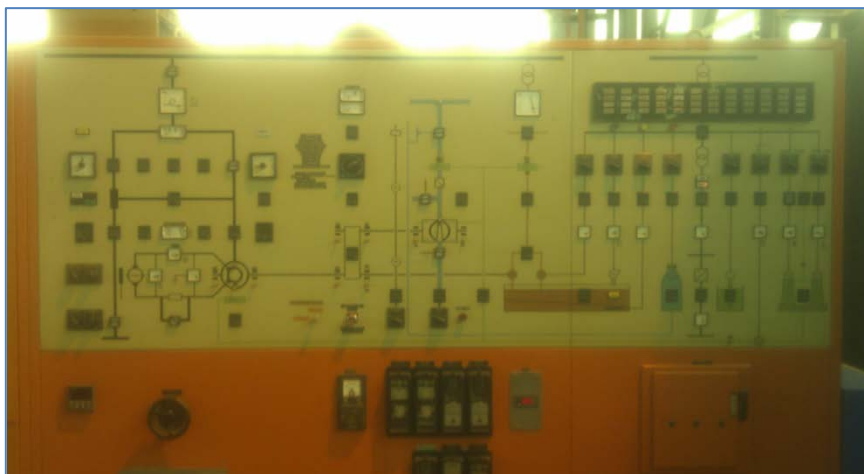


Figure 11: Typical compressor control panel at an old mine

Start/stop is a control method that is not used in an application that has frequent cycling. Repeated start-and-stops will cause the motor to overheat and will require more frequent maintenance on the compressor components (EERE, 2003), (UNEP, 2006). Large compressors in the mining industry are only stopped when there is reduced demand, or when the operation of an extra compressor is no longer required. When a compressor is stopped, it can only be started again after a certain time delay to allow for sufficient cooling. This is usually part of the compressor's control panel design and would typically be a countdown timer. This will allow the armature winding to cool down to a safe temperature before the next start-up is allowed.

On some old mines the control systems are so old that the mines are hesitant to stop compressors. Starting a compressor would entail the assistance of an electrician to ensure the start-up happens safely. In these cases the mine would prefer that the compressor runs continuously.

Load/unload

Load/unload control – also known as constant speed control – allows the compressor to run continuously, but unloads the compressor when the system pressure is adequate (EERE, 2003). This is an improved control method over the start/stop method and is accomplished by releasing, or blowing off, compressed air from the system into the atmosphere (Brown, 1997). Compressor blow-off valves open and compressed air is allowed to escape, allowing the compressor to run freely. In some of the mines additional pipelines are installed for the blow-off valve to release the excess compressed air into one of the underground levels. This is mainly due to the very loud noise a compressor generates when blowing off.

Compressor manufacturers use different strategies for unloading a compressor, but in most cases a compressor will consume 15% to 35% of the full load power while no compressed air is delivered to the network (EERE, 2003), (UNEP, 2006). The power needed is only to overcome basic friction of the motor itself and the compressor. In some instances the no-load power of old compressors is as high as 40%.

Modulating controls (inlet guide vane control)

Modulating (throttling) control varies the compressor output to meet the system flow requirements. This is usually done by open-and-closing the inlet valves (vane position) of the compressors that vary the inlet mass airflow to the compressor (EERE, 2003).

Closing (or throttling) the inlet valve will result in a reduction to the inlet pressure of the compressor and reduce the mass airflow (EERE, 2003).

Inlet valve modulation is normally limited to a vane opening range of 40% to 100% (EERE, 2003). Operating the compressor below this minimum inlet vane opening can cause the compressor to surge, as discussed in Section 2.2.2.

Compressors use a variety of different guide vane controllers, but the most common controller found on the older South African mines is the Moore controller. A Moore controller enables the compressor to operate at a predefined pressure profile or according to specific pressure set points. A 24-hour pressure profile can be programmed into the controller to meet the specific compressed air demand of an individual system.

Compressor selection

For effective demand-side control in a specific compressor system, optimal selection of an individual compressor is essential (Nguyen, Uraikul, Chan, & Tontiwachwuthikul, 2008). Most of the old mines in South Africa consist of several different centrifugal compressors varying in size, capacity and year model. Optimum selection of an individual compressor, or set of compressors, can significantly affect and improve on the overall system efficiency (Nguyen, Uraikul, Chan, & Tontiwachwuthikul, 2008) and lead to better financial savings.

The following parameters should be taken into account when selecting optimal compressor operation (Nguyen & Chan, 2006):

- The system demand
- Compressor performance and controllability
- Cost of operating a specific compressor
- Maintenance cost

In some cases one or more compressors operate together at full load with a modulating compressor. The modulating compressor is the compressor that will be controlled to maintain the required system pressure under higher demand conditions. The modulating compressor is controlled from 40% to 100% inlet guide vane position, while the full load compressor will be operated at 100% inlet guide vane position. In a system with a low compressed air demand, the fully loaded compressor can be stopped or unloaded, so that the modulating compressor can satisfy the reduced compressed air demand (Mcculloch, 2003).

2.3.2 Demand-side control

Demand-side control refers to the effective distribution and control of compressed air to the end-users, either for surface usages or underground mining. Compressed air demand-side control is the most important part when controlling a compressed air system. This is due to the difficulty of control and the impact of compressed air leaks on the entire compressed air system. The difficulty level of control increases with the number of end-users of compressed air and the age of the mine equipment.

Two main techniques used for control of the demand-side compressed air are:

- Surface control valves, and
- Underground control valves.

Surface control valves

A surface control valve will usually be installed in the main header just before the pipeline goes into the mine shaft, referred as the *bank* of the shaft. This valve controls the airflow to the underground mining levels.

Multiple surface control valves are installed at a mine with two or more mine shafts supplied from a single set of compressors. This will allow for a more accurate control of the compressed air usage between the shafts.

In some cases, a single surface control valve is sufficient to control the demand-side compressed air usage, depending on the complexity and the size of the mine.

Underground control valves

Underground control valves are installed on each of the working levels of a mine so that the compressed air to each of these levels can also be effectively controlled.

Installing a control valve on each of the working levels is a much more effective way of controlling the demand-side compressed air usage. In some cases it will be necessary to shut off the complete level for maintenance purposes. This minimises the compressed air wastage and is more effective than surface control valves.

Surfaces control valves and underground control valves are used in combination to allow for optimisation of the compressed air usage. Control of these valves is done with a Programmable Logic Control (PLC) which receives all the relevant information from the operational section that must be controlled. This includes inputs from the up- and downstream pressure and the compressed airflow and the temperature.

The energy efficiency methods discussed in Chapter 1 were used to implement a real-time energy management system at a specific mine, by implementing control on the supply- and demand side on the compressed air system. The results are given in Chapter 4.

2.4 Implementation challenges in old South African gold mines

When implementing a compressed air project in an old gold mine various challenges (as a result of unforeseen problems) will need to be solved. Most of these problems that are presented have not yet been encountered in the newer, more modern, South African gold mines.

Inevitably, these challenges may be responsible for project delays and reduced savings resulting in an increased financial burden. The typical challenges encountered on old gold mines are discussed in the following sections.

2.4.1 Absence of control infrastructure

Most of the systems and instrumentation on these mines made use of old and obsolete technologies, including analogue measuring devices. Very little, or no PLC technology usage was encountered on old mines. Some of the notable problems, and the proposed solutions, are:

a) No compressed air control and monitoring on the mining levels.

The absence of PLC control and the lack of proper infrastructure on the mine mean that automatic control is not possible. By installing appropriate instrumentation on the underground mining levels, adequate control can be implemented. Installation will include a PLC, controllable valve and the measuring devices for control.

b) Constant pressure set-point control on the compressors.

To establish proper control of the compressors a PLC must be installed and an updated control philosophy introduced. Usually the compressors make use of constant set-point control. By implementing the PLC control various set-point controls could be established. With the

completion of such a project, all the control could be done automatically with the aid of a remote real-time energy management system.

c) Inadequate training of the control room personnel.

With all the above mentioned technologies and automated control installed, training for the control room personnel will be necessary. The focus of the training will be to introduce the automated system; and how to operate and maintain the system.

2.4.2 Old infrastructure

The age of the mine has a large effect on its minimum installed equipment and compressed air network. Most of the old mines use old and outdated equipment and technologies. There appears to be a reluctance to replace the older equipment, while newer mines tend to update their technologies more often. Furthermore, regular maintenance has become more difficult, not just due to the age of the mine, but also due to the increased mining areas. The problems encountered with the old infrastructure and the solutions to the problems include:

a) Old and rusty isolation valves on the underground levels.

There is an isolation valve on each mining level. By installing the new proposed control valve and equipment it will - as part of the installation procedure - first be necessary to close the isolation valve. Due to the age of a mine, the valves may be seriously rusted and not in a proper working order. If a specific isolation valve at a mining level cannot be closed, the entire compressed air system will have to be stopped to allow for the installation of the new components.

The solution to this problem will be to first identify the operational condition of the isolation valves; then to schedule the installation for an off-mining weekend at the levels. An off-mining weekend usually occurs every second week which will allow underground maintenance to be scheduled. During an off-mining weekend it will be possible to stop all the compressors to allow for work on the pipe network without losing production.

b) Rusty compressed air pipes lines.

Rust is a major cause of increased friction and leaks in the compressed air supply lines. Rusty pipes will complicate the installation during the welding process required for fitting the valve

and the equipment. Therefore, more time will be required for the successful installation of the equipment. The condition of the pipes - which can only be seen in the inner lining of the pipeline - can only be investigated during the installation phase.

c) Obsolete mass airflow controllers.

Apart from the fact that there is minimum installed equipment at an old gold mine, the compressors are usually controlled by old technologies. The control of the compressor is normally done with outdated Moore controllers. The old controllers use old technologies and are unable to communicate with a PLC. To include this control into the supervisory control and data acquisition (SCADA) system, these old Moore controllers must be upgraded. The upgraded Moore controller will transmit all the necessary information and control options to the SCADA in the control room.

When upgrading the Moore controllers, the old control philosophy and software needs to be copied to the new Moore controllers. The aim of upgrading the Moore controllers is to keep the original control of the compressors and ensure communication with the control room.

d) Obsolete analogue metering equipment.

In an old gold mine the power meters of the compressors are usually outdated analogue meters. The high-tension (HT) panels of the compressors use analogue instruments to measure the volts, amps, power, power factor, temperatures, etc. Rarely, where the compressor does have its own intelligent control and logging system, the control software was found to be outdated.

Upgrading the compressor control will include installation of digital power meters on all of the compressors to monitor the performance and power usage on the SCADA system. This will enable the control room operator to monitor other important aspects, which include:

- Delivery pressure
- Mass airflow
- Vane opening
- Blow-off percentage (BOP)

2.4.3 Compressed air leaks

Compressed air leakages can seriously affect the mine's production if not detected timeously. Therefore, compressed air leak-detection must be monitored on a regular basis.

With the implementation of an EE/DSM project, the mass airflows and the pressures of all the high production levels must be continuously monitored. By analysing the measured data of the flow and the pressures, major leak-detection can be identified in advance to improve the efficiency of the compressed air network.

2.4.4 High volumes of water in the compressed air columns

Due to condensation it has been experienced that high volumes of water occur in the underground pipelines. The amount of water is considerably more than in other younger mines. In any deep-level mine, a main water trap must be installed on each working level of the compressed air pipe column. Due to degradation, water traps in old mines will not operate as effectively as they once did.

The high water volumes in the pipelines will damage the valve positioners. Miniature water traps must be installed into the 50 mm pipeline – which is the pipe between the main air column and the pneumatic valve positioner – to protect the valve positioner.

2.4.5 Influence of energy efficiency on production

With the implementation of an EE/DSM project, which includes reducing the compressed airflow, there is the possibility that the mine's production will be influenced. Proper planning, scheduling and special precautions must be taken so that gold production will not be affected due to inadequate compressed air supply to the working levels and the refuge bays.

The first challenge is to ensure that the valves on all the levels are supplying enough compressed air. Therefore, it is essential that the status of the valve is known, and that all the instrumentation is in perfect working condition. The control philosophy can be defined for each specific level by taking the compressed air losses in the pipeline, and the mining schedule in consideration.

The second challenge is to ensure that the compressors are operated at the correct pressure set point. Care must be taken to ensure that the compressors deliver sufficient air to meet the compressed air demand. Accurate knowledge of various mining schedules and the historical data will mean that correct decisions can be made regarding stopping and starting a compressor.

2.4.6 Shaft access

Usually, with only one access point into the mine, the shaft access to the underground levels is a concern. Installations can, for the most part, take place during off-mining weekends. This will, however, result in a longer time being required to complete the underground work because of the restricted shaft access.

Shaft access varies from mine to mine, because of their particular scheduling and other possible entry points to reach the underground working areas. To avoid project delays – due to shaft access – advanced planning is necessary to establish the required time complete the work.

2.5 Conclusion

The feasibility of applying DSM initiatives on a compressed air system on an old South African mine was discussed in this chapter. A better understanding was provided regarding compressed air usage in the mining industry, compressor surge and the compressed air losses associated with compressed air usage. By analysing a mine's compressed air network, the possibility of optimising the compressed air system by implementing effective supply- and demand-side management was proposed to be a viable option. These control strategies include adequate selection of a control strategy; compressor or compressor set usage; and installation of underground control valves using appropriate working-level instrumentation. With the aid of energy management, automatic control of the compressed air system can be implemented at a mine.

After the implementation of EE/DSM, collection and recording of the compressor's electrical consumption data is essential. In conjunction with the energy usage data, the pressure data is also required. This data is used to calculate the EE potential of the compressors and the performance of the DSM implementation at the mine.

Chapter 3: ENERGY EFFICIENCY STRATEGIES FOR A COMPRESSED AIR SYSTEM OF AN OLD GOLD MINE

Construction of the new Medupi power station near Lephalale (Ellisras)--started in November 2008.



This chapter demonstrates the financial impact and savings as a result of the implementation of the energy efficiency DSM project. The energy efficiency potential of an old South African gold mine's compressed air network system is presented, which includes a set of three compressors. Conclusions are made regarding the possibility of electrical savings; and the DSM strategy was implemented on a real system.

3.1 Introduction

There is a possibility for energy and financial savings at the old gold mines of South Africa. The focus of this chapter is on the design of a remote real-time energy management system, and the techniques used to ensure energy savings.

3.2 Baseline establishment

3.2.1 Baseline calculation

Three months' data were required to establish a baseline for the compressor electrical power usage. The data to be gathered over the three-month period has to include power, pressure and flow data. The data will then be calculated and averaged out to a daily profile of hourly intervals.

Data was collected in order to calculate the energy usage baseline for a specific case study (the case study is introduced in Chapter 4). Because of the age of the mine, no historical or archived data was available. Therefore, it was necessary to install portable Dent loggers in the HT panels of the three individual compressors. The data for the initial baseline was logged for the period from February to March 2009. Data was captured every 15 minutes, recalculated to an hourly interval profile, and is presented as a stack chart where the power usage of the compressors is accumulated to indicate the total power usage of all three compressors. The system baseline was prepared by calculating the average hourly demand profile for an average working weekday.

From the baseline it could be seen that the mine used the Sulzer and the Brown, Boveri and Company (BB) compressors as a constant base load during the entire day. The GHH compressor was only used to meet the requirements for increased compressed air when the demand for air was very high. The baseline obtained also clearly showed that the Sulzer and BB compressors were operated at their respective full power ratings of 4 400 kW and 2 600 kW.

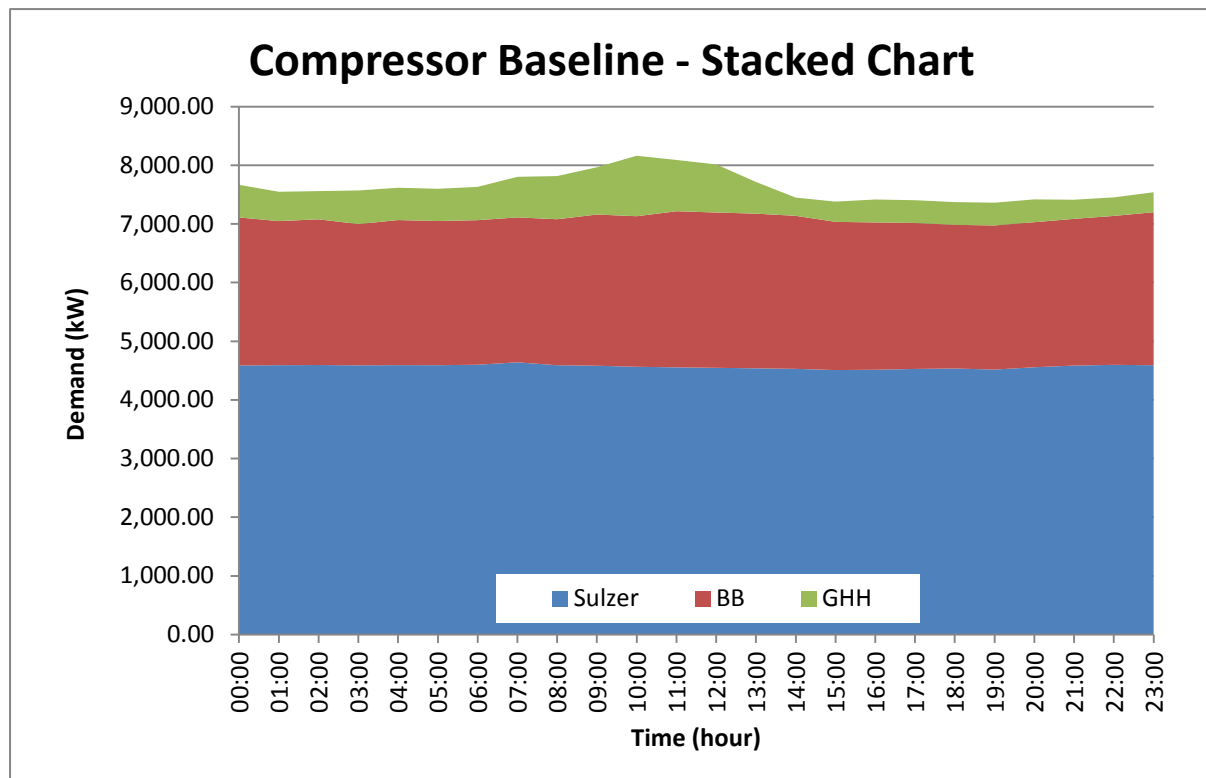


Figure 12: Accumulated compressor baseline, 1 February 2009 – 31 March 2009

Updated baseline

The project was delayed during the implementation phase of the project and the initial baseline was outdated. The delay was caused by inadequate project planning, and an extended delivery lead time of ordered equipment. Therefore, due to increased usage of the compressors, an updated baseline was calculated. The Dent loggers were reinstalled at the HT panels of the mine to collect new data. The new baseline data was acquired during the first week of May 2011. This data was verified by the measurement and verification (M&V) team of the North-West University of Potchefstroom (see Appendix B). The data was collected at 15-minute intervals and compiled for an hourly average per day.

A graphical representation of this data is shown in Figure 13, where the dashed line indicates the original baseline; and the stacked chart the restructured baseline. The figure also shows that the GHH compressor was used during the morning peak drilling period and the early morning cleaning hours.

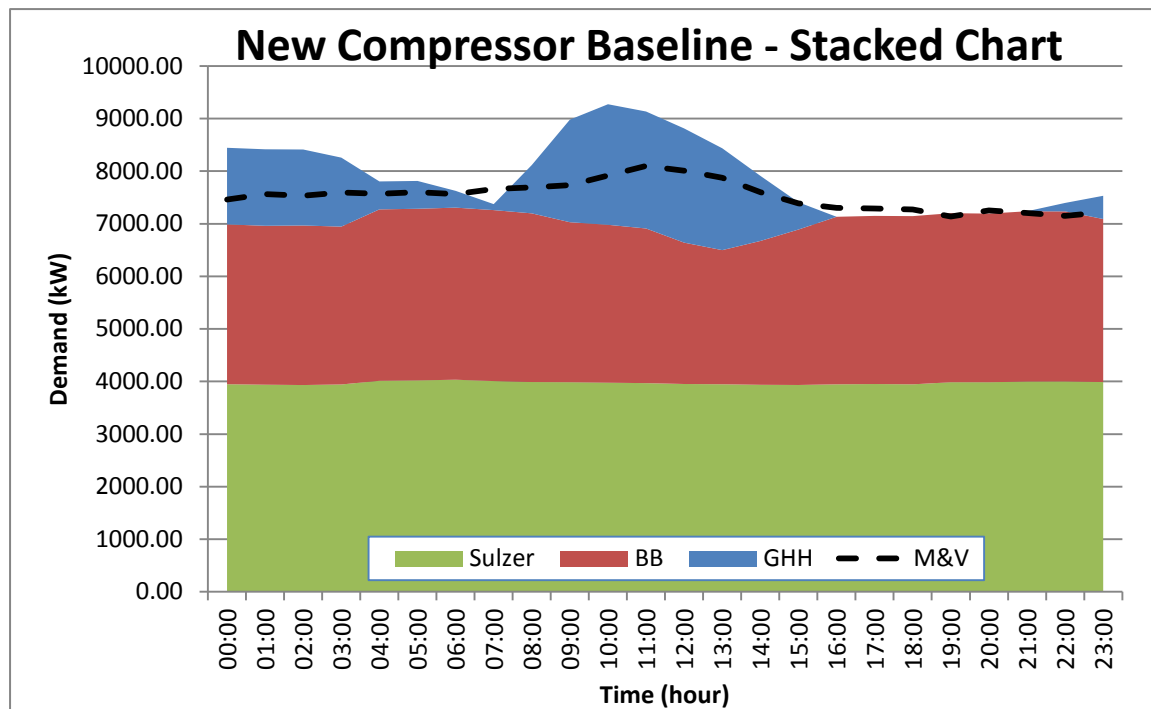


Figure 13: Restructured baseline

In Figure 13, it can be seen that the Sulzer and the BB compressors were still used as baseload compressors for the compressed air power profile. However, the Sulzer compressor was operating at lower power than the initial baseline. After a detailed investigation the following possible reasons were given for this anomaly:

- The compressor efficiency decreased over a period of one year from when the data was first obtained. The Sulzer compressor was also due for its 5-yearly maintenance and overhaul scheduled for the end of 2011 or early 2012.
- The primary inlet vanes of the Sulzer compressor could not be opened fully due to mechanical degradation of the compressor vanes. On average, the vanes opened to a maximum of 95%.

The black broken line in Figure 13 is the original baseline, which was confirmed by the independent measurement and verification (M&V) team from the North-West University. The change in the initial baseline was confirmed by the mine personnel, and was due to the following:

- Lower power usage of the Sulzer compressor.
- A change in the mine's production. The increase in the production is reflected by the higher air usage and therefore higher electrical energy consumption.

- As the mine ages, the condition of the compressed air supply lines will deteriorate, increasing the probability of air leaks. Although maintenance is carried out on the compressed air supply lines, it remains a difficult and time-consuming task to minimise the air leaks. Therefore, the baseline may even become higher over time.

The updated baseline was used as the new baseline. It will be used to calculate the electrical energy and financial savings of the mine.

3.2.2 Compressor power calculation formula

The calculation of air power for compressors can be calculated using the measured values of the pressure and temperature as well as the mass flow of the compressor output. Several formulas are available to calculate the power usage of compressors. This section provides the open system, steady-flow air power equation (CAI & Toshihary, 2010).

$$\dot{E} = \frac{\kappa}{\kappa - 1} P Q \left(\frac{T}{T_0} \right)^{\frac{\kappa - 1}{\kappa}} \quad [1]$$

Where:

Table 4: Definitions for Equation 1 (CAI & Toshihary, 2010)

Symbol	Definition	Units
κ	Specific heat ratio	
$\dot{E}$	Compressor power	kW
P	Outlet pressure	Pa
Q	Volume flow	kg/s
T	Outlet temperature	K
R	Characteristic gas constant	kJ/kg·K
Subscripts		
i	Inlet conditions	
o	Outlet conditions	

From Equation 1 a value was obtained for compressor power which was derived for the calculation of air power. If there is a negligible difference in temperature ($T/T_a \approx 1$), Equation 1 can be simplified to give Equation 2 (CAI & Toshihary, 2010).

$$\text{---} \quad [2]$$

Equation 3 was used for a first order approximation of compressor power (Mills, 2004):

$$\text{---} \quad [3]$$

Where:

Table 5: Definitions for Equation 3 (Mills, 2004)

Symbol	Definition	Units
P	Compressor power	kW
P_o	Outlet pressure	Pa
P_i	Inlet pressure	Pa
T_i	Inlet temperature	K
	Mass airflow	kg/s
R	Characteristic gas constant	kJ/kg·K

To convert from mass flow to volumetric flow:

Volume flow rate (m^3/s) = mass flow rate (kg/s)/density of air (kg/m^3)

Where the density of air is 1.225 kg/m^3 ;

With $R = 0.287 \text{ kJ/kg}\cdot\text{K}$ for air; and

$T = 288 \text{ K}$.

Equation 3 (Mills, 2004) is reduced to:

$$\text{---} \quad [4]$$

This equation was used to determine the possible savings as calculated in this chapter.

3.2.3 Calculated energy savings

As stated in Paragraph 3.2.1, portable loggers were installed in the HT panels. For a certain time frame the energy usage was logged, and the pressure and flow data was collected for this period. The latter information was manually logged.

The data collected between 1 February and 31 March 2009 are represented in Appendix B, Table 13. All the data were prepared by converting the data to an average demand profile for a 24-hour day. A 24-hour profile of the power, flow and pressure data was calculated which represented the operational baseline of the compressors.

In order to calculate the savings for the project these air pressures and airflows had to be scaled down using specific percentages. Assumptions were made regarding the percentage savings on the pressure and the airflow as respectively 80% and 85%. Assumptions were made by assessing the current pressure delivered to the mining levels and the most optimum working pressure needed for the mining equipment. Therefore, new proposed pressure and flow profiles were calculated. The calculations are as follows (these savings were calculated with the initial logged data gathered in March 2009):

$$[5]$$

$$[6]$$

Using Equation 4 the proposed power usage per hour was calculated:

[7]

To calculate the hourly savings, Equation 7 was used from the calculated data for the proposed pressure and flow profile. By adding the hourly savings the average monthly power reduction was calculated to be **1.96 MW**:

[8]

The average power reduction per hour was calculated by the difference of the baseline power and the projected power for a specific hour of the day. A representation of the savings is shown in Figure 14, in which the baseline and the projected power usage are plotted. The difference between the baseline and the actual power usage is the savings for the project.

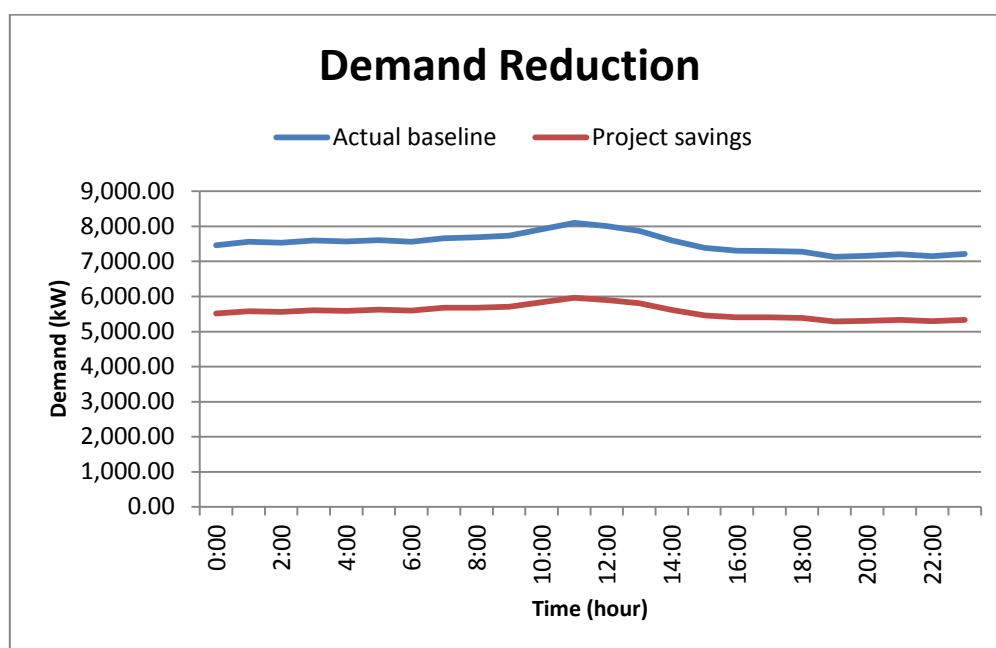


Figure 14: Actual baseline vs projected power usage

3.2.4 Baseline scaling

Due to the change in the baseline, the average daily power reduction was calculated on the updated baseline to achieve the same savings as in the previous section. Baseline scaling was needed due to the change in mining production. The project, which required a year to complete, resulted in higher production at the gold mine. The gathered data is represented in Appendix C, Table 14:

[9]

The average daily reduction baseline is represented in Figure 15. The savings are calculated for the implementation of energy efficiency on the mine compressor system. The M&V team approved the updated baseline and this can be found in Appendix E, Figure 48.

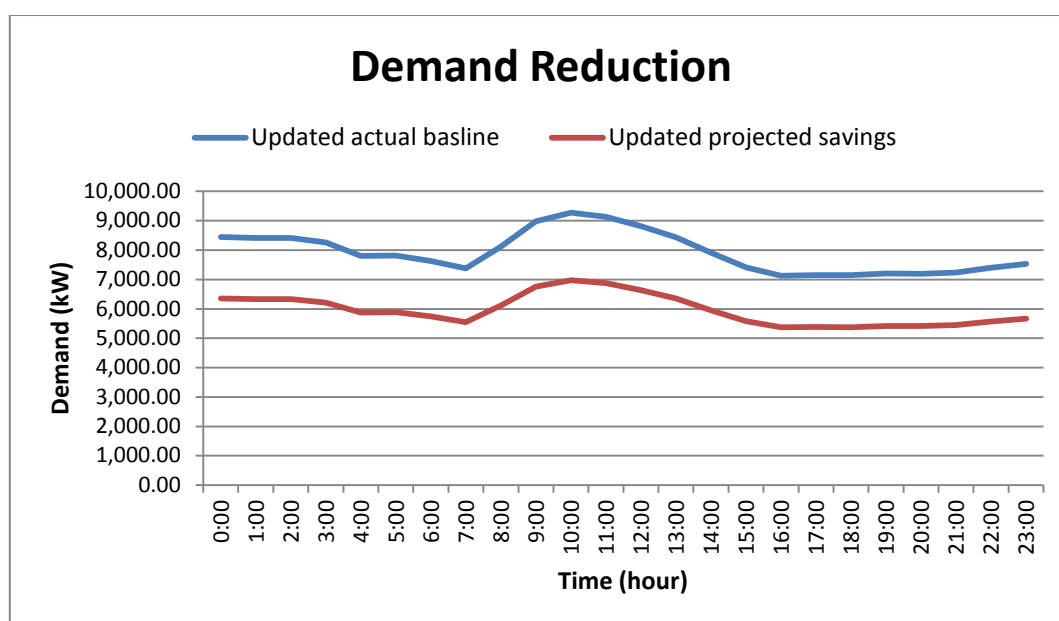


Figure 15: Update actual baseline vs updated projected power usage

3.2.5 Calculated financial savings

The financial impact on the mine is presented in Appendix D, Table 15. The average financial saving per day is calculated by using the Megaflex tariff structure. Average savings are calculated by multiplying the difference between the baseline and the proposed savings with the hourly tariff and the hourly period. The financial savings for a summer and a winter month were calculated:

[10]

[11]

The projected winters day financial savings were calculated to be R31,004; while the projected summers day financial saving were calculated as R14,736.

3.3 Optimisation strategies

While optimising a compressed air network, an energy management system is needed to automate the complete compressed air system. Before the implementation of compressed air optimisation strategies, the mine schedule and the blasting times must be adhered to. The mine schedule and blasting times are represented in the following sections:

3.3.1 Typical mine schedule

The operational working schedule of a typical mine (similar to this mine) is as follows – where the times may vary depending on the different shifts for each mine:

1. From 00:00 to 02:30 – Early morning cleaning shift.
2. From 02:30 to 06:00 – Change-over time between cleaning and drilling shift.
3. From 06:00 to 13:00, or 16:00 – Drilling shift starts. The lower levels have longer drilling times due to the longer travel time required to get to the work areas.
4. From 13:00 to 17:00 – Upper level drilling decreases. Drilling continues on the lower levels.
5. From 17:00 to 21:00 – Shaft clearance for blasting and changeover between drilling shift and the late-night cleaning shift.
6. From 21:00 to 0:00 – Start of the late-night cleaning shift, which continues until about 02:30.

3.3.2 Blasting times

Newer mines are equipped with centralised blasting equipment. This enables the mine to schedule their blasting according to a specific time. Therefore, all the underground drilling periods stop at a specific time. This allows the shaft to be cleared (shaft clearance time) to create a safe environment to initiate the blasting for all the levels.

At the old gold mine where this investigation was done, they did not use centralised blasting. Due to the layout of the mine, blasting occurred at the top level first, which would not influence the lower levels. Blasting commenced at the top level at about 13:30. After a certain time interval blasting would occur on the next lower level, until blasting had been completed on all the levels. Usually, blasting would take place at approximately 15:30 on the last level.

Blasting would only occur on days when the levels were properly prepared. The blasting schedule was planned so that the shockwave would not influence the lower levels. There was a blasting clearance time after the blasting to allow for dust to settle and be extracted from the working areas.

Through knowledge and understanding of the mine schedule and the blasting times, underground control valve can be implemented.

3.3.3 Underground valve control and measuring equipment

It is necessary to install a control valve and measuring equipment to control underground compressed air. The typical requirements per level are as follows:

- PLC
- Flow meter
- Pressure transmitter for each valve (downstream and upstream)
- Control valve
- Temperature probe
- Water trap

The installation layout for each level is represented in Figure 16. By installing the miniature water traps the valve actuators, which are required for any compressed air system, will be protected.

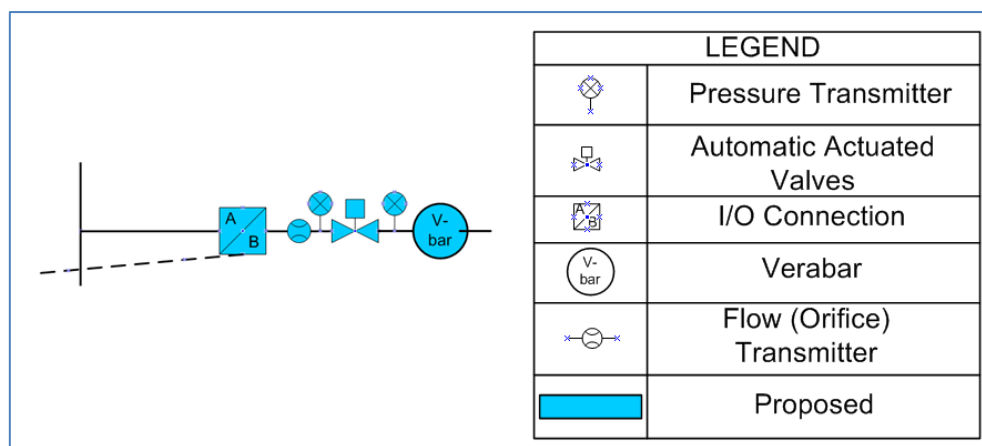


Figure 16: Level installation

Control of the underground valves is synchronised with the mine schedule of cleaning, and drilling-and-cleaning, with their different compressed air demand requirements.

3.3.4 Underground level control philosophy

As set out in Table 6, the following set points for the underground valves will be used by adhering to the mine schedule:

Table 6: Underground level control philosophy

Time	Set point for normal operation (kPa)	Set point for FP level (kPa)	Motivation
00:00	440	440	Early morning cleaning shift
03:00	250	300	Change-over shift: leaning to drilling
05:00	400	400	Charging of the column for the drilling shift
06:00	450	450	Start of the drilling shift
07:00	470	470	Peak time for drilling
13:00	450	450	Decrease in demand for drilling
16:00	400	400	Changeover: drilling to cleaning
17:00	250	300	Shaft clearance for blasting
21:00	440	440	Start of cleaning shift

Fridge plants (FP) are installed on two of the underground levels. The minimum required pressure for these plants is 250 kPa. The FP's power will trip if the supply pressure drops below 250 kPa. Therefore, it is necessary to maintain the correct supply pressure during the off-peak times. The minimum pressure for the FP levels is therefore set to 300 kPa. This establishes a safety margin and allows for the variation in pressure because of the pressure-actuated control of the valves.

There is a variation of the pressure downstream from the valve due to the slow open-and-closing speed of the valve. The slow open-and-closing speed of the valves ensures that there are no rapid changes in the pressure as a result of the longitudinal disturbance occurrences that can cause shockwaves in the pipelines. These shockwaves can result in serious damage and even destruction to the supply line.

In conjunction with the implementation of an underground control philosophy, the compressor control philosophy must also be upgraded.

3.3.5 Compressor control philosophy

With the underground components installed, the compressor control philosophy needs to be upgraded. This involves upgrading of the compressors' Moore controllers. The new control philosophy will result in the mine using compressors more effectively to satisfy the compressed air

demand. During the off-peak production period and time/change-over shifts, all the valves will close to a minimum value, and only one compressor may be required to satisfy the demand. The compressor control philosophy is shown in Table 7.

Table 7: Compressor control philosophy

Time	Set point (kPa)	No. of running compressors
00:00	430	2
02:30	430	1
05:00	430	2
17:00	430	1
21:00	430	2

The active inlet guide vane control of the compressor caters for the compressed air demand of the mine for the entire day, which will enable variable set-point control for a 24-hour day. During the low-demand periods the compressors will cut back to a minimum guide vane position, and during the maximum demand for compressed air, the compressor guide vanes will open completely. The compressor's operational specification requires that the minimum guide vane position may not be less than 40%. This requirement is to prevent a possible surge condition. A surge may severely damage the compressor. Thus, the compressor PLC will send a minimum offset to the guide vanes to ensure that the guide vanes will not be below 40%.

3.4 Simulation of savings potential

A simulation of the mine's compressed air network was done using the KYPIPE software package. The simulation was done for the installed compressors and was based on the underground layout and compressed air requirements of the mine (KYPIPE, 2009).

Figure 17 indicates the initial mine compressed air usage, showing the different pressure drops and pressure increases due to auto-compression.

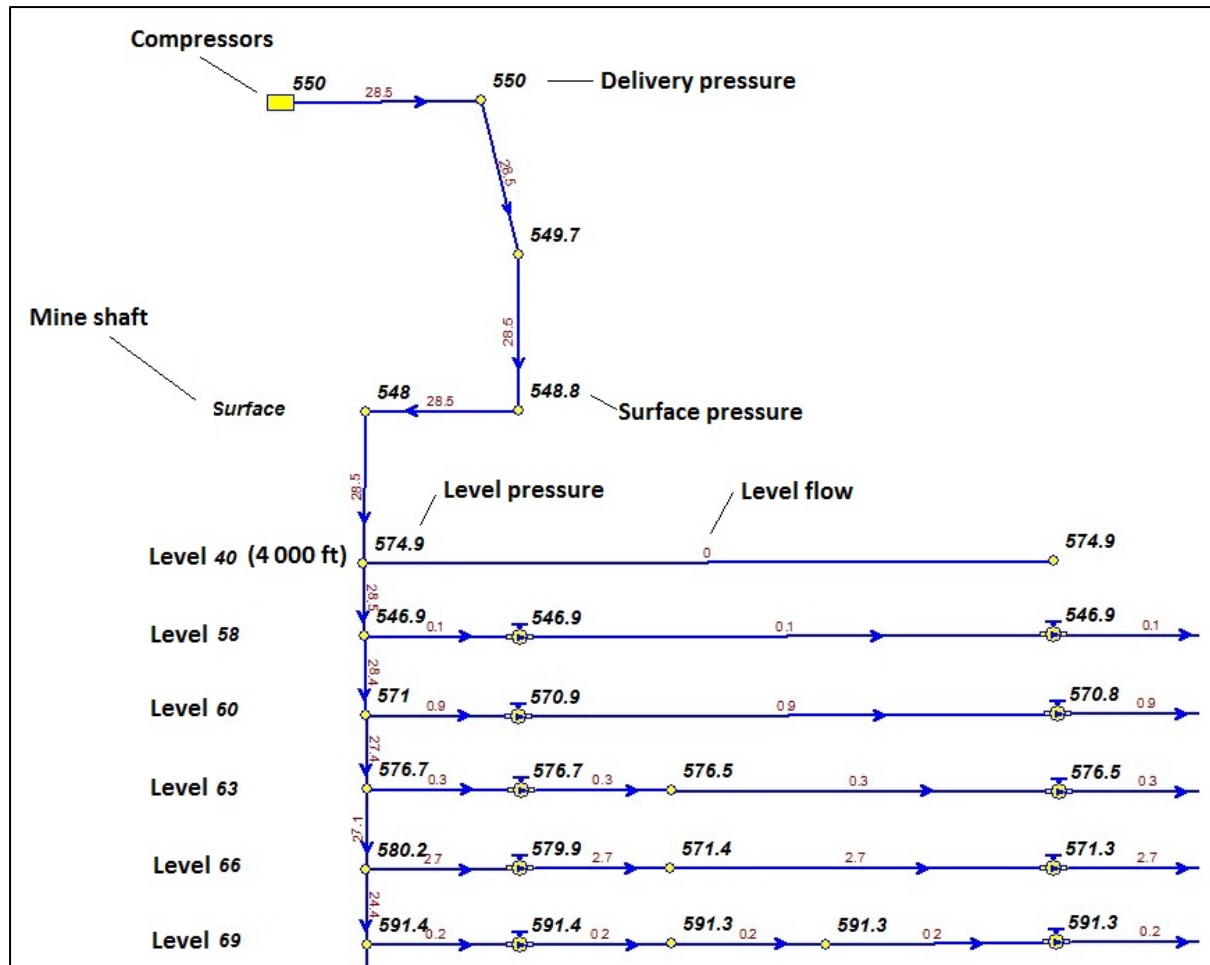


Figure 17: Simulation – before control optimisation

During the first simulation, noted as *before control optimisation*, the compressed air usage of the mine is simulated without the implementation of compressed air control. A high pressure (550 kPa) is delivered to the underground mining levels that produced certain flows, as indicated in Figure 17 (only a sample of the simulation, complete simulation can be found in Appendix F). The pressures and flows are much higher than needed, and the main purpose of the first simulation is to indicate compressed air usage at a certain delivery pressure.

To validate the simulation model, the results of the model were compared to the actual compressed air usage of the mine before the implementation of compressed air control on the levels. This comparison is made in Table 8.

In Table 8 the variation of the actual flow and the simulated flow is calculated. A very high variation (due to the small flow on the specific level) was calculated on some of the levels. A minor difference between the actual flow and the simulated flow will have a huge impact.

Table 8: Comparison of simulation results vs actual results before implementation

Level	Actual flow results (kg/s)	Simulation results – before control optimisation	
		Flow (kg/s)	% variation
L58	0.1	0.1	0.00%
L60	0.8	0	-100.00%
L63	0.2	0.8	300.00%
L66	1.5	2.9	93.33%
L69	0.1	0.2	100.00%
L71	1.1	1.4	27.27%
L73	1.2	1.8	50.00%
L75	0.2	0.4	100.00%
L91	1	1.2	20.00%
L95	7	8.9	27.14%
L100	4.1	5.1	24.39%
L103	3.8	4	5.26%
Total	21.1	26.8	27.01%

The flows for each of the levels are added to indicate an approximate total flow for the mine shaft. The simulation resulted in a **27.01%** variation according to the actual total flow. Table 8 demonstrates the high variation for certain levels due to the size of the flow on the specific level, but does not influence the total variation of the model.

With a working simulation, the aim of the second simulation (defined as *after optimisation*) is to simulate the reduction of flow by reducing the downstream pressure of the control valves. Implementing compressed air control in the PIPE simulation will result in reduction of the pressure and the flow on the mining levels. With less air needed for mining purposes, the main shaft pressure will decrease as indicated in Figure 18. Therefore, less compressed air needs to be generated by the compressors and will lower the compressor operations.

A decrease in flow can be seen in the two simulation figures.

By using the simulation software the possibilities of compressed air savings are shown. In the PIPE simulation the underground layout was designed to indicate the influence of active valve control.

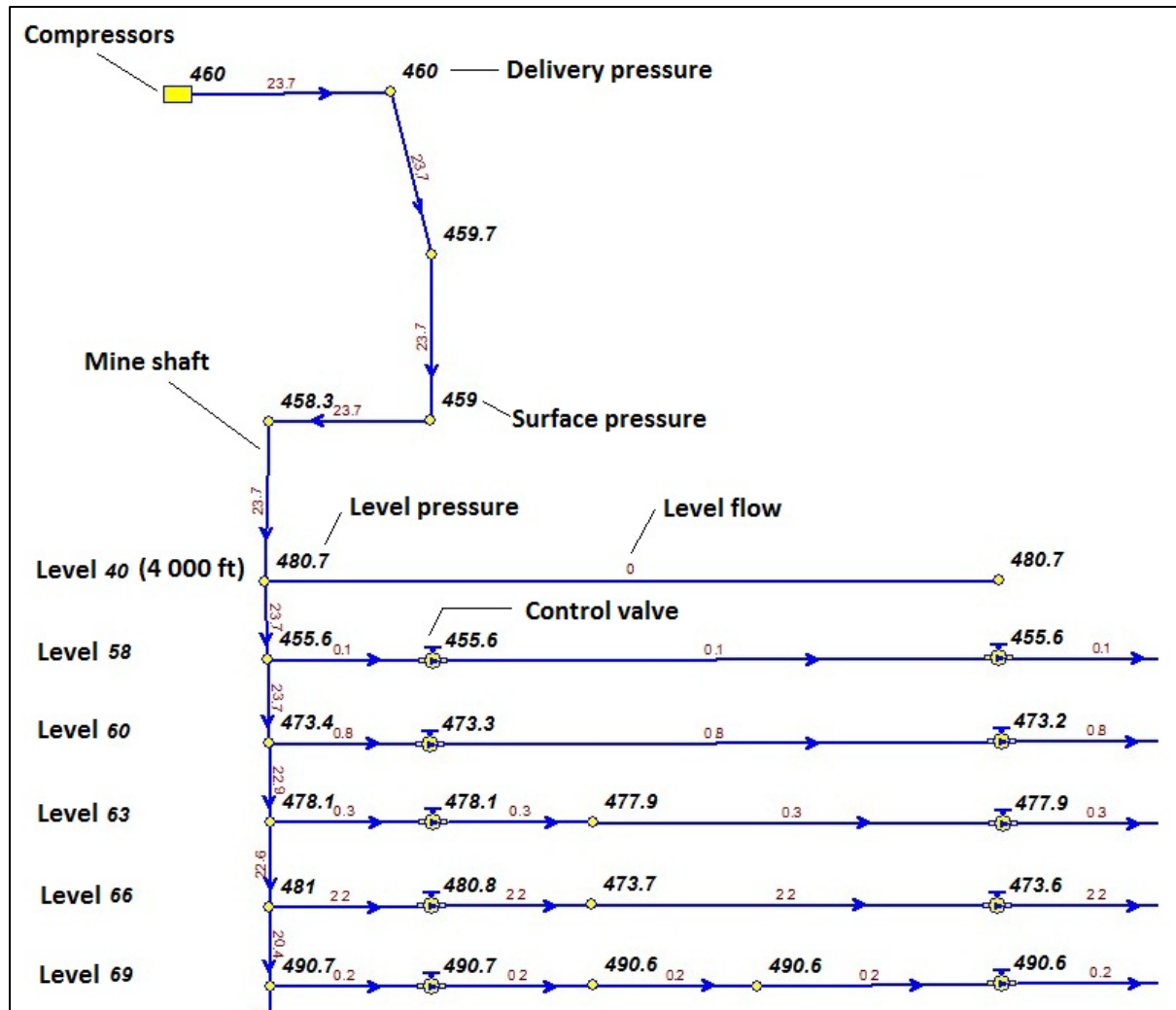


Figure 18: Simulation – after control optimisation

A presentation of the entire simulation is shown in Appendix F, Figure 49 and Figure 50.

3.5 Energy management system requirements

An automated system is required in order to implement the DSM strategies, and to ensure sustainability and maximum savings for an optimised compressed air system. A real-time energy management system (REMS) has been developed over the years and has been implemented in various DSM projects in the mining industries. The REMS installation successfully resulted in energy savings in the mining industries.

As mentioned in Section 2.3, the REMS for optimised air networks (OAN) has been designed for the supply- and demand-side control of the compressors and underground valve installations

respectively. REMS can communicate directly with the PLC, or via the OPC¹ to the mine's onsite SCADA system. REMS-OAN has been used for the implementation of the DSM strategies for the purposes of this study.

The REMS-OAN platform consists of various components/tools for the optimum control of a compressed air system. These tools will be used to construct a layout representation of the mine's compressed air system.

REMS-OAN compressor icon

The REMS-OAN compressor icon (Figure 19) represents a compressor and will display all the necessary information. This icon is used for the effective control of the compressor according to a specific set of control set points.

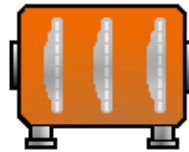


Figure 19: REMS-OAN compressor icon

REMS-OAN compressor control icon

The control set points are read into the REMS-OAN compressor control icon as demonstrated in Figure 20. A set point for the different times of the day can be programmed according to the mining schedule and the compressed air demand. If applicable, a single set point can be used throughout the entire day, depending on the mine's application.



Figure 20: REMS-OAN compressor control icon

¹ Object Linking and Embedding (OLE) for Process Control

REMS-OAN control valve icon

Every valve included in the network is represented by a REMS-OAN control valve icon as seen in Figure 21. The valve icon displays the up- and downstream pressure, the airflow through the valve and the percentage opening of the valve.

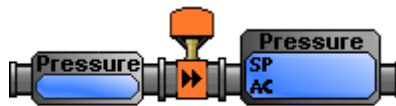


Figure 21: REMS-OAN control valve icon

REMS-OAN pressure and flow icon

The REMS-OAN pressure and flow icon only displays the pressure and the flow at the position on the pipeline where the pressure transmitter and a flow meter have been installed.



Figure 22: REMS-OAN pressure and flow icon

REMS-OAN valve control icon

The set-point control for each valve is done with the REMS-OAN valve control icon, shown in Figure 23. Similar to the compressor control icon, the set point can be set at specific times of the day, according to the mine schedule and the compressed air demand.



Figure 23: REMS-OAN valve control icon

REMS-OAN trend tool icon

The REMS-OAN trend tool icon and the REMS-OAN visual trend tool icon are shown in Figure 24 and Figure 25 respectively. They are used to display data by either opening the trend tool icon; or the visual trend tool icon. Data can vary from the energy used, to a pressure- or flow profile of a compressor or valve.

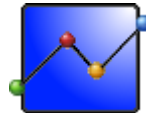


Figure 24: REMS-OAN trend tool icon

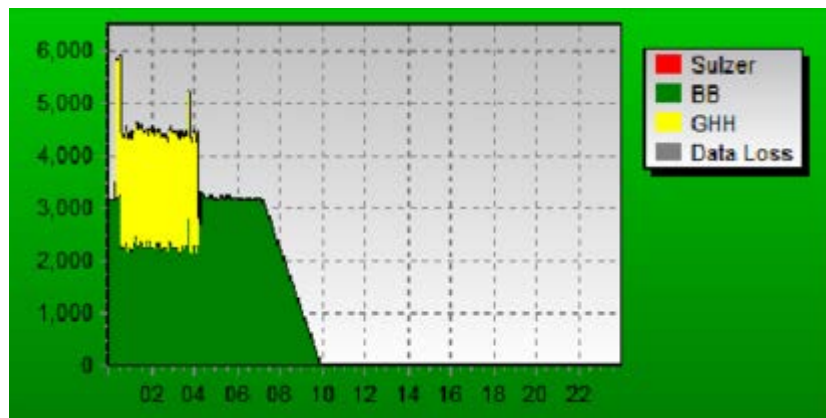


Figure 25: REMS-OAN visual trend tool icon

The REMS-OAN software will be installed on two standalone servers, with one acting as a backup. These servers will have full control of the compressed air system (supply- and demand-side). REMS-OAN is therefore essential to the efficiency of the project.

REMS platform design

As mentioned in the above section, REMS was used to implement the DSM strategies on an old South African mine. The layout of the system is represented in Figure 26.

Part of the REMS platform design is the following:

- Main page, displaying the entire compressed air network.
- Compressor layout and information page.
- Pages for the underground layout of the mine.
- Logging information page.

In Figure 26, the compressor layout consisting of the compressors, the control of the compressors, and the required information of the compressors are shown. The information is displayed with the REMS-OAN visual trend tool (as discussed in Section 0) – one showing the compressor energy usage and the other the pressures of the main and the subshaft of the mine. In Figure 26 a surface meter is indicated for the West Shaft flow and pressure.

A representation of some of the valves for the underground layout can be seen in Figure 27. In each valve information page, four valves are represented with their valve control icon and a visual trend tool for display of the pressure and flow of each valve. Extra display icons were added for additional information.

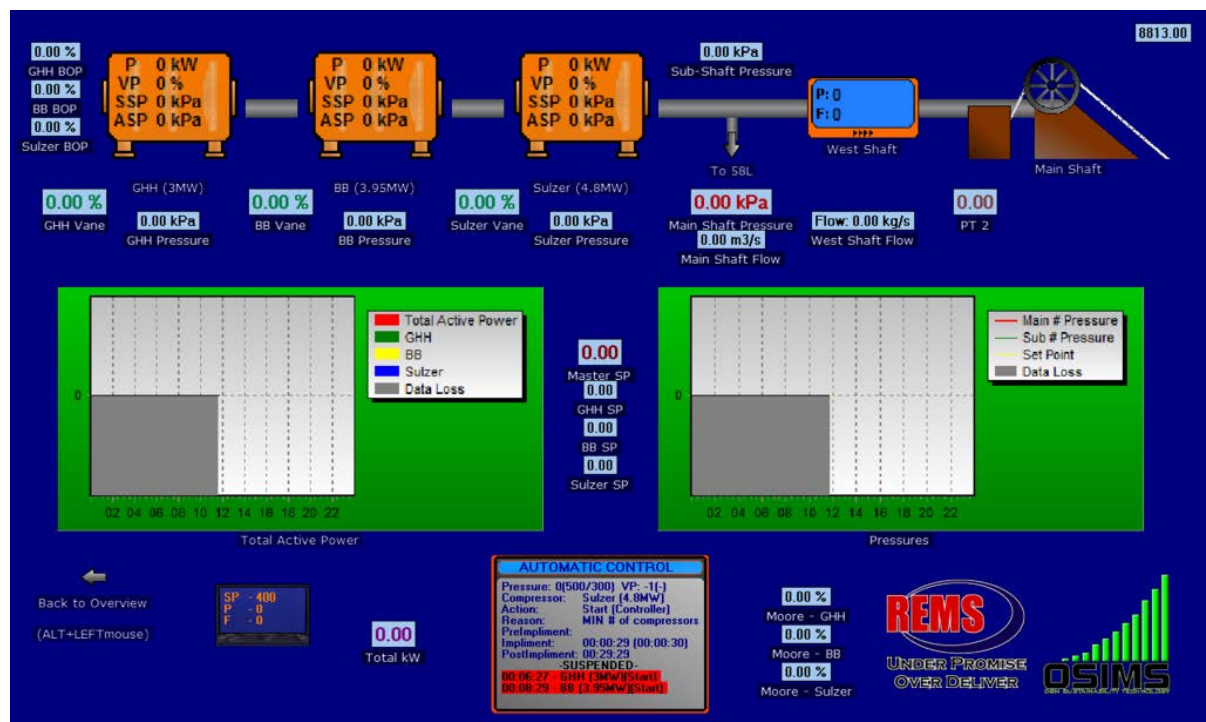


Figure 26: REMS-OAN layout of the compressors

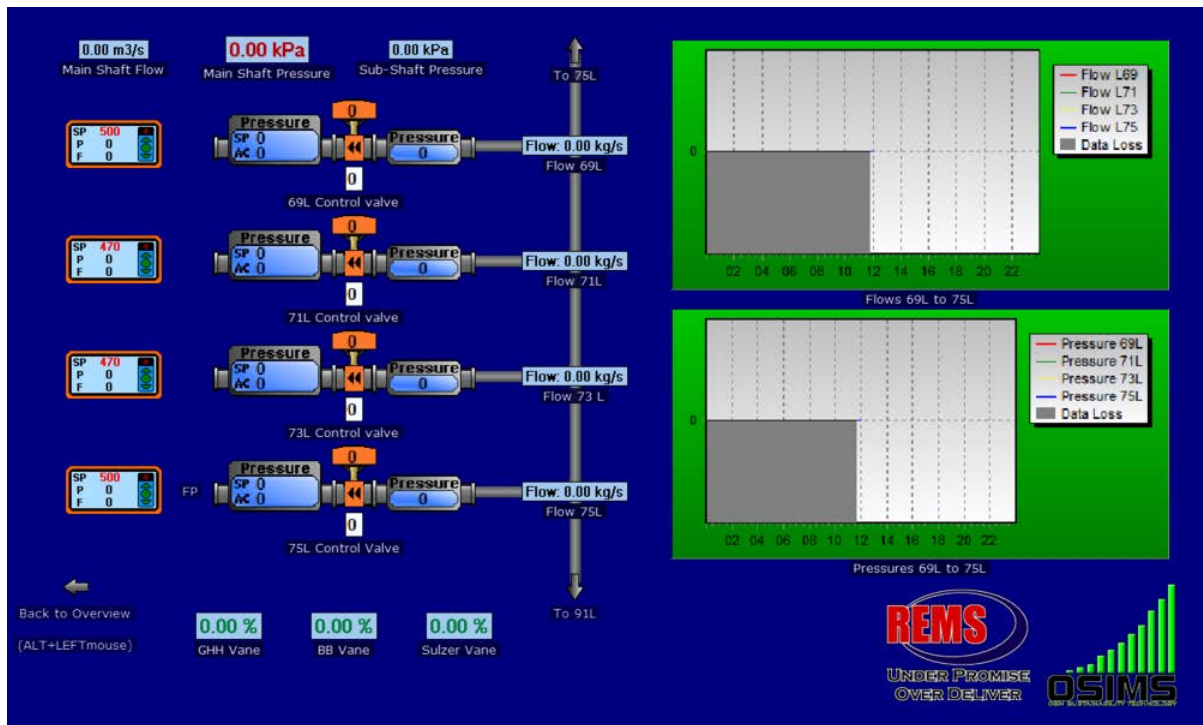


Figure 27: REMS-OAN layout of underground control valves

All other relevant information on the compressed air system is indicated on the logging page of the REMS platform. These include:

- Each compressor vane position.
- The total kilowatt usage for the compressors and the M&V baseline to calculate the energy savings per hour.
- Each compressor's instant output pressure.
- Kilowatt usage for each individual compressor.
- Different underground pipe section flows.

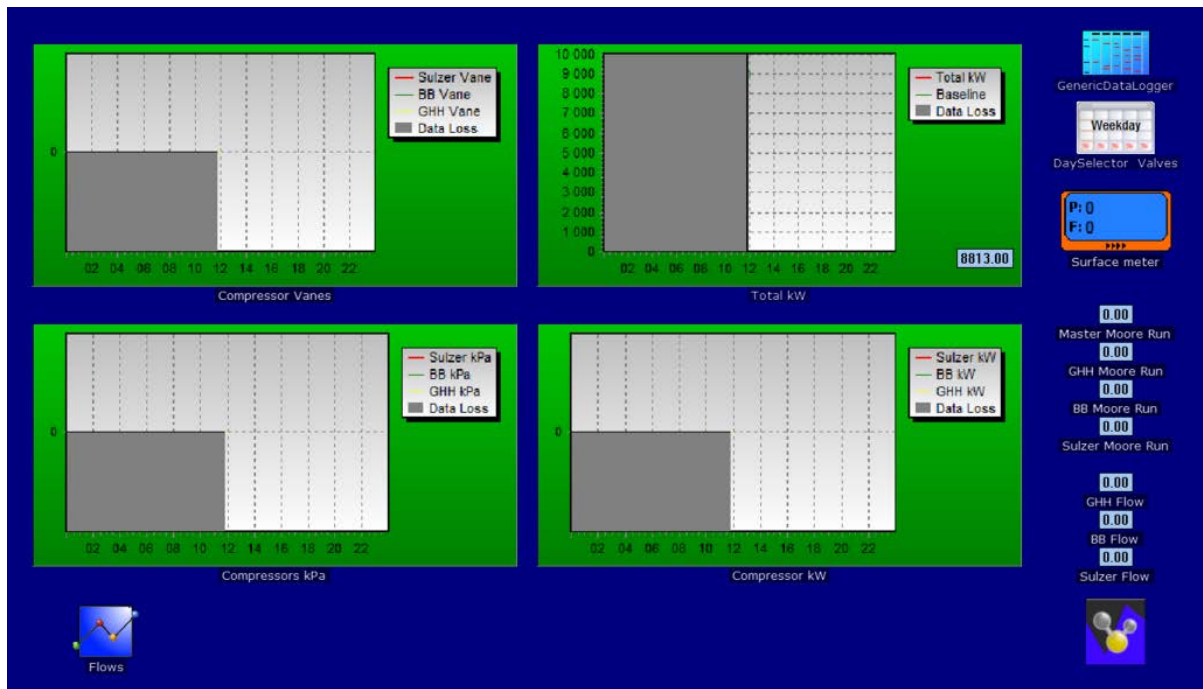


Figure 28: REMS-OAN layout of data logging

3.6 Conclusion

In this chapter, the possibility of energy efficiency on an old South African mine was investigated by analysing the compressed air network system. In Section 3.2.2 the method for the potential calculated saving was outlined and discussed.

The optimising strategies in this chapter showed that there is a potential for improving energy efficiency and electrical savings. A single set of compressors and the underground layout of the mine allow for a simplified and economically feasible control philosophy. With the implementation of the optimising strategies, the high production was identified. Due to the fact that implementation will be on an old mine, there are concerns regarding the condition of the existing equipment and the condition of the compressed air supply lines.

This chapter showed that there is large potential for energy efficiency DSM on old mines. With the previous control philosophy of the mine, compressed air was delivered and mostly wasted through the blow-off valves during the low-demand period.

Chapter 4: CASE STUDY – OPTIMISED COMPRESSED AIR USAGE



In Chapter 3 the case study for implementing an improved compressed air network project in an old South African gold mine was introduced. The possible savings were calculated and the control strategies were implemented. All the implementation results of the energy efficiency project are included in this chapter.

4.1 Introduction

The installation period for this case study was completed at the end of March 2011. A performance assessment period followed to evaluate the projected savings and to validate the control philosophy. The performance assessment period for gathering and analysing the results took place between 1 May and 31 July 2011.

Results obtained from the actual mine data were compared with the pre-calculated target savings. During implementation some distinctive challenges associated with implementing these strategies were encountered and overcome.

The energy efficiency strategies included:

- Full automation of the three compressors to realise the proposed savings.
- Installation of the variable control valves on 12 different underground high production levels of the mine.
- Implementation of a SCADA system to allow full control of all the newly installed equipment, as well compressor equipment, from a central location.
- Installation of a REMS that will communicate with the mine's SCADA system to manage automated control.

All the results are evaluated and compared with the calculated savings given in Chapter 3. Furthermore, all the challenges associated with the implementation of the project, including the derived solutions, will be discussed.

4.2 Overview of the case study

Due to privacy and intellectual property requirements, the mine cannot be named and will be referred to as *MINE-A*. This mine is nearing the end of its production lifetime because of high operating costs and reduced ore grades. *MINE-A* also provides the opportunity for energy savings which will result in financial savings.

The mine consists of 20 underground levels, but mining is primarily taking place on 12 productive levels only. Little to no mining takes place on the remaining 8 levels. Deep-level mining operations take place at depths of 3 680m below the surface (Harmony, 2011).

4.2.1 Compressed air supply overview

The installed capacity of the three different compressors can be seen in

Figure 29. The total installed capacity of the compressors is 11.75 MW and consists of:

Table 9: Compressor list

Compressor	Installed capacity (MW)	Flow rating (m ³ /s)
GHH compressor	3 MW	9.4 m ³ /s
BB compressor	3.95 MW	11.8 m ³ /s
Sulzer compressor	4.8 MW	14.1 m ³ /s

The larger capacity BB compressor is used together with the Sulzer compressor for the baseline power profile of the main shaft. If the air demand increases above the capabilities of these two compressors the GHH is brought online. As shown in

Figure 29, the mine consists of a Main and a West Shaft that are interconnected with a compressed air pipeline and a manually operated isolation valve.

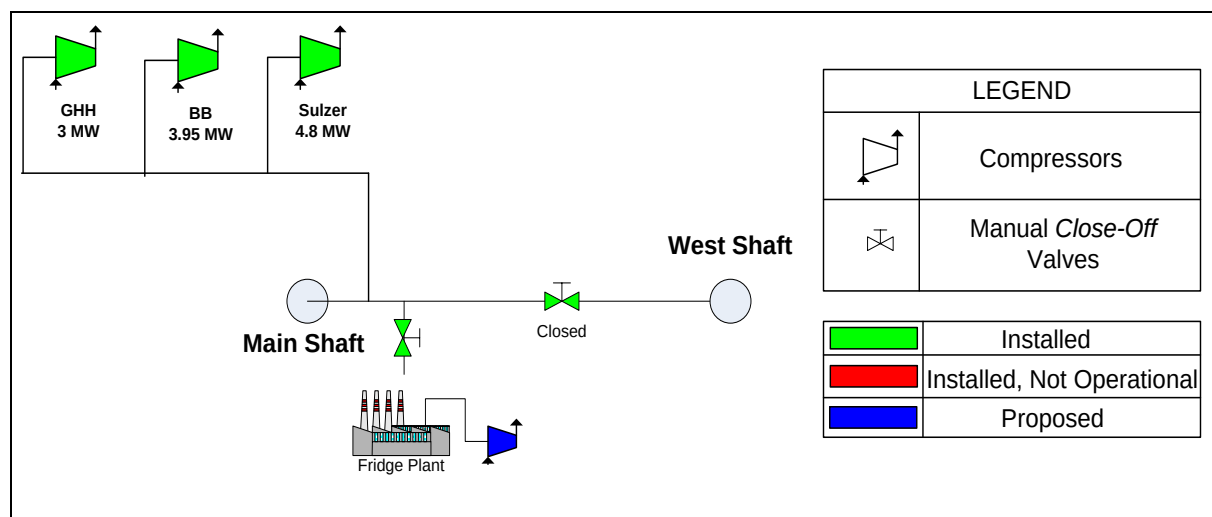


Figure 29: Surface compressed air layout

Other than supplying compressed air to the underground levels, compressed air is also provided to:

1. Preparation plant.

The preparation plant is the only one of its kind in the entire Free State. Sample crates from other mines in the province are all sent to this plant. Tests are conducted on these samples to ascertain the gold quality of each mine.

2. Excitation dams at West Shaft.

3. Minor preparations at West Shaft for the pillar project which should be completed during 2012.

The overall compressed air consumption of the West Shaft is not very high and is included in the power consumption baseline.

Compressor set-point control

A Moore controller controls each one of the three compressors individually. An extra fourth controller is available for use as a master controller to simultaneously take control over all three compressors. However, individual compressor control is then lost.

The compressor output is controlled by the Moore controller to deliver a predetermined set-point pressure. If the master Moore controller is not active, each individual compressor will be controlled by its own Moore controller and by active inlet guide vane control.

Compressor guide vane control

The compressors all operate with inlet guide vane control. During high-demand periods, the compressors deliver maximum pressure and flow, requiring full opening of the guide vane. At reduced compressed air demand, the guide vanes will automatically start closing and reduce the inlet mass airflow, usually referred to as compressor cutback. Another method to reduce the mass airflow to the system is to open a blow-off valve at the compressor outlet. The cutback/blow-off sequence of the compressors is as follows:

1. GHH
2. BB
3. Sulzer

When the guide vane opening closes below a certain percentage and the delivery pressure is still too high, the blow-off valve will be opened to prevent possible surge.

All three of the compressors make use of a single set of inlet vanes, except for the older GHH compressor. This compressor makes use of two sets of inlet vanes, but inlet guide vane control was only installed on the one set of inlet guide vanes.

After implementing the study with the newly engineered control philosophy, tests were conducted on the operation of the compressors. This included the number of running compressors during certain time periods of the day, based on the mine schedule. For maximum energy savings it was planned to operate only one compressor during the early morning- and late afternoon change-over shifts.

During these times only the one Sulzer compressor was operated. The main shaft pressure was considerably reduced and stabilised, but was not sufficient enough to operate the loading boxes on Levels 70, 76, 105 and 107. The loading boxes require a minimum pressure of 400 kPa to ensure satisfactory operation.

The proposed solution to this problem was to install smaller standalone compressors. These compressors augmented the existing system pressure to ensure proper operation of the auxiliary pressure cylinders. However, the mine decided to close the shaft and no further work was done on the lower levels.

Surge curve protection

During implementation of this project a minimum guide vane offset was programmed into the PLC control of the compressors. This caused each compressor to reduce the vane opening to the pre-set value while still ensuring sufficient airflow for safe and continuous operation.

4.2.2 Compressed air reticulation overview

Of the 20 mining levels, only 12 are in use for production. For this particular compressed air study, restrictions were imposed on the financial costs. To ensure that the project remained within the budget constraints, valve control was restricted to the production levels. The full layout of the underground levels is given in Appendix A.

The eight control valves required in the main shaft are shown in Figure 30.

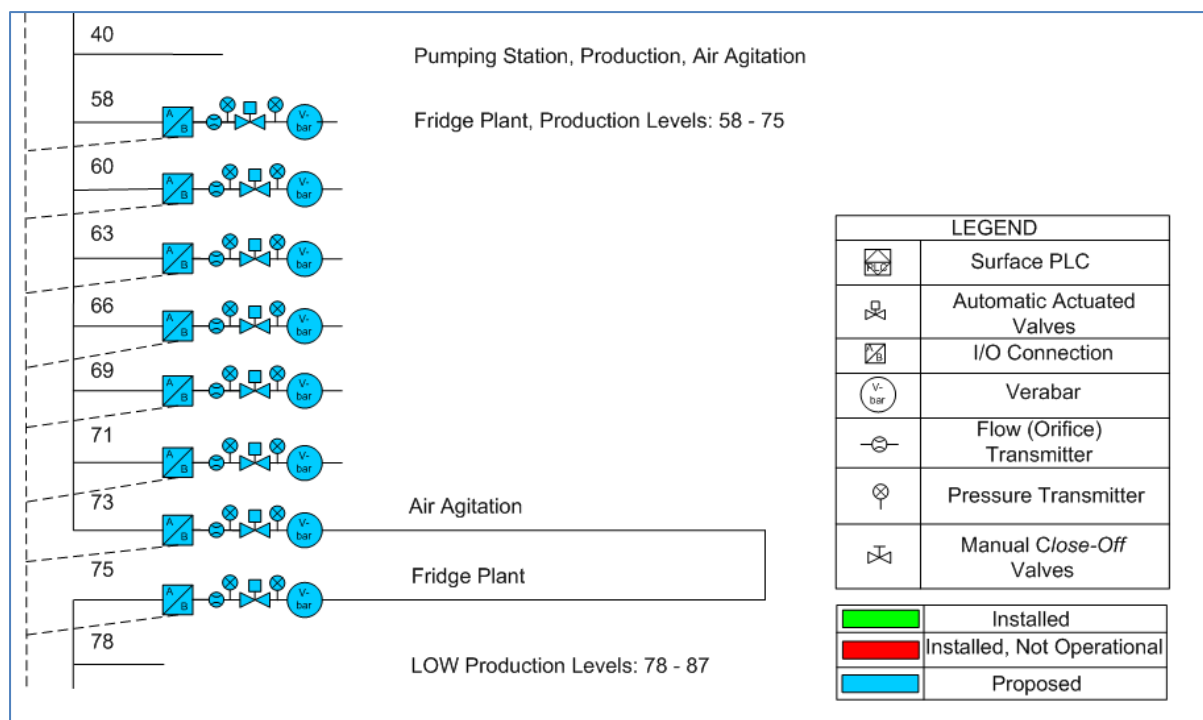


Figure 30: Main shaft layout (see Appendix G)

These eight control levels are an integral part of the main shaft. Figure 31 shows the four control levels on the subshaft.

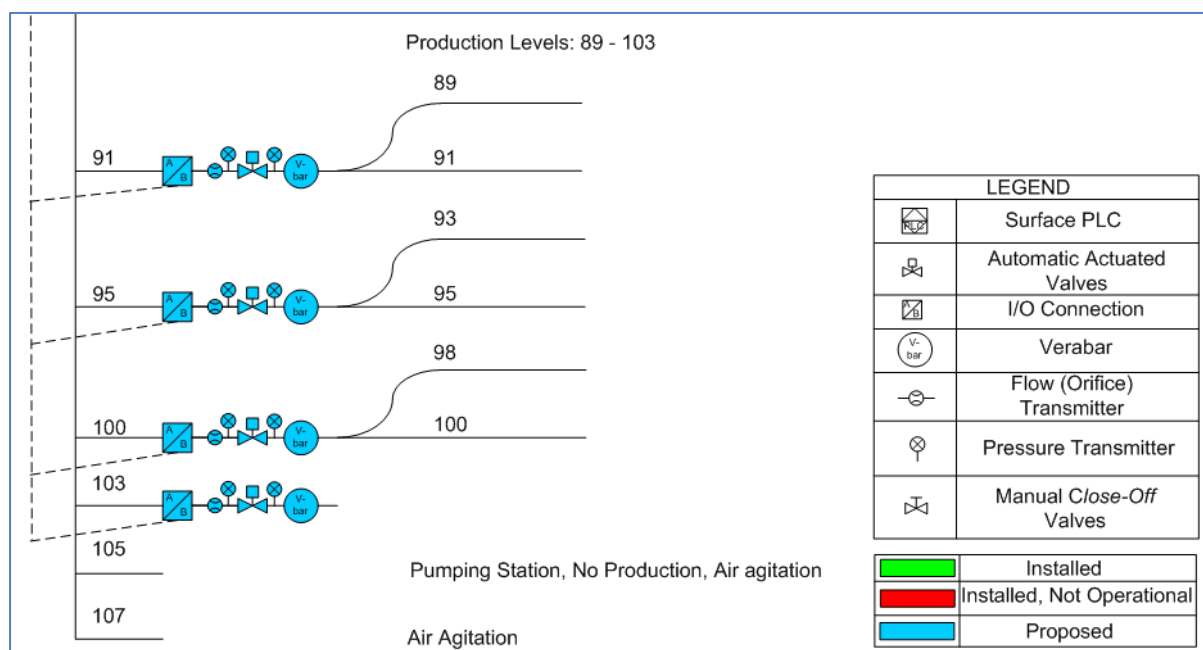


Figure 31: Subshaft layout (see Appendix G)

With all the valves and equipment installed at each of the underground levels, control of the compressed air can be accomplished at each of the 12 production levels of the mine.

The diagrammatic representations of the underground compressed air network in Figure 30 and Figure 31 show controllable valves, pressure transmitters, temperature probes, flow meters and the energy manager that is installed in the PLC. The energy manager receives signals from the pressure and temperature transmitters, strategically placed in the airflow region, to calculate the mass flow through the valve.

These parameters are used to control the underground valves at the appropriate pressure to ensure uninterrupted and effective mining at the stopes according to a predetermined time schedule. Stope refers to the area that is left behind after the ore has been removed in an underground mine, by a process called stoping.

Figure 31 demonstrates that the valves installed on Levels 91, 95 and 100 simultaneously provide compressed air to Levels 89, 93 and 98 respectively. Thus, the flow at these levels will be much higher than the other levels. The higher flow requirement is due to the levels being major production levels of the mine.

Water traps for valve actuators

Water traps (shown in Figure 32) were installed to protect the valve actuators.

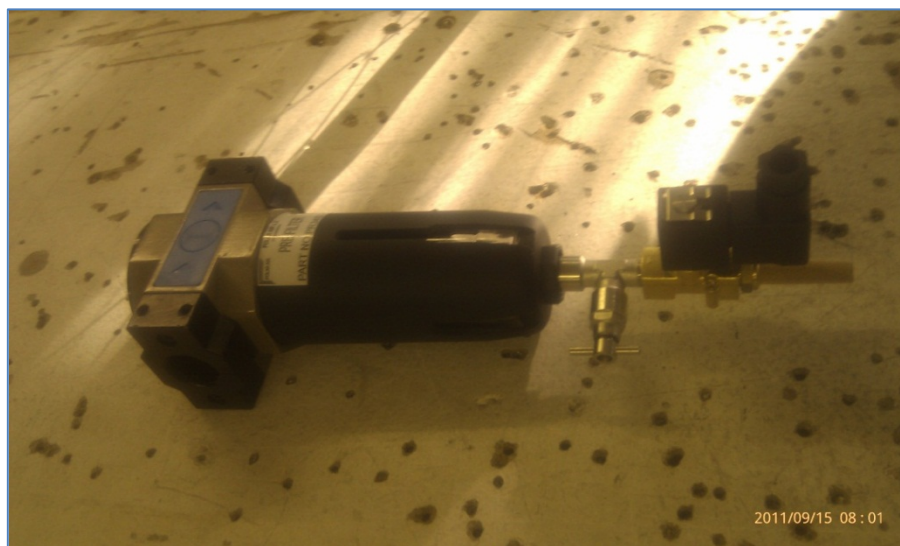


Figure 32: Miniature water trap

The water trap is fitted with a solenoid, which opens a valve to release the trapped water into the level. The solenoid is connected to the PLC and is programmed to open every 15 seconds, so that the trap does not fill up with too much water.

The requirement for water traps became evident after some of the valve actuators were damaged by moisture during the commissioning phase of the levels.

Uninterrupted power supply (UPS)

Continuous, uninterrupted power and stable voltage control of the equipment is essential. To this end two UPS units were installed on Level 69 and Level 91. The installation will ensure that stable electrical power to the PLCs is always available. This will prevent:

- Data loss
- Loss in control
- Erased PLC software

This information is essential to ensure proper, continuous and sustainable control operation and data acquisition. The valves that will be used for the project are fail-safe control valves that will open fully in the event of a power failure to the valve or valve controller. The UPS is shown in Figure 33.



Figure 33: UPS to be installed

4.2.3 Fibre optic communication back bone

Improved means of communication between the component parts is necessary in the older mines. To ensure reliable communications, a fibre optic network was installed due to the long distance between the levels; and to minimise data losses.

Communication will be provided between each of the PLCs at the 12 levels and the compressor house, which in turn, will communicate with all the components and retrieve the relevant information.

As part of this project, two fibre optic cables were required. A single-mode, 20-fibre, fibre optic cable is required for use from the surface to the first working level (Level 58). A second combined fibre optic cable (that consists of 12 fibre optic cores) and a three-core copper cable were installed from Level 58 to the lower underground level (Level 103). The three-core copper cable was used to power the UPS system.

Cable order and installation

During implementation of the project, a multimode fibre optic cable, instead of the proposed single-mode cable, was incorrectly ordered and installed. In the mining industry, single-mode cable is preferred because it is able to provide communication over longer distances than multimode cables. As expected, the multimode cable did cause communication difficulties over the more than three-kilometre deep gold mine. This included data loss and unstable communication.

The first part of the solution (to the communication problems caused by the incorrect cables) required PLCs to be installed on each of the mining levels. The newly installed PLC with the Hirschman network switch (used for the fibre optic communication) acted as a fibre optic network booster. The distance between the eight main shaft levels, as well as the distance between the four subshaft levels, did not cause any data loss when using the Hirschman switches.

A second problem area was identified because of the 533 metre distance between the last main shaft level (Level 75) and the first subshaft level (Level 91). This distance exceeded the maximum useful operational limit of the multimode cable.

To solve the incorrect cable installation problem (as done by the subcontractor), a booster switch had to be supplied and installed. The switch was installed on Level 84. After installing the network booster switch, the communication problems over the entire system was resolved.

4.3 Flow and pressure analysis

To analyse the performance of the system, airflow data was recorded and calculated for each day. This data was compared to the initial data logged at the beginning of the project as each level's equipment was commissioned.

Leakages on certain compressed air working levels were identified. These leakages occurred during the performance assessment period which had a huge impact on the performance due to the severity of the compressed air leaks. Compressed air leak-detection could only be done after implementation of the REMS.

Leak-detection is a continuous process in the mining industry, and is not restricted to the age of the mine. Leak occurrences in older gold mines are much higher due to the degrading and expansions of the mine's compressed air network.

4.3.1 Level leak-detection

During the performance assessment period, two major leaks were identified which had a huge impact on the electrical savings of the project. The leaks identified were as follows:

1. During May 2011: Level 91 – 7 kg/s leak
2. During June 2011: Level 103 – 8 kg/s leak

Leak-detection should be done on a regular basis in the mining industry. But, with a compressed air management system, continuous data can be measured and the results can be used to aid the detection of compressed air leaks.

Level 91 leak

An unexpected and sudden deterioration in performance occurred during May 2011. A leak in the compressed air delivery line was identified on Level 91, but only at the end of May 2011. This leak was reported to the mine and repaired on 1 June 2011.

In Figure 34, the calculated results of the flow on Level 91 are shown. It can be seen that the leak actually occurred on 13 May 2011 and averaged about 7 kg/s, an increase of approximately 700%. After being repaired, an average daily demand reduction of 1.5 MW was achieved.

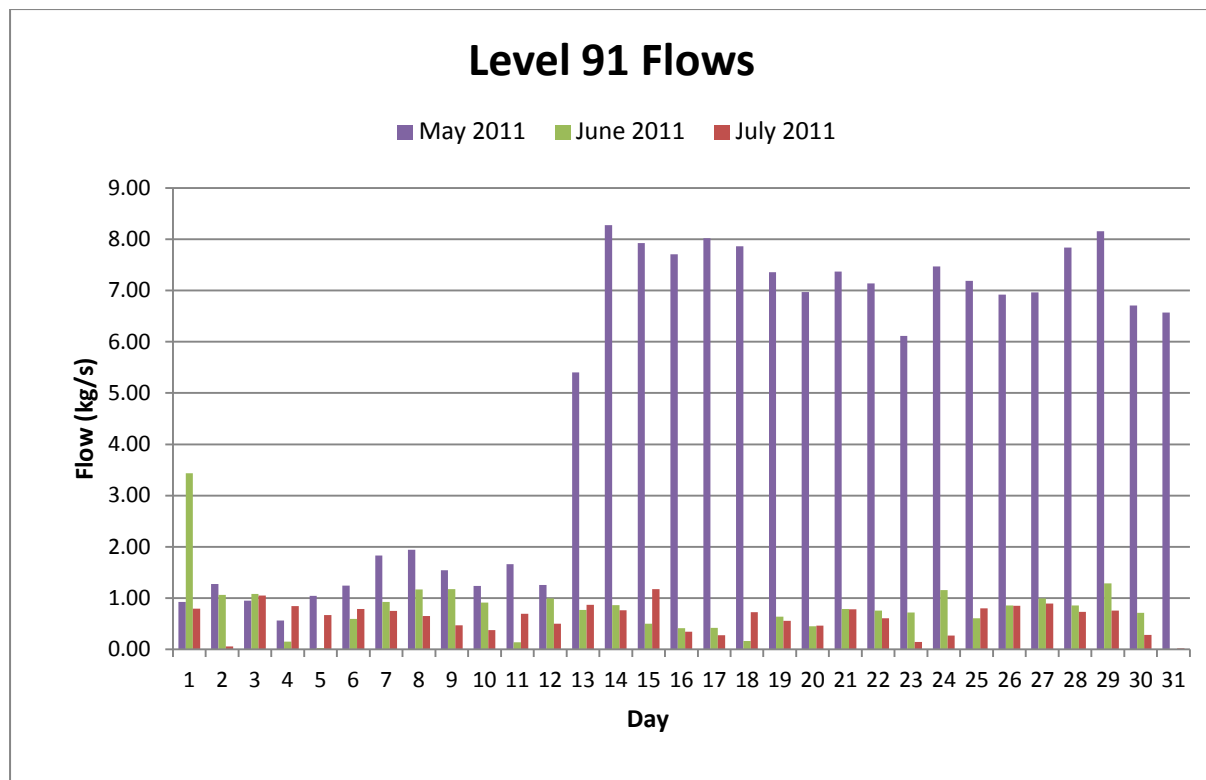


Figure 34: Level 91 flows

A second unusually large leak occurred during June 2011 on Level 103.

Level 103 leak

As seen in Figure 35, the airflow in Level 103 increased by more than 200% on 19 June 2011. The leak at this level averaged at 8 kg/s, resulting in a 1 MW loss in average electrical demand. After reporting the leak to the mine personnel it was repaired. No further leaks occurred during July 2011.

Compressed air leaks can have a significant effect on the compressed air as well as on cost. Therefore, it is essential to monitor and repair the compressed air pipelines on a regular basis. In old gold mines, an employee is responsible to detect and report compressed air leaks for each mining level. With the new technologies installed, the data received from the underground levels can be analysed to indicate compressed air leakages, thus making it easier to detect the precise leak location.

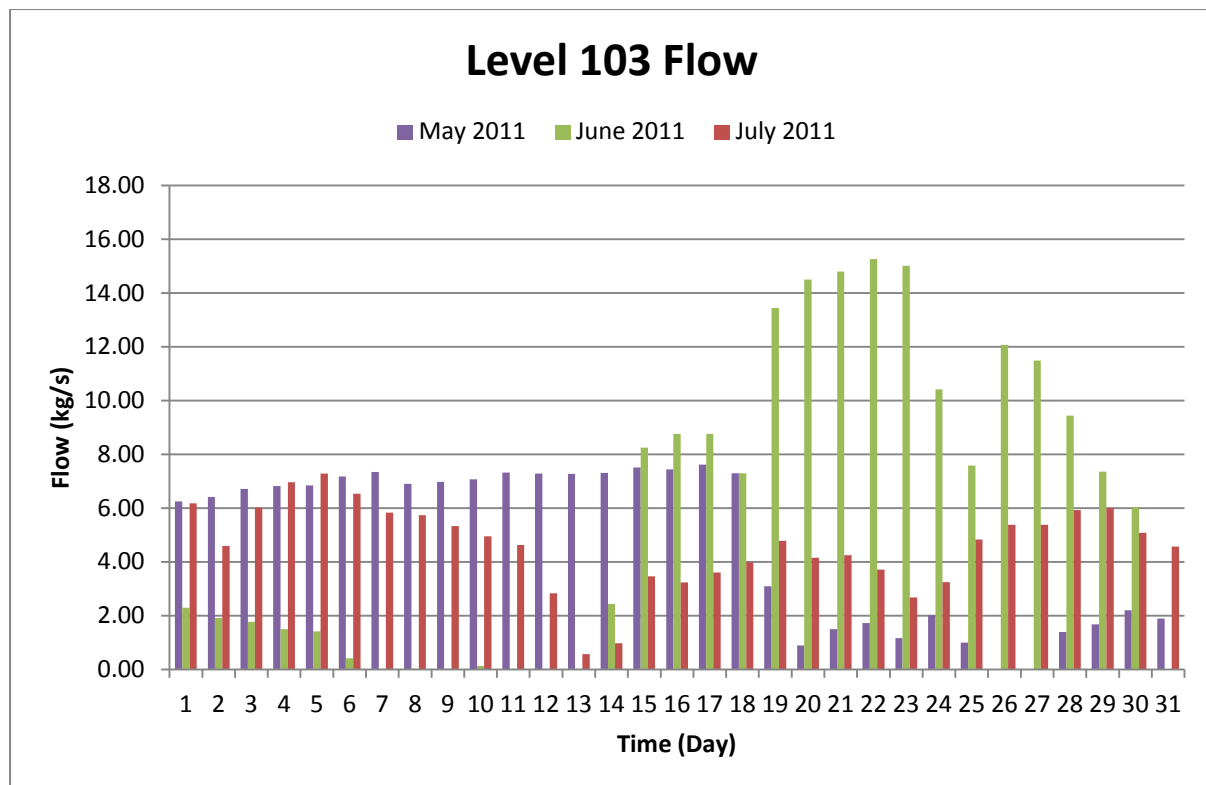


Figure 35: Level 103 flow

4.3.2 Pressure losses between levels

Over the years, mining operations have progressed to depths of up to 3000 kilometres below the surface. The air pressure (at the very deep levels at which mining activities take place) is considerably greater than the atmospheric pressure on the surface, sometimes referred to as auto-compression. This also leads to a natural increase in temperature; over and above the increase due to the transfer of heat from the hot rock face.

In Table 10 the auto-compression between two different levels is indicated. Each valve in the table indicates the pressure difference between two levels. An average pressure value of the auto-compression between levels is indicated for a 24-hour profile. The minor changes in auto-compression are due to different compressed air usage during specific times of the day.

Table 10: Auto-compression between the different levels

Time	L58 to L60 (kPa)	L60 to L63 (kPa)	L63 to L66 (kPa)	L66 to L69 (kPa)	L69 to L71 (kPa)	L71 to L73 (kPa)	L73 to L75 (kPa)	L75 to L91 (kPa)	L91 to L95 (kPa)	L95 to L100 (kPa)	L100 to L103 (kPa)
0:00	3.55	3.61	4.47	4.44	0.86	6.05	-19.29	24.08	6.35	10.52	-0.71
1:00	3.54	3.58	4.45	4.40	0.88	6.00	-19.18	24.05	6.32	10.42	-0.82
2:00	3.59	3.53	4.57	4.38	1.01	5.86	-18.32	24.15	6.28	10.58	-0.91
3:00	4.00	4.96	5.43	5.59	2.54	5.51	-11.51	30.11	8.54	12.37	-0.46
4:00	3.91	4.54	5.25	5.28	2.13	5.56	-12.72	28.60	8.11	12.07	-0.65
5:00	3.98	4.17	5.47	5.29	2.13	5.57	-13.07	28.61	7.68	12.21	-0.63
6:00	3.93	4.10	5.31	5.26	1.88	5.68	-14.26	28.12	7.72	11.71	-0.37
7:00	3.78	4.16	5.12	5.26	1.72	5.74	-14.21	27.76	7.77	11.36	-0.34
8:00	3.53	3.42	4.82	4.99	0.98	6.13	-18.25	25.40	6.64	11.17	-0.43
9:00	3.30	3.47	4.30	4.70	0.71	6.23	-20.24	24.11	6.36	10.57	-0.50
10:00	3.41	3.27	4.34	4.64	0.59	6.29	-20.63	23.86	6.21	10.63	-0.51
11:00	3.50	3.15	4.71	4.53	0.52	6.41	-21.23	24.15	6.23	10.76	-0.28
12:00	3.53	3.20	4.78	4.46	0.75	6.06	-18.84	24.09	6.39	10.79	-0.48
13:00	3.64	3.72	4.65	4.50	0.96	5.96	-17.79	24.86	6.46	11.05	-0.65
14:00	3.66	3.81	4.72	4.41	1.23	5.82	-16.78	25.19	6.62	11.01	-0.64
15:00	3.73	3.85	4.87	4.45	1.36	5.77	-15.97	25.65	6.78	11.14	-0.49
16:00	3.86	4.15	5.23	4.81	1.74	5.69	-14.29	27.29	7.54	11.46	-0.29
17:00	3.99	4.63	5.49	5.21	2.16	5.61	-12.48	29.16	8.19	11.74	0.09
18:00	3.99	4.46	5.43	5.08	2.02	5.68	-13.16	28.72	7.98	11.64	0.06
19:00	3.99	4.63	5.41	5.19	2.12	5.61	-13.26	28.98	7.96	11.82	0.11
20:00	4.24	5.15	5.89	5.77	2.88	5.56	-16.07	24.75	6.86	10.44	-0.35
21:00	4.29	4.92	5.87	5.62	2.63	5.92	-17.39	22.02	5.74	9.77	-0.58
22:00	4.12	4.34	5.44	5.19	1.93	5.90	-17.50	21.19	5.46	9.65	-0.68
23:00	3.26	3.16	4.10	3.86	0.59	5.62	-20.05	21.60	5.62	9.70	-0.88
Average	3.76	4.00	5.00	4.89	1.51	5.84	-16.52	25.69	6.91	11.02	-0.47

By knowing the average pressure value of the auto-compression between levels, the pressure in the main shaft can be monitored. Any change in comparison to the average value in Table 10 will indicate a pressure loss in the main shaft compressed air column, and therefore a compressed air leak.

As noted in Table 10 each column's value (auto-compression valve between two levels) is very constant, resulting in an average value used as a baseline value. The negative value for Level 73 to Level 75 is due to the position of the valve. Level 75's valve is on the same pipeline as Level 73 over a

long distance (as shown in Figure 36), thus the negative value is related to compressed air losses in the pipeline.

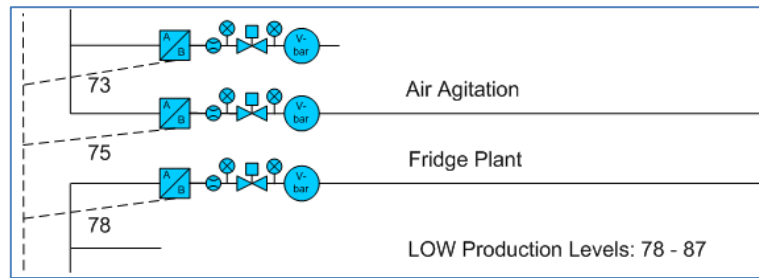


Figure 36: Pipe layout between Level 73 and 75

The negative auto-compression average between Level 100 and Level 103 indicates that there is a compressed air leak between the levels. Due to the difficulties of working at extreme depths in the main shaft, this was not attended to at the time this data was collected.

4.4 Implemented control system

All the results obtained were collected and calculated by REMS-OAN. All the data regarding the project was logged and stored on the REMS servers. The implemented compressor layout is shown in Figure 37 - it is a snapshot of the display monitor; a *running* compressor is indicated in green, while a *stopped* compressor is indicated in orange.

The compressors can be controlled by individual set points, but the final control philosophy makes use of a main control set point.

To manage the compressor each Moore controller commands the percentage vane opening which is indicated next to the REMS logo in Figure 37. To prevent the compressor from approaching a surge condition a minimum offset for the vane openings is programmed into the Moore controllers. The minimum offset of the vane openings are as follows:

- GHH = 0% (discussed in Section 4.2.1)
- BB = 42%
- Sulzer = 38%

The valve control is presented in Figure 38, showing four of the control valves with their output flows and pressures.

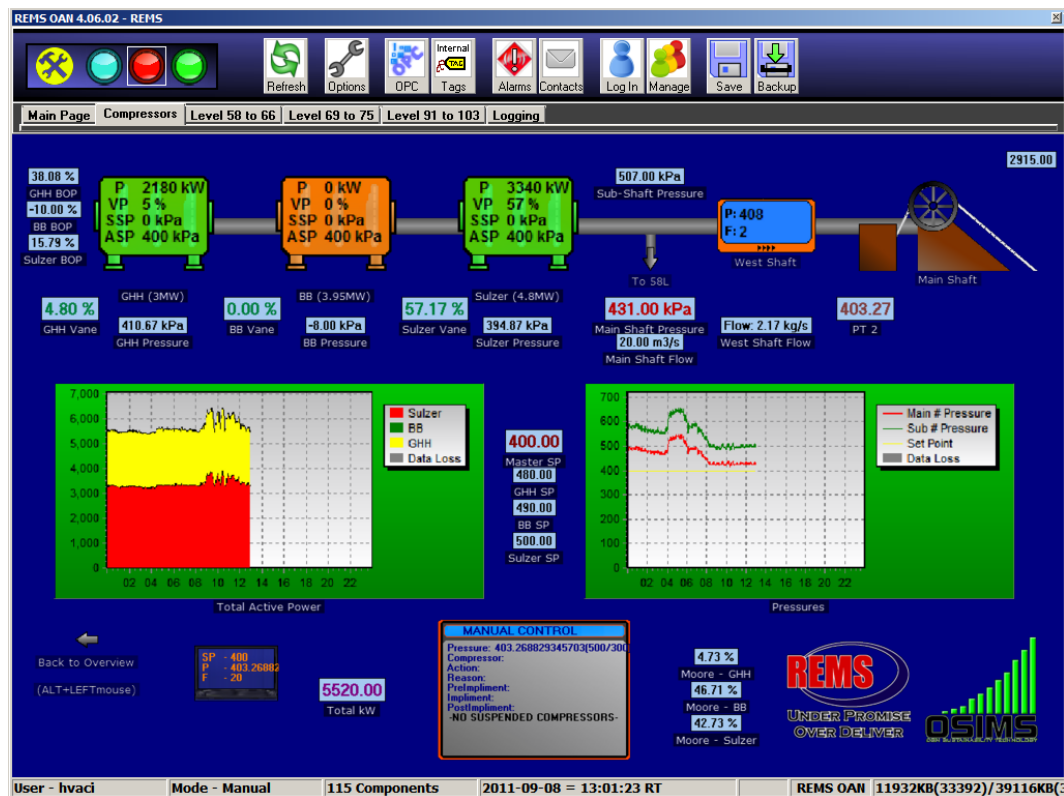


Figure 37: Implemented REMS-OAN – compressors

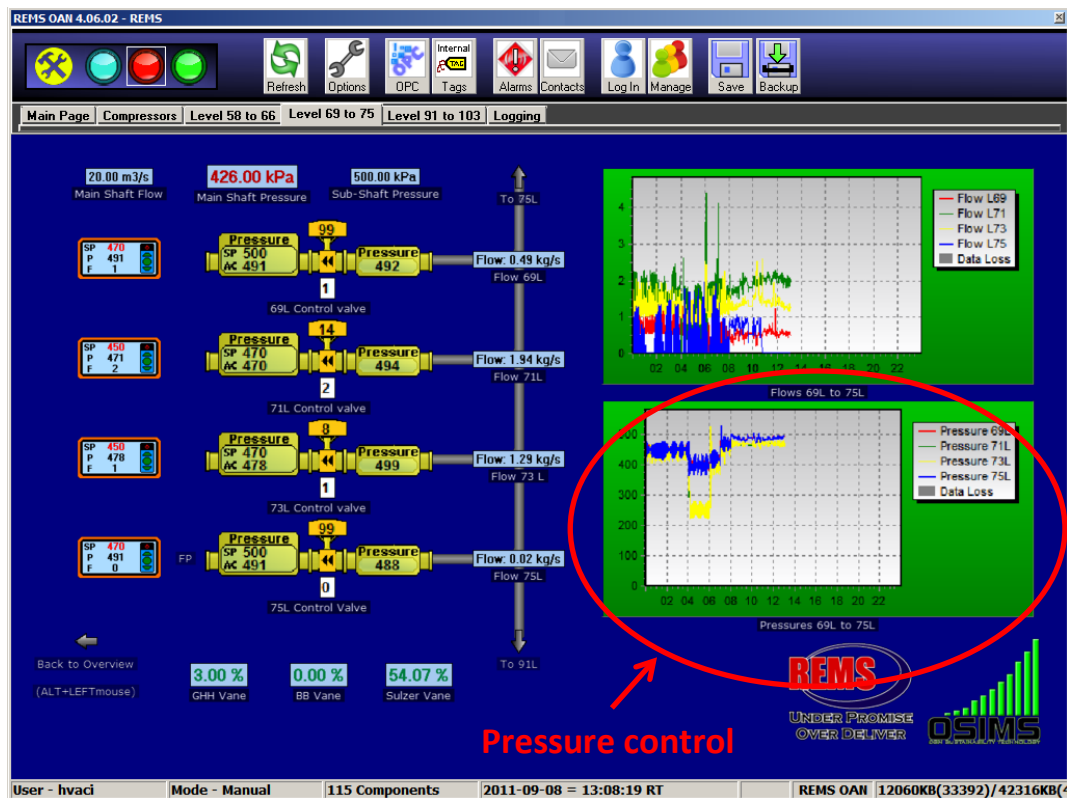


Figure 38: Implemented REMS-OAN – underground valves

From the pressure graphs in the REMS-OAN platform of Figure 38, the pressure control can be seen on the output pressure as required by the mining schedule.

Figure 39 displays the logging information page which is included in the REMS platform, and is discussed in Section 0.

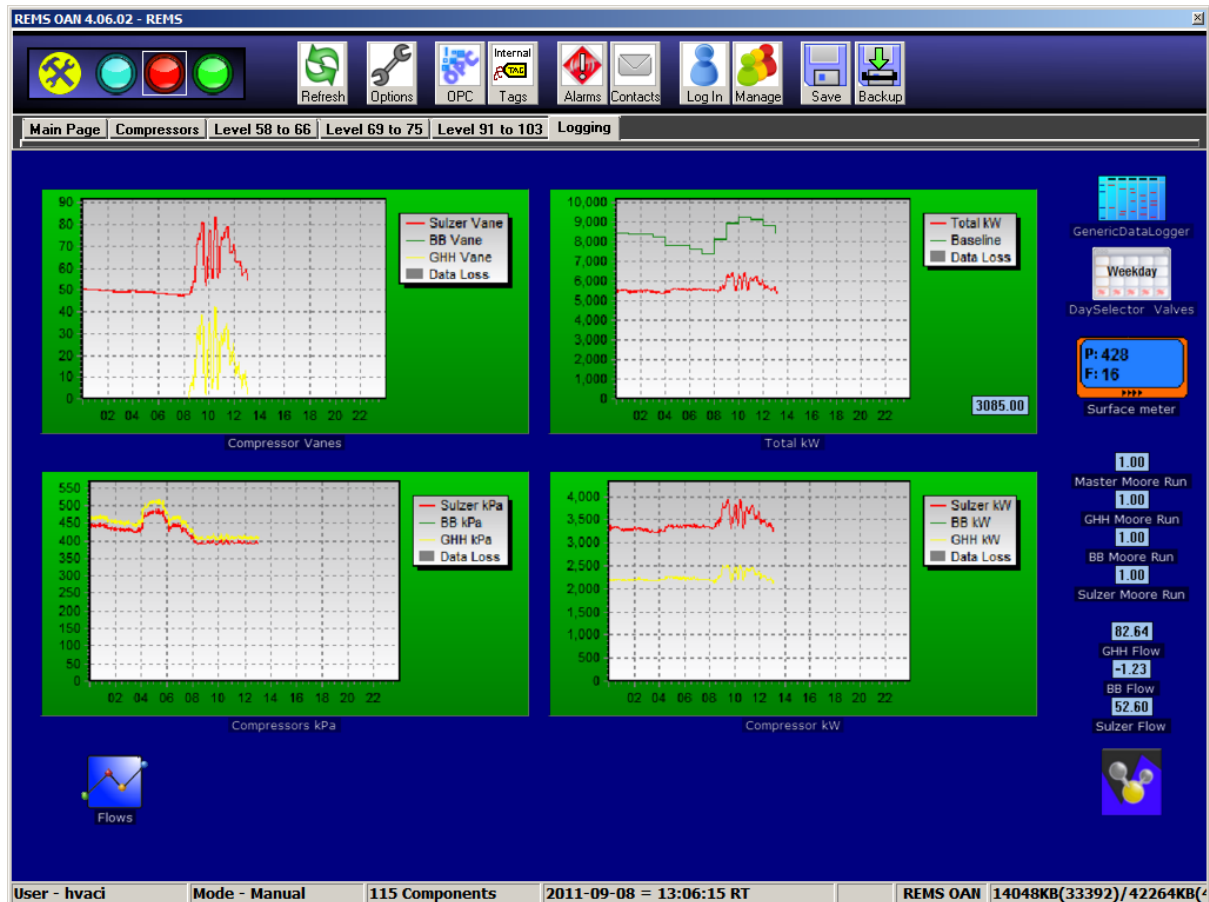


Figure 39: Implemented REMS-OAN – logging page

The REMS-OAN software was also used for compressed air leak-detection and fault-finding.

4.5 Measured compressors performance results

To achieve the energy efficiency strategies that were discussed in Chapter 3, the compressors at the mine must be automated and controlled according to various pressure set points. Furthermore, the underground valves and instrumentation must be installed, tested and commissioned. The control and the data logging were done by REMS. In order to achieve the electrical energy savings the following schedules are important:

- Only two compressors should be used for the entire day.
- During low demand the two compressors must be able to cut back to a safe minimum operating pressure.
- The underground control valves should control the pressure of each level to reduce the compressed airflow to the minimum acceptable pressure without loss of production. This will ensure that the total compressed air demand is reduced, resulting in lower energy usage of the compressors.

After implementation, the performance assessment for the project was instigated. During this time the control philosophy was implemented for the underground valves and compressors. During the performance assessment period results were obtained and analysed to find possible upgrades to improve on the performance of the control system.

Due to the unique challenges of the project, some of the work was delayed as discussed in Section 2.4. This resulted in the installations on the outstanding levels only being implemented during the performance assessment period.

The performance assessment period was from 1 May 2011 to 31 July 2011. The results for these months are presented in the following sections.

4.5.1 Measured flow results

After implementation, a procedure was developed to solve the various problems that arose. The airflows were recorded and logged. Calculations were based on values, and averaged out over a 24-hour period.

The flow data was used to monitor the performance of the project. In Figure 40 the main shaft flow is indicated. The main shaft flow for April 2011 acted as the flow baseline before commencement of the project and was measured as **32kg/s**. As the performance assessment period progressed and as the project challenges were solved, the main shaft flow decreased to **21kg/s**. The improvement can be seen by the significantly reduced airflow during June and July 2011.

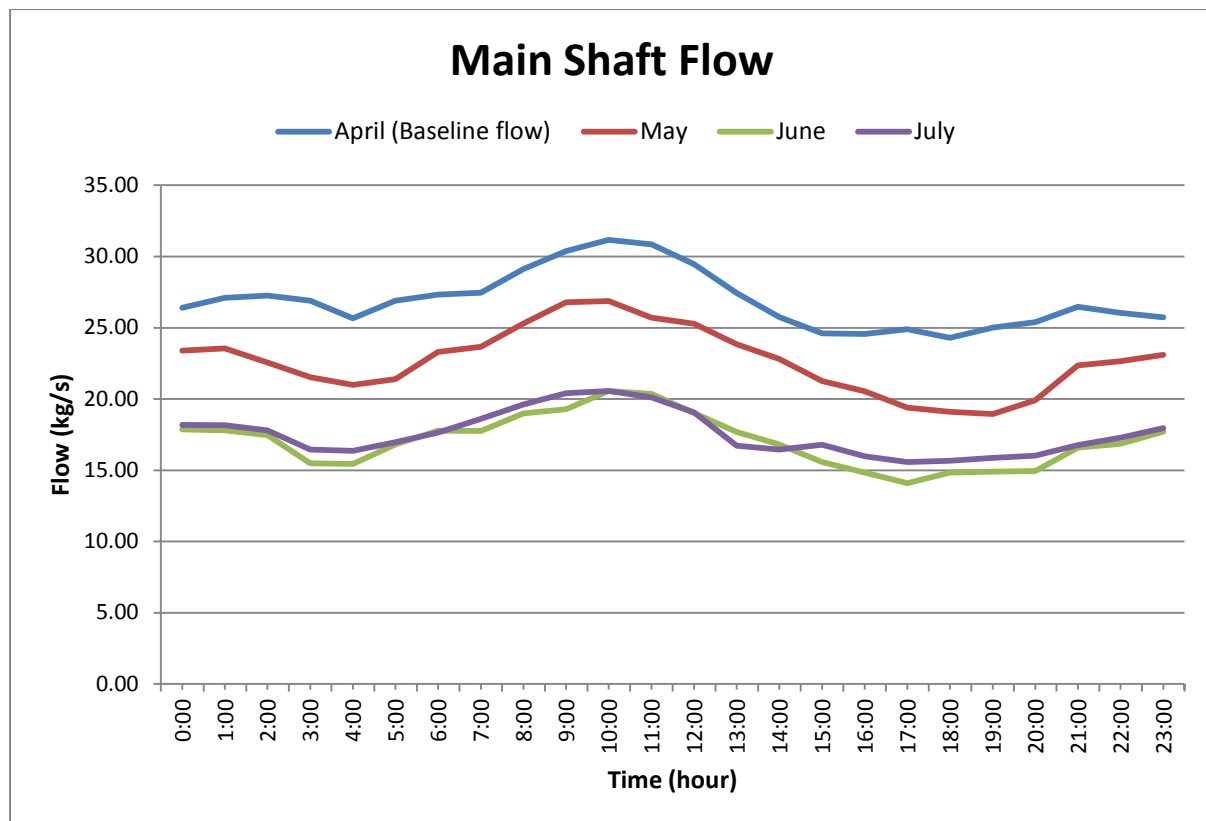


Figure 40: Main shaft flows

A positive improvement for the mine control room information is the availability of flow and pressure data for the compressed air network. By analysing the data, fault-finding can be done.

The electrical energy savings obtained from the reduced airflow is outlined in the following sections. In these sections reasons are provided for the improved performance of an old South African gold mine.

Actual flow results compared to simulation results

In Table 11, the actual flow results are compared to the simulation results. From the initial simulation it was noted that air pressure and flow is reduced by implementing active valve control on the mining levels. The total flow of all the levels is calculated as **21.1 kg/s**, which resulted in a **9.48%** variation of the simulated results.

Table 11: Actual flow vs simulation results

Level	Actual flow results (kg/s)	Simulation results- after control optimisation	
		Flow (kg/s)	% variation
L58	0.1	0.1	0.00%
L60	0.8	0	-100.00%
L63	0.2	0.6	200.00%
L66	1.5	2.4	60.00%
L69	0.1	0.2	100.00%
L71	1.1	1.2	9.09%
L73	1.2	1.5	25.00%
L75	0.2	0.4	100.00%
L91	1	1	0.00%
L95	7	7.7	10.00%
L100	4.1	4.5	9.76%
L103	3.8	3.5	-7.89%
Total	21.1	23.1	9.48%

From the percentage variation for each of the levels it can be seen that the simulation helped to make a project on compressed air a possibility at an old gold mine. The high percentage variation on some of the levels is due to the small flow on these levels as discussed in Chapter 3. However, the unique challenges associated with the mine can affect the efficiency of such a project.

4.5.2 Results - May 2011

The results of the energy efficiency project started to officially come in during May 2011. During the first performance assessment month there was still uncompleted work and the control philosophy was not completed. The initial poor performance is underwritten by the following:

- No control to the subshaft levels due to an outstanding booster network switch on Level 84. The set-point control is done downstream of the pressure valve. Downstream pressure transmitters in Levels 60 and 66 were not working due to damaged units. Therefore, these two levels could not be controlled.

- The valve position feedback on Level 69 was out of order.
- Due to the outstanding installations of the water traps for each valve positioner, the other levels were not permitted to be controlled during May 2011 to prevent their valve positioners from being damaged as well. The water trap installations were completed by the end of May 2011.

Because of these problems the expected electrical energy savings were not realised.

The results obtained during May 2011 are shown in Appendix H: Table 16, where the power consumption for the three compressors and the M&V baseline is shown. By using the M&V baseline and the actual energy usage of the compressors, the hourly demand reduction was calculated. The total savings for May 2011 was **0.92 MW** with a proposed calculated target of **1.96 MW**. Further improvements were required to ensure that the shortfall of **1.04 MW** was achieved.

The performance results for May 2011 were plotted on a stacked chart and are shown in Figure 41. During May 2011 the GHH compressor was used to satisfy system compressed air demand (due to outstanding project issues), whereas the control philosophy was based on operation of only the BB and the Sulzer compressors.

The different working shifts of the mine can be seen from the plotted data. The cleaning shift takes place in the early morning and late at night, while the drilling shift is completed during the midday. To increase the savings the average compressor usage should be lowered. This can be accomplished during the change-over shifts, when only one compressor is required. These times can be seen in Figure 41 where there is a reduced demand:

- From 02:00 to 05:00 – the change-over shift from the cleaning to the drilling shift.
- From 17:00 to 21:00 – the blasting clearance time, which leads to the start of the late-night-cleaning shift.

In Figure 41 the dashed line represents the M&V baseline.

To achieve the proposed target the following procedures were recommended:

- Complete all the underground level installations and implement the control philosophy for all the control valves.
- Change the control of the compressors by reducing the main control pressure set point.

Change the minimum offset of the compressor vane positions to an optimum value.

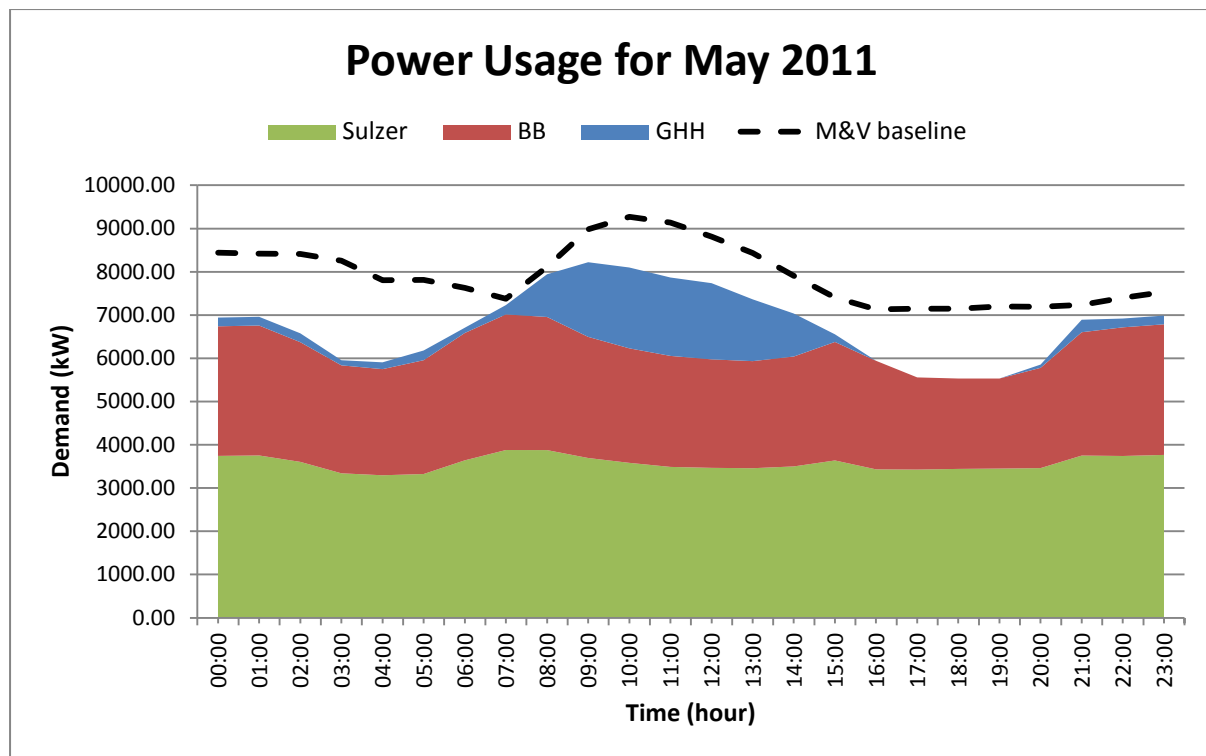


Figure 41: Compressor power usage for May 2011

By having complete control of the entire system, the average energy usage will be reduced over the 24-hour normal working weekday. To achieve the target electrical energy savings, the main shaft airflow must be reduced by establishing the optimum working pressure for the mining levels. The optimum pressure should be sufficient to meet the compressed air demand during the drilling shift and reduced when no drilling takes place.

4.5.3 Results - June 2011

The results for June 2011 are represented in Appendix I, Table 17. During June, most of the outstanding issues carried over from May were completed:

- A leak on Level 91 was repaired.
- PLC software failure on Level 66 which resulted in lost control. The PLC unit was removed so that the software could be replaced and updated.
- Outstanding valve positioner on Level 100 due to water damage was repaired.
- The valve positioner on Level 103 was removed, repaired and reinstalled during June.
- Unreliable communication to the subshaft was repaired.

With most of the installations completed – only one valve was still inoperative due to a mechanical failure – there was a significant increase in the electrical savings. The daily demand reduction for June 2011 was calculated to be **1.68 MW** which resulted in an **81.5%** increase in comparison to the previous month. The increase in the savings is also due to an upgraded control philosophy and improved compressed air leak-detection and repairs.

The results for June were calculated to be **85.5%** of the target savings. During the previous performance assessment month the outstanding issues were fixed and an increase in electrical savings was achieved.

The stacked chart of the compressor power usage is shown in Figure 42. An increase in the electrical demand reduction can be clearly seen as well as:

- A decrease in the use of the third compressor (GHH).
- The usage of the BB and the Sulzer is almost similar to the first performance assessment month (May 2011), with an average decrease in energy usage.
- The difference of the peak electrical usage is almost 1 MW, due to implementation of compressed air control.

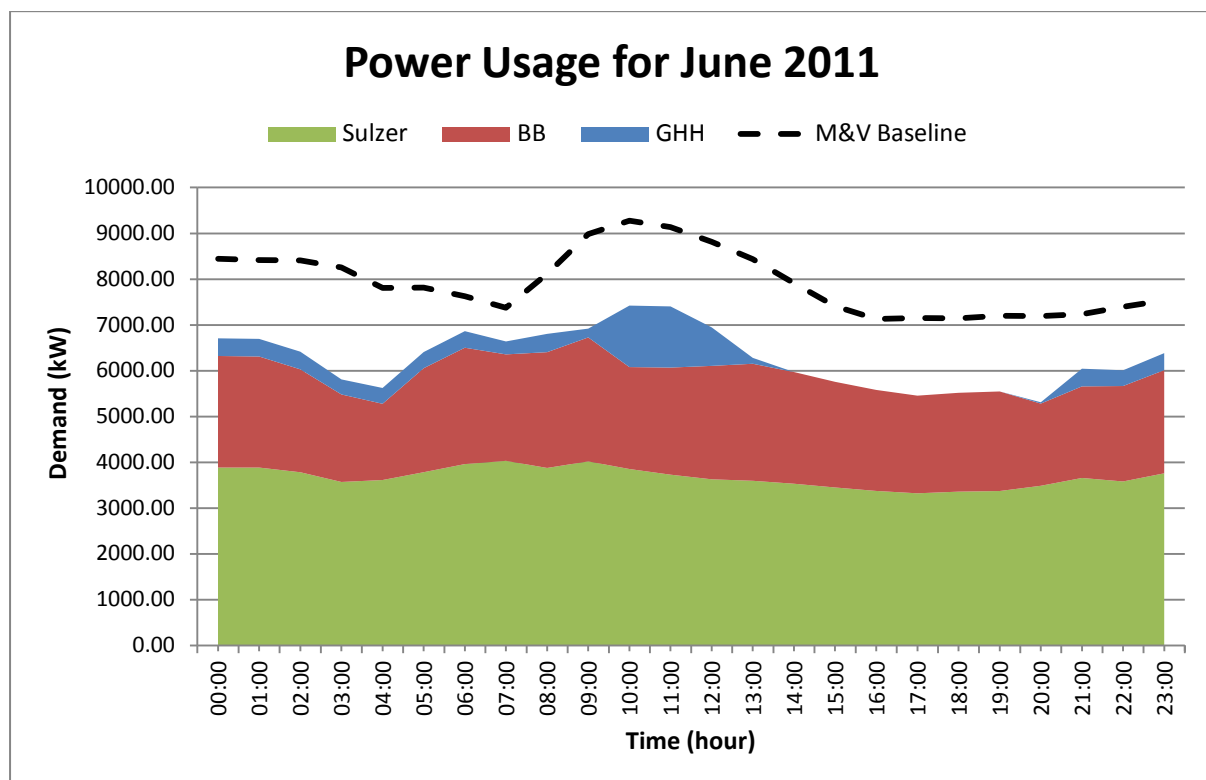


Figure 42: Compressor power usage for June 2011

4.5.4 Results - July 2011

During the last performance assessment month the replacement of one underground valve was outstanding (Level 103), due the mechanical failure of the valve. A new valve was ordered but because of the delivery lead time, the valve was only installed during August 2011. Level 103 is one of the high production levels that consume large volumes of compressed air and pressure.

The performance results for July 2011 are outlined in Appendix J, Table 18.

There was a **10%** increase in the electrical savings when compared to the previous month. The average daily demand reduction during July 2011 was **1.87 MW** over a typical 24-hour working weekday. This was **94%** of the proposed target savings.

The stacked chart of the compressor usage is shown in Figure 43.

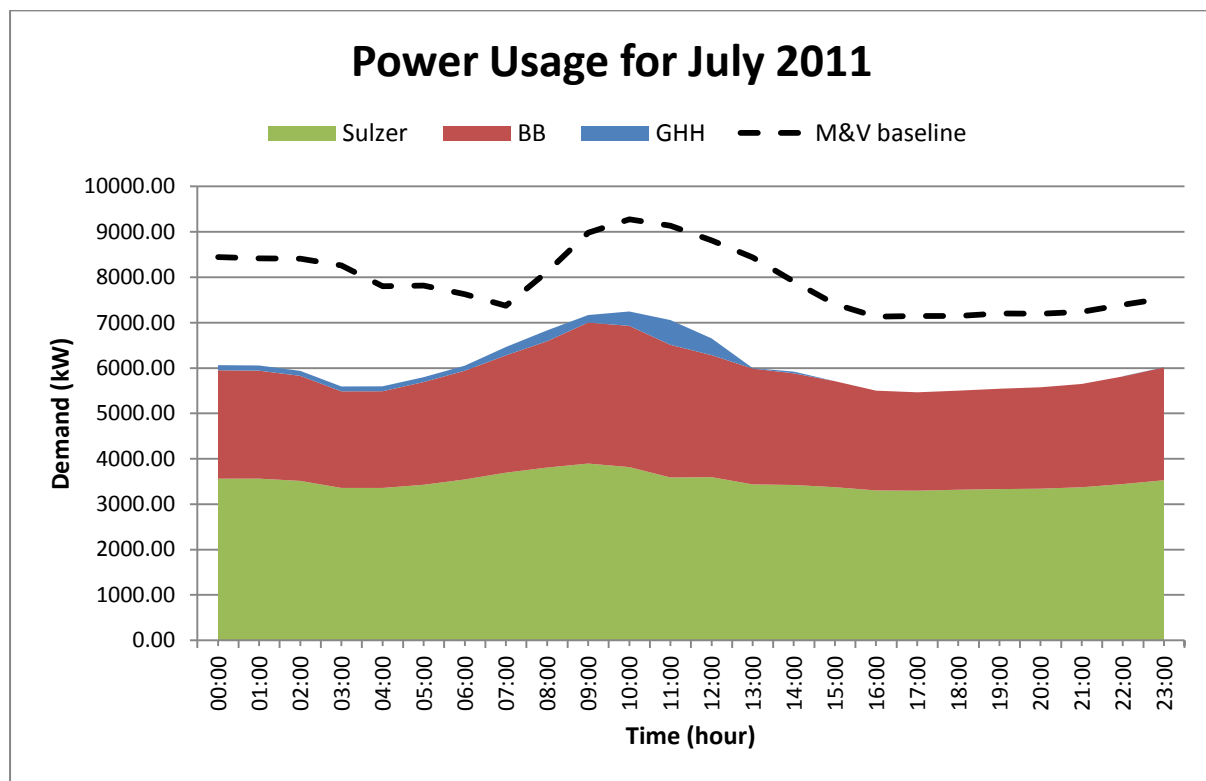


Figure 43: Compressor power usage for July 2011

Figure 43 shows that the usage of the GHH compressor decreased during July 2011. The third compressor (GHH) was only used during the morning cleaning and drilling shift.

4.5.5 Compressor usage summary

In Appendix K: Table 19, the data for the three-month period can be seen, as well as the average hourly decrease in electrical power consumption.

The three months' energy usage is plotted in Figure 44. These graphs show that the new control philosophy has been successfully implemented and upgraded during the performance assessment period.

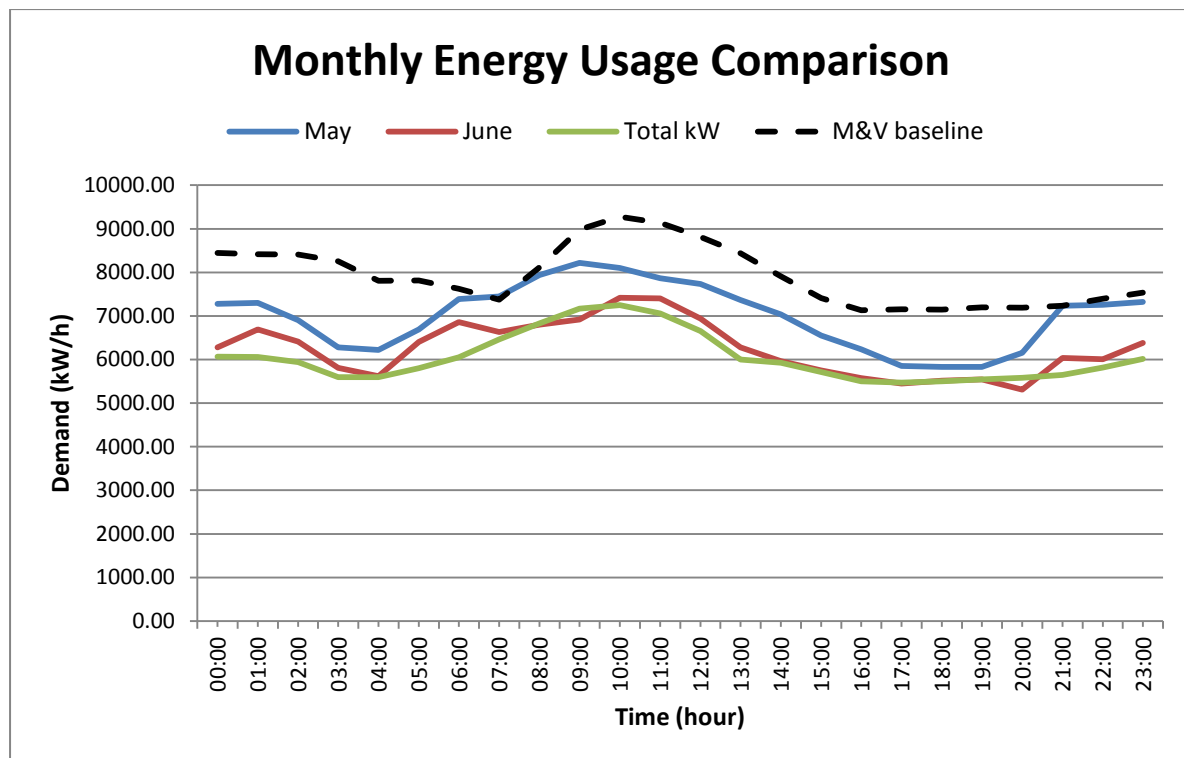


Figure 44: Compressor power usage comparison

For each month the daily electrical power savings are represented in Appendix K: Table 20. For each day the savings are indicated as a percentage of the proposed target savings. The days that experienced data loss are indicated in red; the days the project over performed are indicated in green.

During July 2011, the miner's union proceeded with strike action during the end of the last week of the project. This resulted in an artificial high performance for 29 July 2011. According to M&V, the average savings of the project was calculated as **1.80 MW, 91.6 %** of the target savings.

The average daily savings for the three performance assessment months are indicated in Figure 45. At the start of the performance assessment period, low energy savings were achieved due to compressed air leaks and unfinished installations. However, the energy profile indicates an improved average demand reduction trend as the implementation of the compressed air control was perfected. At the end of the performance assessment period the average demand reduction stabilised.

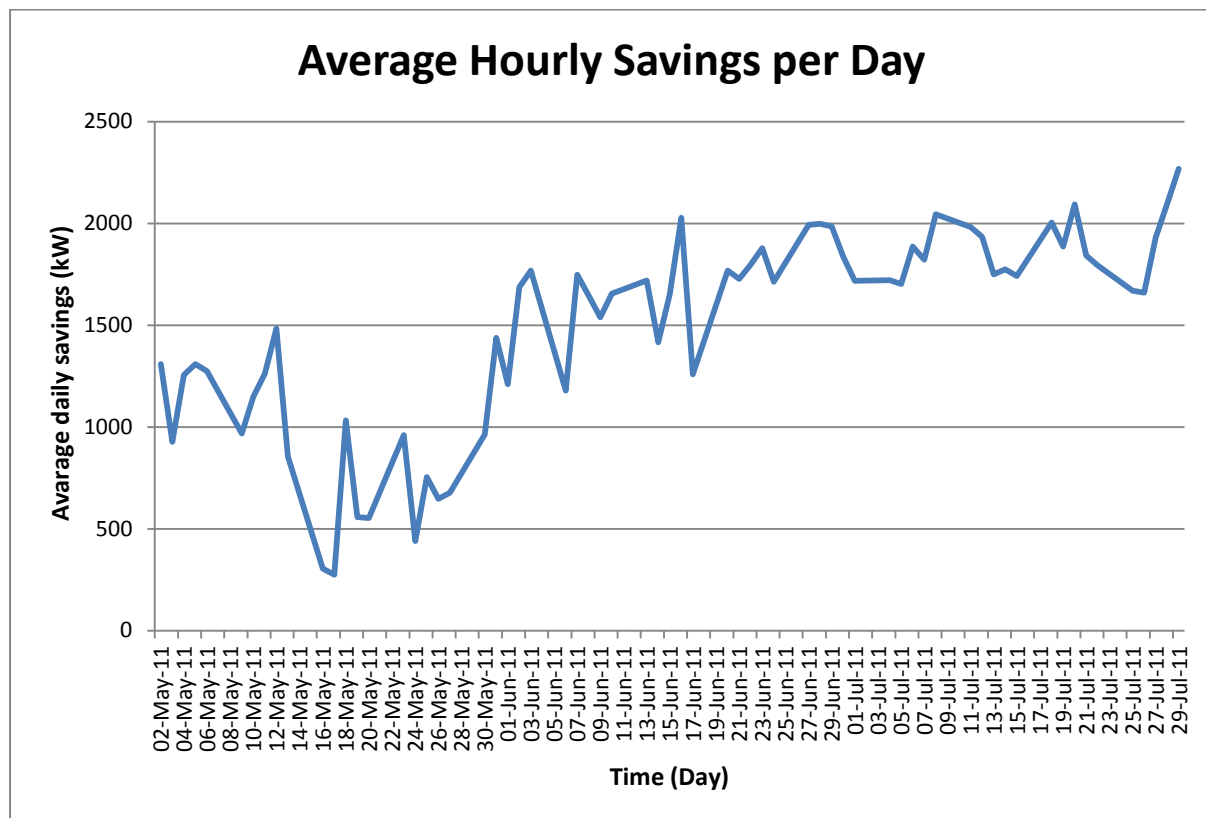


Figure 45: Average hourly saving per day

4.5.6 Compressor blow-off percentage (BOP)

While commissioning the compressors according to the new control philosophy, care should be taken in operating these machines in order that:

- The control room personnel starts and stops the machines correctly.
- The compressors are not operated below a minimum guide vane position opening (not less than 40%).
- Compressors do not go into a surge condition.

The BOP was programmed into the SCADA system and used to monitor the compressors. The BOP was calculated to a 24-hour profile for July 2011 and is represented in Figure 46 where 0% indicates a blow-off condition.

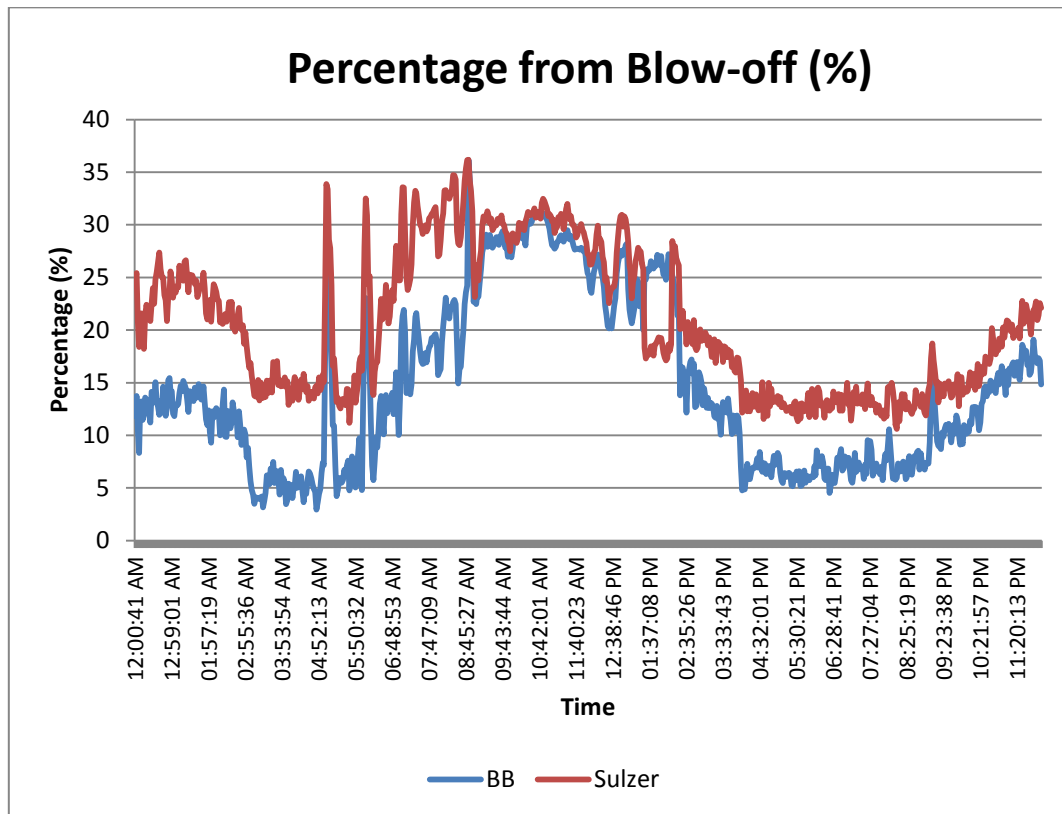


Figure 46: Blow-off percentage of the compressors

Figure 46 indicates that after implementation of the new control, the two compressors were operated in the optimum region without going into a blow-off condition. The logged data is averaged for one week in July 2011. The blow-off percentage is calculated by the Moore controllers by using the surge curve of each of the compressors.

The blow-off percentage depends on the amount of pressure it should deliver at a certain guide vane opening. If the main shaft pressure is much higher than the set point – with the compressor operating at a minimum guide vane opening – the blow-off valve will open.

4.6 Financial impact

Table 12 indicates the financial savings that were calculated by the energy efficiency project for the time period allowed for the analysis of the system. The financial savings potential for the mine was not fully met due to the project challenges discussed in this chapter.

Table 12: Financial savings generated by the mine for the period of analysis

Month	Average demand reduction (MW)	Accumulated monthly savings per week (MWh)	Estimated monthly financial saving (R)	
			Potential (R)	Obtained (R)
May-11	0.92	550.1	R 350,000.00	R 165,772.12
Jun-11	1.69	1 127.9	R 720,000.00	R 603,443.68
Jul-11	1.88	1 261.7	R 720,000.00	R 675,446.21
Total			R 1,790,000.00	R 1,444,662.00

The actual and proposed financial savings are calculated according to Eskom's Megaflex tariff, as explained in Section 1.2.2. The financial saving is determined with the aid of a proposed electrical power usage of the compressor for a day. The Megaflex tariff is based on the time-of-use. The tariff structure varies for winter and summer months. As can be seen, May is considered as part of the summer months, hence the lower potential savings. If maintained properly the project could result in **R5.31 million** annual savings.

The proposed financial savings are only an indication of what can be expected due to the following:

- The cost impact is only valid if M&V metering is done at the point where billing metering is installed. Otherwise, the energy part of the tariff is used to estimate the financial impact of the project.
- The tariff is imposed on the typical average working weekday, Saturday and Sunday profiles derived from the applicable data.

4.7 Conclusion

The results of an EE/DSM on a compressed air network for a specific case study were illustrated. In Section 4.2.1 the old control philosophy of the mine was presented and was subsequently upgraded to the control philosophy laid out in Section 3.3.

Regardless of the challenges that arose during the performance assessment months, the implemented control resulted in reducing the flow and pressure of the mining levels. During April a flow of **32kg/s** was measured. After implementation of this project this flow was reduced to **21kg/s** by the end of July 2011. During the performance assessment period two large leaks appeared on different levels. One of these leaks resulted in an air loss of **7kg/s**; the other **8kg/s**. After being repaired, the average demand reduction resulted in a 1 MW saving.

The projected target demand reduction was calculated to be **1.96 MW**. Poor performance in the first assessment month of May 2011 resulted in an average demand reduction of **0.92 MW**. In June 2011 and July 2011, average respective demand reductions of **1.68 MW** and **1.87 MW** were realised. An average demand reduction of **1.80 MW**, which was **91.6%** of the proposed target deduction, was achieved. The performance of the project was only measured during the last two performance assessment months due to data loss during the first month of evaluation.

Some condonable days influenced the financial savings and most of these condonable days were caused by the old infrastructure and improper shaft access. Overcoming these challenges, the financial impact on the mine resulted in a **R1.44 million** financial saving. By maintaining the compressed air system control, an annual saving of **R5.31 million** can be expected. Without the implementation of automated REMS, these savings would not have been possible.

Chapter 5: CONCLUSION AND RECOMMENDATIONS

Abandoned mine shafts in Maasmechelen, Belgium.



An overview of the dissertation is given in this final chapter. A conclusion is derived based on the results and observations obtained during the study of a compressed air network of an old South African gold mine. Recommendations for further research are also made.

5.1 Conclusion

In this dissertation, the investigation and the implementation of load efficiency strategies on a compressed air network on an old South African mine were discussed. With the use of REMS-OAN, the load efficiency potential has been achieved through optimal control of the mine's SCADA system for the compressed air system.

5.1.1 The demand-side management potential on old gold mine of South Africa.

An investigation on the compressed air system of an old gold mine was completed and EE/DSM was successfully implemented. By focusing on the utilisation of the compressors and on the underground compressed air usage, effective control was implemented. Sustainable energy efficiency methods were calculated and presented. These results were verified and discussed in Chapter 4.

During the implementation period, various problems and challenges were encountered. Most of these problems are uncommon to newer mines and will not cause as many project delays as is the case in this case study. The average demand reduction during May, which was the first month after implementation of this project, resulted in **0.92 MW**. This was **47%** of the proposed demand reduction.

During the months of June 2011 and July 2011, the savings increased as each problem was resolved. The average demand reduction for June and July were **1.68 MW** and **1.87 MW** respectively. Project target power savings were **1.96 MW**, resulting in **85.5%** and **95.5%** of the proposed demand reduction savings.

These results confirmed that, to conserve energy in an old mine, EE/DSM strategies can be implemented. To ensure successful implementation all the challenges associated with the project must be correctly identified and solved. On completion of the performance assessment period the average performance was calculated during June and July 2011 only. The final performance of the project was calculated to **1.80 MW**, **91.6 %** of the proposed demand reduction.

Implementing energy efficiency projects on old mines proved to be highly potential. In particular, project delays because of inadequate shaft access caused many missed energy savings opportunities.

5.1.2 Sustainable DSM energy strategies at old gold mines

Concerns about sustainable energy savings were raised by the absence of a real-time energy management system (REMS) at the mine. After implementation of the DSM strategies with the aid of the REMS, the mine reaped the benefits of the system. Regular training and commitment of the mine personnel will ensure on-going sustainable energy savings.

The average mass airflow at the main shaft decreased by **33%** - from **31 kg/s** to **20.5 kg/s** - during the peak drilling time. These reduced flows were maintained over the last two performance assessment months.

5.1.3 The challenges presented during implementation of DSM energy saving strategies at old gold mines

During implementation of DSM strategies for the compressed air network, a number of challenges were identified:

- Absence of control infrastructure:
 - No compressed air control and monitoring on the mining levels.
 - Only constant pressure set-point control on the compressors.
 - Inadequate training of the control room personnel.
- Old infrastructure:
 - Old, rusty and neglected isolation valves on the underground levels.
 - Rusty compressed air pipelines.
 - Obsolete mass airflow controllers.
 - Obsolete analogue metering equipment.
- Air leaks.
- Large volumes of water and moisture in the compressed air pipelines.
- Inadequate shaft access.

5.1.4 The feasibility and financial impact of the DSM strategies at old gold mines

There exists a large potential for DSM energy strategies at old gold mines. This can be achieved through adequate research on the mine layout, the compressed air system and all the possible challenges associated with old gold mines.

The proposed savings for 1 May 2011 to 31 July 2011 was **R1,790,000.00**. For the duration of the performance assessment period the achieved financial savings were calculated to be **R 1,444,662.00**,

which was **80.6%** of the projected savings. The higher electricity tariff for the winter months was largely responsible for the high financial savings. Less financial savings would have been achieved during the summer months, because the winter month tariff is almost three times higher than the tariff for summer months.

The financial impact of this case study indicated that a possible annual saving of as much as **R5.31 million** could be achieved. After the implementation, and during the performance assessment period, the management of the DSM project was handed over to the mine for future control updates and to ensure regular maintenance. If the energy management system is not correctly and regularly maintained, it will have a negative financial impact on the mine.

5.2 Recommendation for further studies

To sustain the energy DSM strategies at an old gold mine, the following recommendations are proposed:

- Provide adequate training to the mining personnel on using the new control system and maintaining the control.
- Establish a maintenance agreement with the mine.
- The required infrastructure for energy efficiency must be upgraded and maintained.
- Automated system control using REMS.
- The management philosophy for the compressors must be continuously maintained and upgraded whenever any changes in the mining schedule or the compressed air demand are made.
- Commitment from mine personnel, especially the control room operators, is essential.

When conducting similar studies on other compressed air networks of old South African gold mines, it is recommended that intensive and comprehensive research is done into the entire compressed air system of the mine. The research should identify all the possible challenges that can cause project delays and unsustainable average demand reduction. Several problem areas were identified in this dissertation. Other mines may experience similar and even greater and unique challenges.

A compressed air network is only one of the large energy consumers on an old mine. Further studies can be conducted on other electrical power consumers of other older mines:

- Pumping system
- Man- and rock-winder system
- Refrigeration system
- Ventilation system

These may produce other unique challenges associated with the type of obsolete equipment and infrastructure used.

In conjunction with an EE project on a compressed air system, a further recommendation is for research on the efficiency of the compressors. The benefits of regular maintenance and compressor monitoring should be introduced and incorporated as part of the general training programme to extend the lifetime of the compressors and other operational equipment.

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In the following sections all of the references to the dissertation can be found.

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APPENDIXES



In the following sections contains the appendixes to the dissertation.

Appendix A: Two basic compressor principles

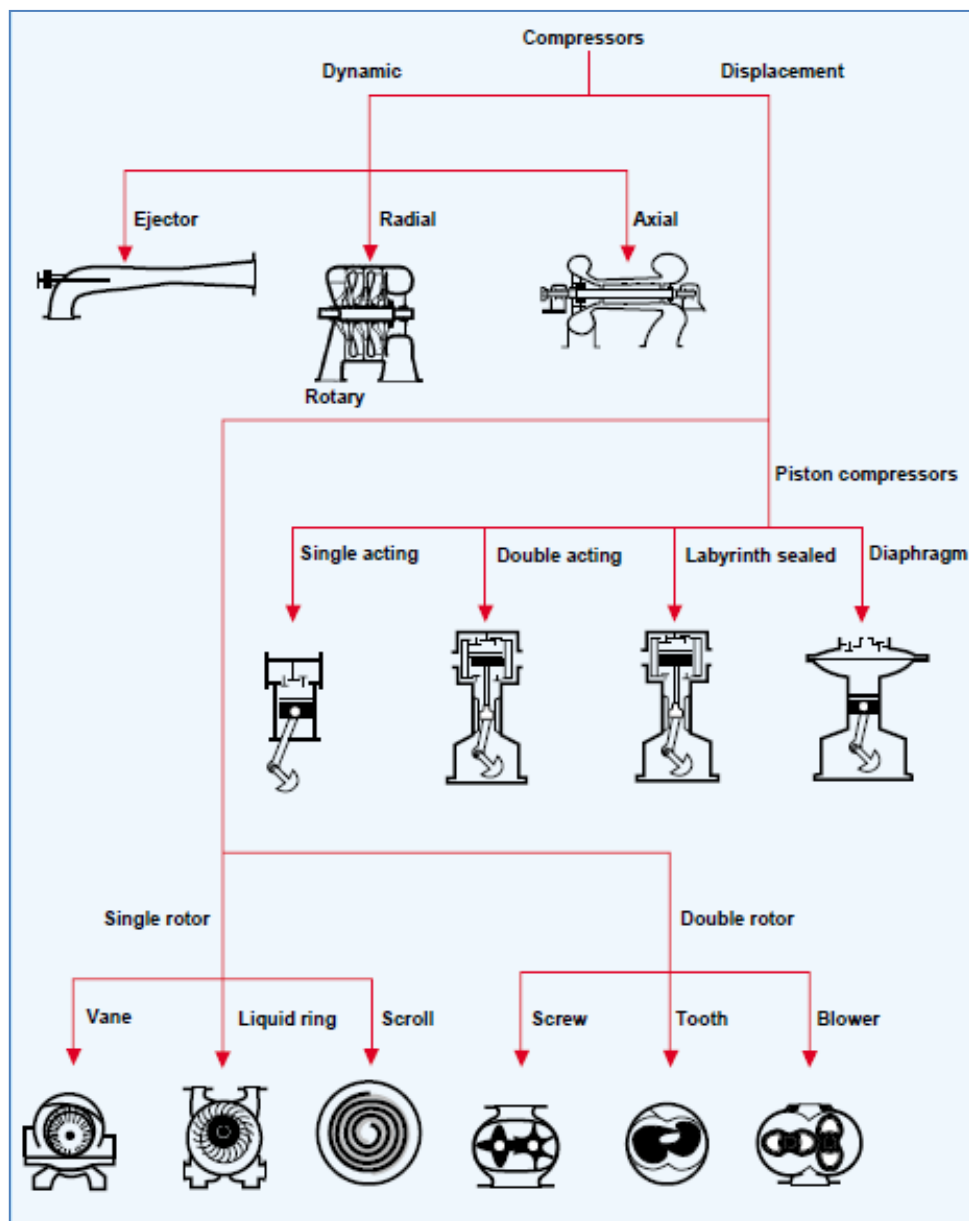


Figure 47: Two basic compressor principles (Lindeberg, 1998)

The chart shows the most common types of compressors, divided according to their working principles. They can also be divided according to other principles, for example, air or liquid cooled, stationary or portable, etc. (Lindeberg, 1998).

Appendix B: Initial acquired baseline data

Appendix B: Initial baseline data

Table 13: Acquired baseline data and calculated savings

Acquired data				Scaling factor		Calculated average demand reduction				
Time	Power (kW)	Pressure (kPa)	Flow (kg/s)	Pressure (%)	Flow (%)	Time	Power (kW)	Pressure (kPa)	Flow (kg/s)	Proposed avg. demand reduction (kW)
00:00	7 460.78	485	26.32	80%	85%	00:00	5 518.97	388.00	22.37	1 941.81
01:00	7 562.85	475	27	80%	85%	01:00	5 582.67	380.00	22.95	1 980.18
02:00	7 535.80	470	27.08	80%	85%	02:00	5 559.02	376.00	23.02	1 976.78
03:00	7 596.98	475	27.13	80%	85%	03:00	5 609.55	380.00	23.06	1 987.43
04:00	7 567.88	480	26.86	80%	85%	04:00	5 593.17	384.00	22.83	1 974.71
05:00	7 603.46	490	26.66	80%	85%	05:00	5 628.62	392.00	22.66	1 974.84
06:00	7 562.30	495	26.36	80%	85%	06:00	5 602.81	396.00	22.41	1 959.49
07:00	7 659.80	499	26.58	80%	85%	07:00	5 679.57	399.20	22.59	1 980.23
08:00	7 690.04	480	27.29	80%	85%	08:00	5 682.71	384.00	23.20	2 007.33
09:00	7 735.29	470	27.79	80%	85%	09:00	5 704.77	376.00	23.62	2 030.52
10:00	7 914.80	465	28.62	80%	85%	10:00	5 832.22	372.00	24.33	2 082.58
11:00	8 101.04	460	29.48	80%	85%	11:00	5 962.77	368.00	25.06	2 138.27
12:00	8 007.69	466	28.92	80%	85%	12:00	5 902.07	372.80	24.58	2 105.62
13:00	7 875.01	472	28.22	80%	85%	13:00	5 809.84	377.60	23.99	2 065.17
14:00	7 599.50	478	27.03	80%	85%	14:00	5 612.74	382.40	22.98	1 986.76
15:00	7 385.95	488	25.96	80%	85%	15:00	5 465.94	390.40	22.07	1 920.01
16:00	7 302.00	492	25.54	80%	85%	16:00	5 406.75	393.60	21.71	1 895.25
17:00	7 292.51	496	25.39	80%	85%	17:00	5 403.82	396.80	21.58	1 888.69
18:00	7 274.84	498	25.27	80%	85%	18:00	5 392.55	398.40	21.48	1 882.29
19:00	7 136.07	500	24.73	80%	85%	19:00	5 291.21	400.00	21.02	1 844.86
20:00	7 155.47	498	24.86	80%	85%	20:00	5 305.05	398.40	21.13	1 850.42
21:00	7 203.55	493	25.17	80%	85%	21:00	5 335.58	394.40	21.39	1 867.97
22:00	7 153.06	488	25.14	80%	85%	22:00	5 293.28	390.40	21.37	1 859.78
23:00	7 218.40	483	25.52	80%	85%	23:00	5 336.43	386.40	21.69	1 881.97
Total	180 595.07	11 596.00	638.91			Total	133 512.42	0.00	0.00	
Avg.	7 524.79	483.17	26.62	87%	79%	Avg.	5 563.00	420.36	21.03	1 961.79

Appendix C: Updated baseline data

Table 14: Newly acquired data for baseline scaling

New acquired data		Scaling factor	Calculated average demand reduction		
Time	Power (kW)	(%)	Time	Power (kW)	Proposed avg. demand reduction (kW)
00:00	8 445.17	75%	00:00	6 356.68	2 088.49
01:00	8 416.66	75%	01:00	6 335.22	2 081.44
02:00	8 412.62	75%	02:00	6 332.18	2 080.44
03:00	8 258.17	75%	03:00	6 215.92	2 042.24
04:00	7 805.33	75%	04:00	5 875.07	1 930.26
05:00	7 814.62	75%	05:00	5 882.06	1 932.56
06:00	7 626.33	75%	06:00	5 740.34	1 885.99
07:00	7 373.80	75%	07:00	5 550.26	1 823.54
08:00	8 117.07	75%	08:00	6 109.72	2 007.35
09:00	8 980.74	75%	09:00	6 759.81	2 220.94
10:00	9 273.47	75%	10:00	6 980.14	2 293.33
11:00	9 135.27	75%	11:00	6 876.12	2 259.15
12:00	8 813.13	75%	12:00	6 633.65	2 179.49
13:00	8 435.87	75%	13:00	6 349.68	2 086.19
14:00	7 911.87	75%	14:00	5 955.26	1 956.60
15:00	7 408.73	75%	15:00	5 576.55	1 832.18
16:00	7 132.93	75%	16:00	5 368.96	1 763.97
17:00	7 150.00	75%	17:00	5 381.81	1 768.20
18:00	7 145.47	75%	18:00	5 378.39	1 767.07
19:00	7 201.27	75%	19:00	5 420.39	1 780.87
20:00	7 193.60	75%	20:00	5 414.62	1 778.98
21:00	7 237.93	75%	21:00	5 447.99	1 789.94
22:00	7 396.47	75%	22:00	5 567.32	1 829.15
23:00	7 532.40	75%	23:00	5 669.64	1 862.76
Total	190 218.91		Total	143 177.77	
Average	7 925.79	75%	Average	5 965.74	1 960.05

Appendix D: Proposed calculated financial savings

Table 15: Proposed calculated financial savings per day – Megaflex

Baseline (kW)	Projected (kW)	Time	Megaflex		Financial Savings	
			TOU tariff - Winter Month (R/h)	TOU tariff - Summer Month (R/h)	Projected - Winter Month (R)	Projected - Summer Month (R)
8 445.17	6 356.68	00:00	24.77	21.33	517.32	445.47
8 416.66	6 335.22	01:00	24.77	21.33	515.57	443.97
8 412.62	6 332.18	02:00	24.77	21.33	515.33	443.76
8 258.17	6 215.92	03:00	24.77	21.33	505.86	435.61
7 805.33	5 875.07	04:00	24.77	21.33	478.12	411.72
7 814.62	5 882.06	05:00	24.77	21.33	478.69	412.21
7 626.33	5 740.34	06:00	46.29	30.48	873.03	574.85
7 373.80	5 550.26	07:00	177.95	49.73	3,244.99	906.85
8 117.07	6 109.72	08:00	177.95	49.73	3,572.09	998.26
8 980.74	6 759.81	09:00	177.95	49.73	3,952.15	1,104.47
9 273.47	6 980.14	10:00	46.29	30.48	1,061.58	699.01
9 135.27	6 876.12	11:00	46.29	30.48	1,045.76	688.59
8 813.13	6 633.65	12:00	46.29	30.48	1,008.88	664.31
8 435.87	6 349.68	13:00	46.29	30.48	965.70	635.87
7 911.87	5 955.26	14:00	46.29	30.48	905.71	596.37
7 408.73	5 576.55	15:00	46.29	30.48	848.11	558.45
7 132.93	5 368.96	16:00	46.29	30.48	816.54	537.66
7 150.00	5 381.81	17:00	46.29	30.48	818.50	538.95
7 145.47	5 378.39	18:00	177.95	49.73	3,144.51	878.77
7 201.27	5 420.39	19:00	177.95	49.73	3,169.07	885.63
7 193.60	5 414.62	20:00	46.29	30.48	823.49	542.23
7 237.93	5 447.99	21:00	46.29	30.48	828.56	545.57
7 396.47	5 567.32	22:00	24.77	21.33	453.08	390.16
7 532.40	5 669.64	23:00	24.77	21.33	461.41	397.33

Average

R 31 004.07

R 14 736.07

Appendix E: M&V team approved scaled baseline

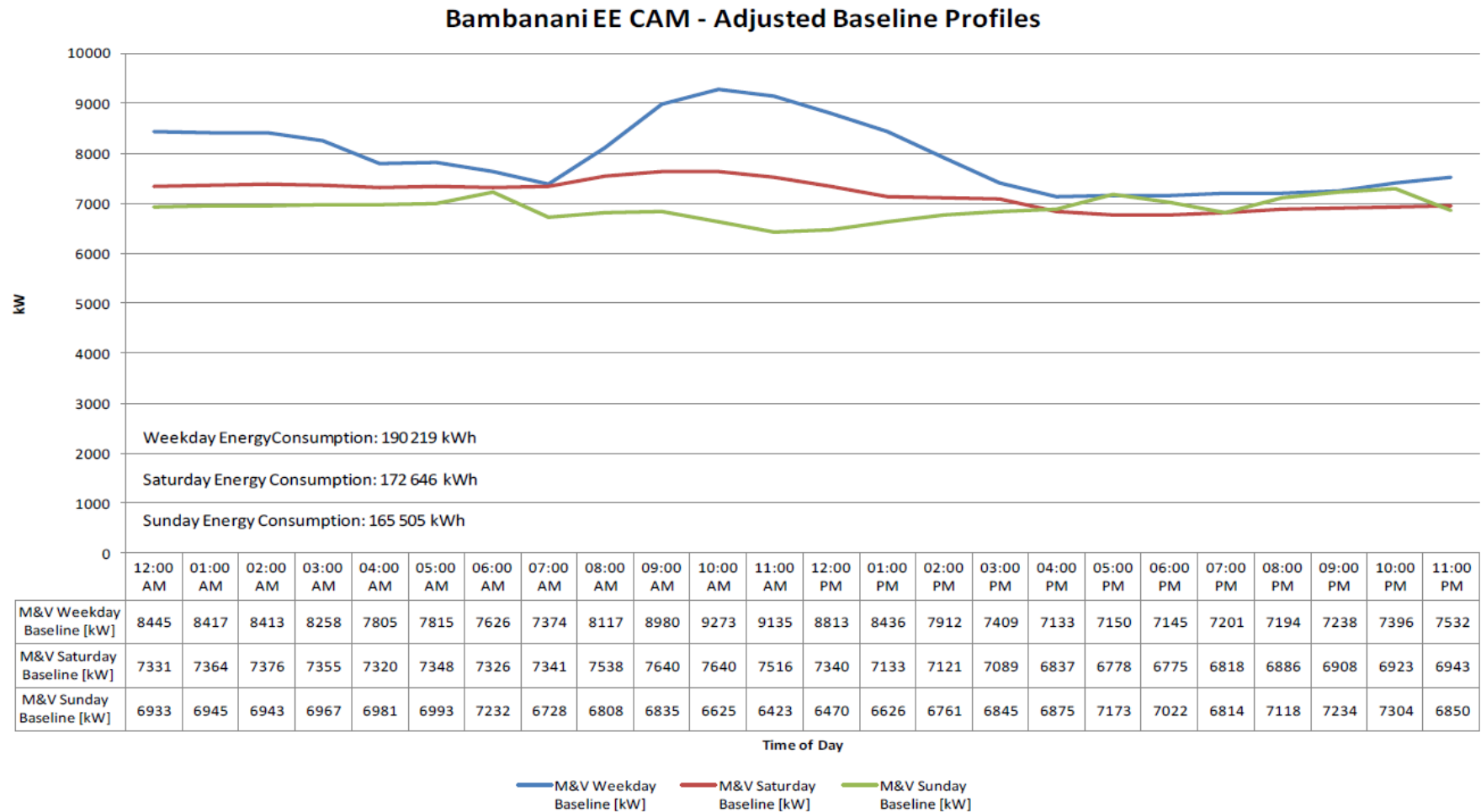


Figure 48: M&V team approved scaled baseline

Appendix F: Simulation

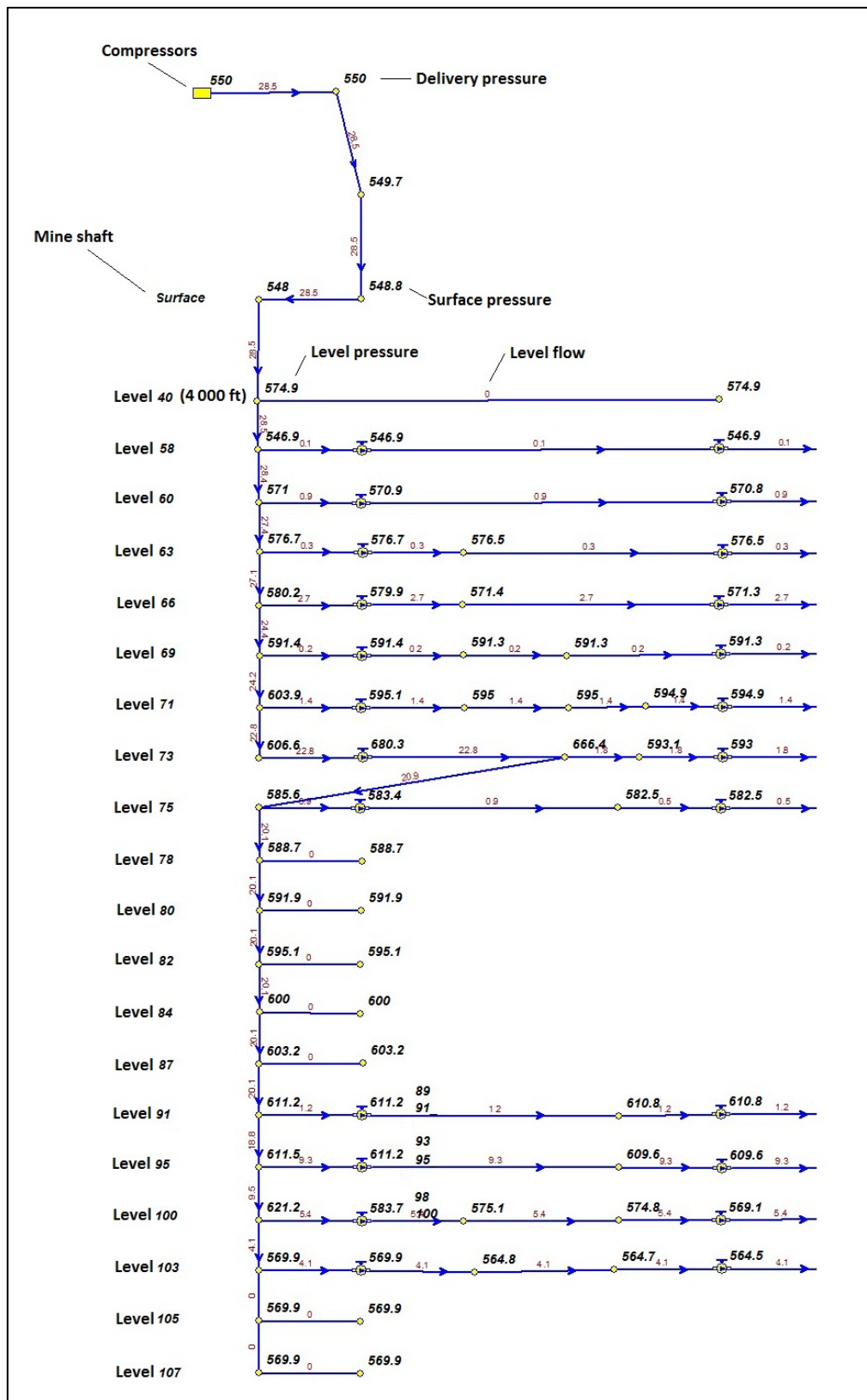


Figure 49: Simulation – before control optimisation

Appendix F: Simulation

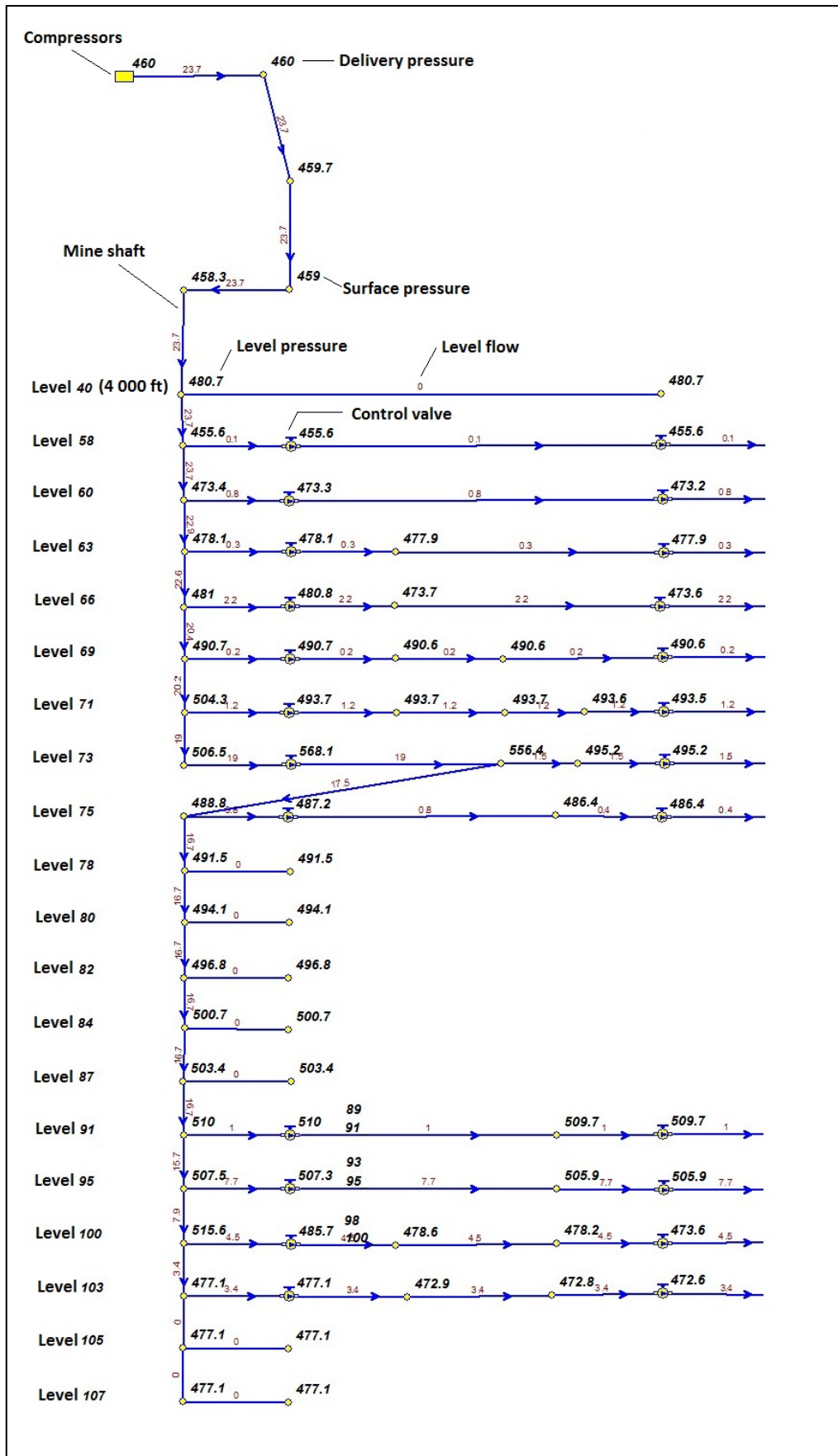


Figure 50: Simulation – after control optimisation

Appendix G: Underground layout

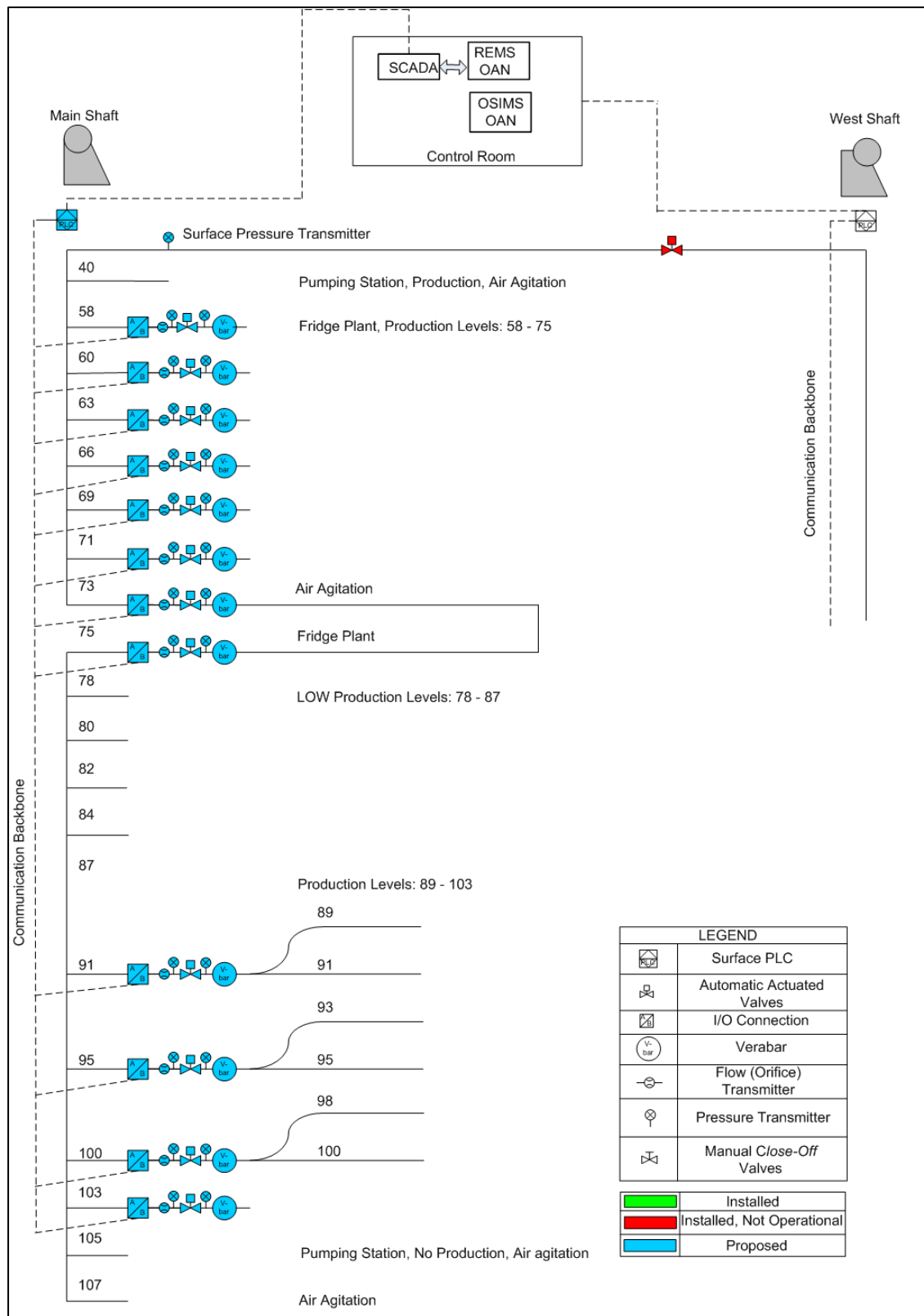


Figure 51: Mine's underground layout

Appendix H: Performance results for May 2011

Table 16: Performance results (kW) for May 2011

Time	GHH (kW)	BB (kW)	Sulzer (kW)	Total kW	M&V baseline (kW)	Savings (kW)
00:00	201.83	2 996.33	3 743.52	7 280.05	8 445.17	1 165.12
01:00	201.59	3 004.02	3 753.53	7 297.09	8 416.66	1 119.57
02:00	204.64	2 767.76	3 605.61	6 905.49	8 412.62	1 507.13
03:00	118.70	2 495.86	3 341.06	6 278.95	8 258.17	1 979.22
04:00	157.15	2 453.86	3 295.56	6 222.83	7 805.33	1 582.50
05:00	224.62	2 631.34	3 324.59	6 687.75	7 814.62	1 126.87
06:00	121.45	2 944.27	3 640.71	7 391.21	7 626.33	235.12
07:00	216.01	3 135.35	3 879.26	7 444.56	7 373.80	-70.76
08:00	986.76	3 077.99	3 877.69	7 942.44	8 117.07	174.63
09:00	1 726.04	2 800.35	3 694.96	8 221.35	8 980.74	759.39
10:00	1 868.78	2 647.56	3 582.91	8 099.25	9 273.47	1 174.22
11:00	1 812.43	2 566.63	3 488.92	7 867.97	9 135.27	1 267.29
12:00	1 761.77	2 508.45	3 467.08	7 737.30	8 813.13	1 075.83
13:00	1 428.65	2 475.71	3 458.67	7 363.03	8 435.87	1 072.84
14:00	993.20	2 541.15	3 500.35	7 034.70	7 911.87	877.17
15:00	176.53	2 739.56	3 638.33	6 554.42	7 408.73	854.31
16:00	0.00	2 509.73	3 432.12	6 238.44	7 132.93	894.50
17:00	0.00	2 130.77	3 427.41	5 855.04	7 150.00	1 294.96
18:00	0.00	2 089.67	3 442.73	5 829.65	7 145.47	1 315.81
19:00	0.00	2 081.95	3 450.45	5 831.14	7 201.27	1 370.13
20:00	75.50	2 318.23	3 461.61	6 155.35	7 193.60	1 038.25
21:00	289.12	2 851.35	3 751.27	7 234.68	7 237.93	3.25
22:00	203.42	2 974.55	3 741.52	7 258.01	7 396.47	138.46
23:00	202.03	3 019.41	3 766.29	7 325.84	7 532.40	206.56
Totals	12 970.23	63 761.86	85 766.12	168 056.54	190 218.91	22 162.37
Average						923.43

Appendix I: Performance results for June 2011

Table 17: Performance results (kW) for June 2011

Time	GHH (kW)	BB (kW)	Sulzer (kW)	Total kW	M&V Baseline (kW)	Savings (kW)
00:00	385.38	2 436.62	3 881.38	6 200.57	8 445.17	2 244.61
01:00	384.95	2 425.62	3 880.90	6 691.48	8 416.66	1 725.18
02:00	385.67	2 247.71	3 778.86	6 412.24	8 412.62	2 000.38
03:00	328.38	1 911.38	3 566.57	5 806.33	8 258.17	2 451.83
04:00	345.43	1 665.00	3 609.00	5 619.43	7 805.33	2 185.90
05:00	352.95	2 271.60	3 779.71	6 404.26	7 814.62	1 410.36
06:00	361.81	2 541.33	3 956.95	6 860.10	7 626.33	766.23
07:00	282.52	2 325.00	4 027.90	6 635.43	7 373.80	738.37
08:00	399.48	2 528.57	3 872.86	6 800.90	8 117.07	1 316.16
09:00	192.29	2 707.81	4 015.62	6 915.71	8 980.74	2 065.03
10:00	1 342.87	2 226.33	3 849.36	7 418.56	9 273.47	1 854.90
11:00	1 335.62	2 339.38	3 725.62	7 400.62	9 135.27	1 734.65
12:00	841.43	2 477.10	3 624.76	6 943.29	8 813.13	1 869.85
13:00	128.19	2 556.00	3 592.24	6 276.43	8 435.87	2 159.44
14:00	0.00	2 439.14	3 528.10	5 967.24	7 911.87	1 944.63
15:00	0.00	2 307.24	3 446.14	5 753.38	7 408.73	1 655.35
16:00	0.00	2 206.00	3 370.52	5 576.52	7 132.93	1 556.41
17:00	0.00	2 132.67	3 318.90	5 451.57	7 150.00	1 698.43
18:00	0.00	2 158.67	3 355.10	5 513.76	7 145.47	1 631.70
19:00	0.00	2 174.29	3 368.76	5 543.05	7 201.27	1 658.22
20:00	28.62	1 795.19	3 483.24	5 307.05	7 193.60	1 886.55
21:00	386.52	2 000.05	3 653.81	6 040.38	7 237.93	1 197.55
22:00	343.95	2 084.14	3 577.67	6 005.76	7 396.47	1 390.70
23:00	371.38	2 253.33	3 755.48	6 380.19	7 532.40	1 152.21
Totals	8 197.44	54 210.16	88 019.46	149 924.25	190 218.91	40 294.66
Average						1 678.94

Appendix J: Performance results for July 2011

Table 18: Performance results (kW) for July 2011

Time	GHH (kW)	BB (kW)	Sulzer (kW)	Total kW	M&V baseline (kW)	Savings (kW)
00:00	112.51	2 388.83	3 564.75	6 066.08	8 445.17	2 379.09
01:00	113.95	2 378.70	3 565.97	6 058.62	8 416.66	2 358.04
02:00	109.33	2 314.40	3 515.92	5 939.65	8 412.62	2 472.97
03:00	107.41	2 128.46	3 361.02	5 596.89	8 258.17	2 661.28
04:00	108.52	2 130.35	3 360.65	5 599.52	7 805.33	2 205.81
05:00	107.75	2 263.02	3 430.46	5 801.22	7 814.62	2 013.40
06:00	111.84	2 395.19	3 547.32	6 054.35	7 626.33	1 571.98
07:00	184.25	2 585.08	3 696.70	6 466.03	7 373.80	907.77
08:00	238.76	2 783.16	3 809.70	6 831.62	8 117.07	1 285.45
09:00	165.41	3 106.75	3 897.79	7 169.95	8 980.74	1 810.79
10:00	317.00	3 111.68	3 819.92	7 248.60	9 273.47	2 024.86
11:00	545.54	2 923.10	3 590.79	7 059.43	9 135.27	2 075.84
12:00	369.73	2 687.86	3 598.52	6 656.10	8 813.13	2 157.03
13:00	10.71	2 551.71	3 439.08	6 001.51	8 435.87	2 434.36
14:00	38.48	2 459.37	3 425.98	5 923.83	7 911.87	1 988.04
15:00	0.00	2 335.12	3 377.07	5 712.18	7 408.73	1 696.55
16:00	0.00	2 198.21	3 305.84	5 504.05	7 132.93	1 628.89
17:00	0.00	2 167.33	3 300.63	5 467.97	7 150.00	1 682.03
18:00	0.00	2 182.90	3 321.27	5 504.17	7 145.47	1 641.29
19:00	0.00	2 211.13	3 335.38	5 546.51	7 201.27	1 654.76
20:00	0.00	2 234.84	3 344.21	5 579.05	7 193.60	1 614.55
21:00	0.00	2 275.33	3 376.19	5 651.52	7 237.93	1 586.41
22:00	0.00	2 372.19	3 445.87	5 818.06	7 396.47	1 578.40
23:00	0.00	2 485.98	3 530.67	6 016.65	7 532.40	1 515.75
Totals	2 641.20	58 670.67	83 961.70	145 273.57	190 218.91	44 945.34
Average						1 872.72

Appendix K: Monthly comparison

Table 19: Monthly power usage comparison

Time	May (kW)	June (kW)	July (kW)	M&V baseline (kW)
00:00	7 280.05	6 278.94	6 066.08	8 445.17
01:00	7 297.09	6 691.48	6 058.62	8 416.66
02:00	6 905.49	6 412.24	5 939.65	8 412.62
03:00	6 278.95	5 806.33	5 596.89	8 258.17
04:00	6 222.83	5 619.43	5 599.52	7 805.33
05:00	6 687.75	6 404.26	5 801.22	7 814.62
06:00	7 391.21	6 860.10	6 054.35	7 626.33
07:00	7 444.56	6 635.43	6 466.03	7 373.80
08:00	7 942.44	6 800.90	6 831.62	8 117.07
09:00	8 221.35	6 915.71	7 169.95	8 980.74
10:00	8 099.25	7 418.56	7 248.60	9 273.47
11:00	7 867.97	7 400.62	7 059.43	9 135.27
12:00	7 737.30	6 943.29	6 656.10	8 813.13
13:00	7 363.03	6 276.43	6 001.51	8 435.87
14:00	7 034.70	5 967.24	5 923.83	7 911.87
15:00	6 554.42	5 753.38	5 712.18	7 408.73
16:00	6 238.44	5 576.52	5 504.05	7 132.93
17:00	5 855.04	5 451.57	5 467.97	7 150.00
18:00	5 829.65	5 513.76	5 504.17	7 145.47
19:00	5 831.14	5 543.05	5 546.51	7 201.27
20:00	6 155.35	5 307.05	5 579.05	7 193.60
21:00	7 234.68	6 040.38	5 651.52	7 237.93
22:00	7 258.01	6 005.76	5 818.06	7 396.47
23:00	7 325.84	6 380.19	6 016.65	7 532.40
Totals	168 056.54	150 002.62	145 273.57	190 218.91
Average	7 002.36	6 250.11	6 053.07	7 925.79

Appendix K: Monthly comparison

Table 20: Daily average demand reduction

Day of the month	May		June		July	
	Demand reduction (kW)	%	Demand reduction (kW)	%	Demand reduction (kW)	%
1			1 210.80	61.78%	1 717.82	87.64%
2	1 309.52	66.81%	1 687.14	86.08%		
3	927.19	47.31%	1 769.05	90.26%		
4	1 255.54	64.06%			1 721.05	87.81%
5	1 309.77	66.82%			1 703.01	86.89%
6	1 275.37	65.07%	1 180.00	60.20%	1 887.34	96.29%
7			1 747.82	89.17%	1 822.34	92.98%
8			1 645.05	83.93%	2 045.19	104.35%
9	967.87	49.38%	1 539.98	78.57%		
10	1 149.75	58.66%	1 655.22	84.45%		
11	1 262.25	64.40%			1 982.97	101.17%
12	1 483.62	75.70%			1 933.82	98.66%
13	855.75	43.66%	1 720.37	87.77%	1 749.34	89.25%
14			1 416.44	72.27%	1 774.37	90.53%
15			1 652.09	84.29%	1 742.39	88.90%
16	304.52	15.54%	2 027.34	103.44%		
17	275.51	14.06%	1 260.00	64.29%		
18	1 032.33	52.67%			2 004.54	102.27%
19	558.47	28.49%			1 885.98	96.22%
20	553.23	28.23%	1 768.36	90.22%	2 093.98	106.84%
21			1 728.21	88.17%	1 843.25	94.04%
22			1 798.48	91.76%	1 793.67	91.51%
23	960.00	48.98%	1 878.94	95.86%		
24	440.00	22.45%	1 713.58	87.43%		
25	754.44	38.49%			1 669.08	85.16%
26	648.25	33.07%			1 660.45	84.72%
27	678.09	34.60%	1 994.04	101.74%	1 930.34	98.49%
28			1 998.91	101.99%	2 097.59	107.02%
29			1 985.73	101.31%	2 268.64	115.75%
30	964.30	49.20%	1 836.25	93.69%		
31	1 438.77	73.41%				
Target	1 960	47.32%	1 960	85.49%	1 960	95.55%
Savings	927.48		1 675.68		1 872.72	