Sustained energy performance on compressed air systems for expanding gold mines

A de Coning

20270186

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Promoter: Dr JF van Rensburg

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Abstract

The energy provider in South Africa, Eskom, faces an increasing electricity demand. The need to ensure sufficient supply gave rise to Demand Side Management (DSM) projects scheme. The DSM focus has shifted to the mining sector in South Africa. The large electricity use of the mining sector ensured the need for Energy Services Companies (ESCo's). The ESCo is contracted to ensure energy savings of DSM projects implemented within the multiple sectors such as mining industry.

The mining sector business model has the constant pressure to increase gold production. This pressure to expand has led to rapid expansion plans to increase the gold output for the relevant company. The expansion process and production increase in turn increases the electricity consumption. Compressed air use is a large contributing factor to the monthly electricity use as it is widely used within the mine sector. The implementation of a DSM project on the compressed air ring of an expanding gold mine was the focus of the study.

This case study focused on an expanding gold mine within South Africa. The DSM lifecycle was followed to initially determine the DSM saving potential. The possible control strategies were investigated with simulation models and savings calculations. The viable option was to be implemented with a preliminary control philosophy. Results were in turn compared with the initial investigations and control philosophy. The deviations as experienced with implementation were addressed and a potential sustainable control philosophy for an expanding gold mine was constructed.

The results indicated, verified Eskom peak clip electricity savings of 2.165 MW of the 2.4 MW target. The energy efficiency component for these performance assessment months was 1.944 MW of the targeted 1.5 MW. The sustainability of the system was proven with production increase on an expanding gold mine.

Key words: *DSM, Demand Side Management, Sustainability, Expanding Gold Mines, Compressed air, Energy efficiency, Peak clip.*

Samevatting

Die energie verskaffer in Suid-Afrika, Eskom, het 'n toenemende vraag na elektrisiteit van die gemeenskap. Om toevoer vir die gemeenskap te verseker is die “Demand Side Management” (DSM) projekte skema tot stand gebring. Fokus op die mynbou industrie in Suid-Afrika as 'n groot verbruiker, het verseker dat die dienste van “Energy Services Companies” (ESCO's) benodig word. ESCO’s is gekontrakteer om energiebesparing van DSM projekte te implementeer, binne die verskeie sektore, soos die mynbou industrie.

Die mynbousektor het deurlopende druk om goud produksie te verhoog. Hierdie druk het verseker dat myne 'n vinnige uitbreidingsplan geïmplementeer het om die goudproduksie te te verhoog. Die uitbreiding proses en produksie verhoging , verhoog die elektrisiteit verbruik.

Die gebruik van saamgeperste lug is 'n groot bydraende faktor tot die maandelikse elektrisiteitsverbruik, aangesien dit algemeen gebruik word in die mynbou sektor. Die behoefte het ontstaan om 'n DSM-projek te implementeer en daar is besluit op om ’n saamgeperste lug ring in werking te stel op ’n groeiende goudmyn. Die verhandeling gevallestudie het gefokus op ’n goudmyn in Suid-Afrika wat uitgebrei word. Die DSM lewensiklus is gevolg om die aanvanklike DSM besparing potensiaal te bepaal. Moontlike beheer strategieë was ondersoek met simulasie modelle en besparings berekeninge. Die lewensvatbare opsie sal in werking gestel word met 'n aanvanklike beheer filosofie. Uitslae sal vergelyk word met die aanvanklike ondersoeke en beheer filosofie. Die afwykings, soos ervaar met die implementering sal aangespreek word en 'n potensiële volhoubare beheer filosofie gefinaliseer vir 'n groeiende goudmyn.

Die resultate wat verkry is, met data verifikasie, het aangedui dat die piek knip besparing van 2.165 MW teenoor die teiken van 2.4 MW behaal is. Energie-doeltreffendheid vir hierdie prestasie-assessering maande was 1.944 MW van die 1.5 MW teiken. Volhoubaarheid van die stelsel is bewys met produksie toename op 'n groeiende goudmyn.

Sleutelwoorde: *DSM, Demand Side Management, Volhoubaarheid, groeiende goudmyn, Saamgeperste lug, Projek besparing, Energie-doeltreffendheid*

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List of abbreviations

BRPM	Bafokeng Rasimone Platinum Mine
CFM	Cubic feet per minute
DSM	Demand Side Management
EMS	Energy Management System
ESCo	Energy Services Company
HT	High transmission
IDM	Integrated Demand Management
kg/h	kilogram per hour
km	kilometre
kPa	kilo Pascal
kW	kilowatt
M&V	Measurement and verification
MAD	Measurement acceptance date
mm	millimetre
MW	Megawatt
NEC	New engineering contract
oz	ounces
PA	Performance assessment
PC	Performance certificate
PID	Proportional integral derivative
PLC	Programmable Logic Controller
PT	Performance tracking
REMS	Real-Time Energy Management System
ROI	Return on investment
SCADA	Supervisory Control and Data Acquisition

SLA	Service level adjustment
SP	Set point
TOU	Time of use
VSD	Variable speed drives
%	percentage

1. INTRODUCTION

1.1 Energy constraints and demand side management

South African electricity supply reached limitations in late 2007 causing electricity supplier, Eskom, to take drastic measures. Increased demand, plant outages, coal supply and coal quality has forced that load shedding had to be implemented. The load shedding programme assisted that national blackouts would not occur and rather implement partial planned power outages nationally. The power outages had a significantly negative economic impact [1].

Demand side management

The Demand Side Management (DSM) programme was initiated in 2004 with the intention of lowering the demands of the end user. This programme was intended to induce a short-term reduction on the national power grid. The Integrated Demand Management (IDM) programme to improve energy efficiency initiatives was initiated in 2010. The programme’s key focus was to improve energy efficiency for the short to medium term. These programmes are used to ensure lower demand while the long-term power generation plants programme was initiated in 2005. The intention was to have the expansion plans complete by 2018 [2] [3] [4] [5].

The electrical sales for Eskom have been mostly constant for the past three financial years. The implementation of DSM projects is focussed on the mining and industrial sectors. These projects are mostly conducted by Energy Service Companies (ESCo’s). The IDM implemented projects that include the municipal sector with energy efficiency projects. The electricity sales for the financial years 2009 to 2012 can be seen in Figure 1.

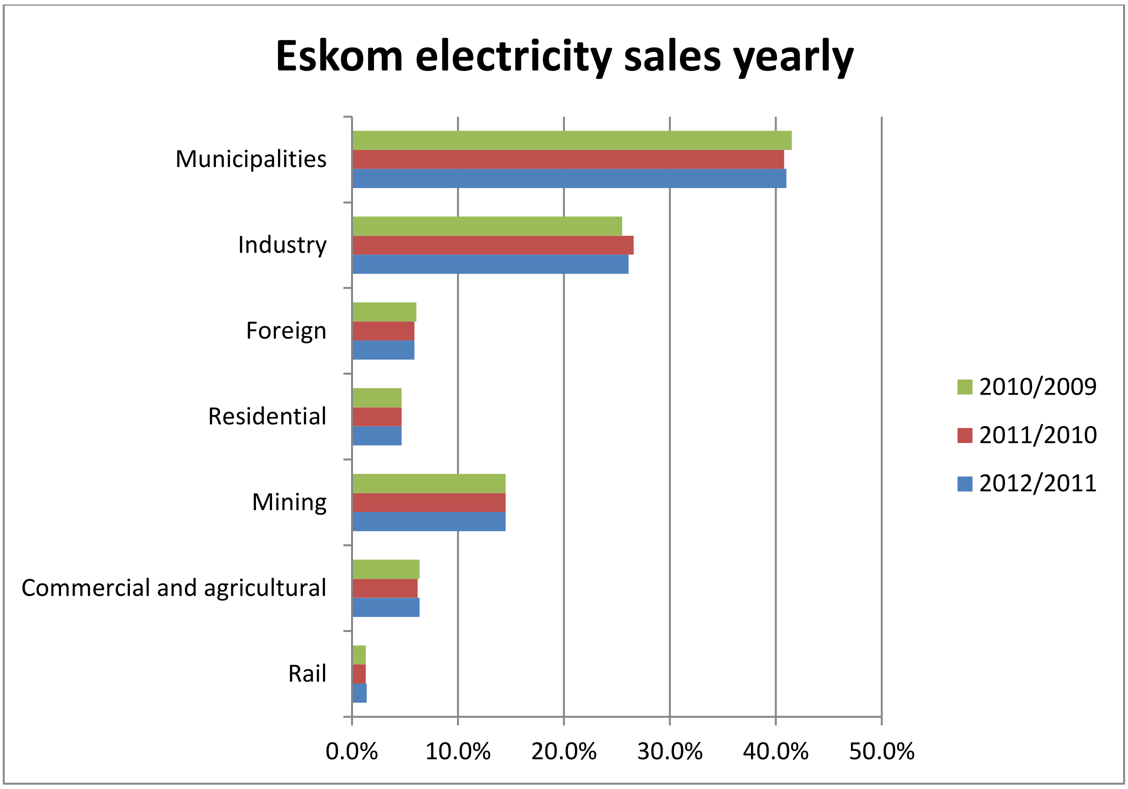


Figure 1: Eskom electricity sales yearly [2] [6]

The projects implemented are intended to lower the load on Eskom peak time which is from 18:00 to 20:00 and other projects which are focused on 24 hour energy efficiency. This time of use (TOU) schedule can be seen in Figure 2 . The projects either focus on peak clipping, load shifting, energy efficiency or process optimisation. The Peak Clip Project will lower energy consumption within the Eskom peak periods. Load shift will ensure that power consumption is lowered in peak Eskom time and shifted to lower demand periods. Lower demand periods will ease the Eskom supply grid. Energy efficiency will ensure that a lower profile be implemented during the entire day of use. Process optimisation will ensure that equipment will lower compressed air usage in Eskom peak times and optimise the running schedule of a plant. Eskom has implemented a finance scheme to fund ESCo's in the process for DSM projects [7].

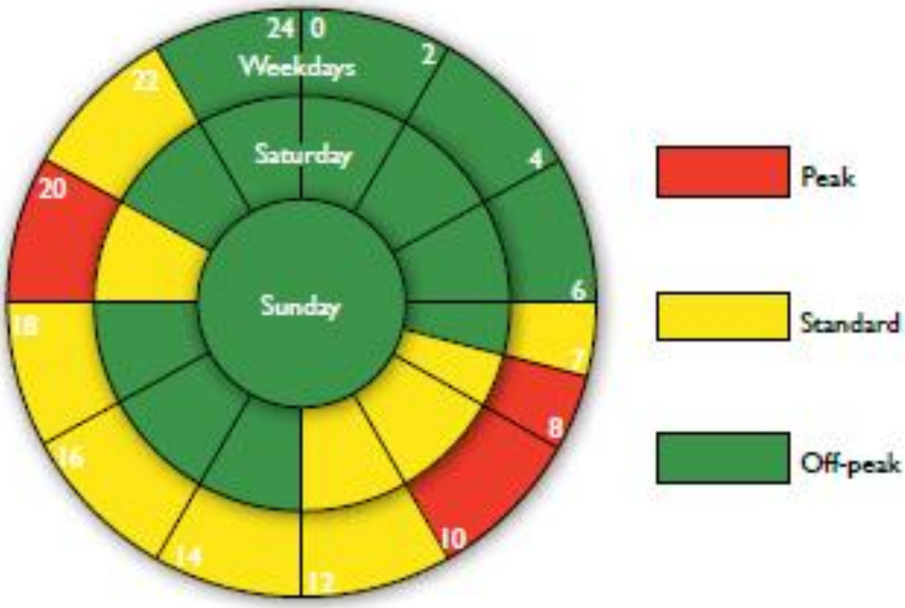


Figure 2: Time of use [8]

Demand side management benefits

DSM projects implemented have several benefits. The project viability and client cooperation are dependent on these benefits. In some cases the client will have to assist with payment for a project. If the projects are not financially viable the client may decline the DSM project. The electrical cost savings is one of the main reasons for participating in these projects. This minimal DSM power savings may ensure that the buyback period is too long for the client to consider [4].

The benefits will also include multiple hidden aspects that are overlooked in the project cost benefit analysis. The benefits include the new automation equipment, an optimised running schedule and the avoidance of Eskom penalties. The automation equipment may ensure that equipment is monitored, started and stopped remotely, lowering the need of operators and in turn, a lower labour cost. With an optimal running schedule the equipment will either run less or be started and stopped less. This will ensure minimal wear and tear which will in turn lower maintenance costs. The DSM programme has a focus on the electricity saving potential, but includes additional savings in global warming, agricultural and pollution [4] [9].

The DSM funding will not in all cases ensure the installation of an optimal control system. By making use of an ESCo with dedicated staff and long-term experience, a cost- and time-effective system may be devised. The system will be able to upgrade essential infrastructure to implement a DSM project. The funding which is available may ensure an equipment upgrade that might not have been previously viable for the client [10].

DSM projects are widely implemented in the USA, UK, Europe and Australia. The implementation may easily ensure benefits for developing countries. The increase in electricity supply capacity is slow: it may take up to 15 years to erect a new power plant. DSM implementation will lower the current demand in the developing countries. Implementation includes energy-efficient equipment and variable speed drives (VSD). Heating systems, air-conditioning, ventilation and lighting systems may all benefit from these projects. The mining sector in South Africa is a high energy consumer. With the mining sector so prominent in South Africa, it is an ideal site for attempting potential savings [5].

The mining industry in South Africa

The mining sector, as previously seen, uses 14.5% of Eskom’s annual sales. Gold mines are responsible for 47% of the capacity used followed by platinum mines with 33%. Energy-efficient projects have large saving potential within this sector. Processing and mineral handling are the main contributors to high energy consumption. Compressed air systems are the next highest contributor with 17% of the use. Some of these compressor systems have the installed capacity of up to 85 MW. A chart showing the breakdown of energy use in mining is shown in Figure 3 [11].

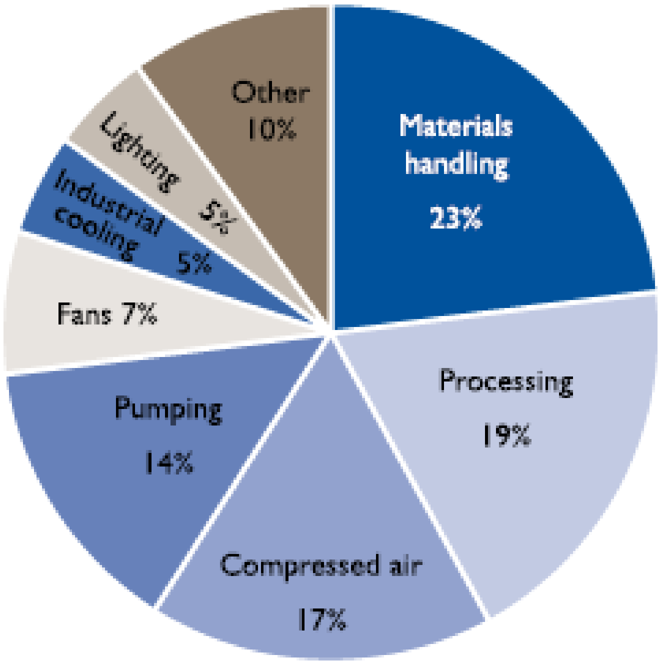


Figure 3: Energy use within mining sector [11]

Compressor's capital costs are made up of roughly 80% electricity cost of the compressors lifecycle. Efficiencies within a compressed air system can have losses in the range of 70% to 90%. These losses occur due to heat, friction, equipment misuse and noise. The large installed capacities of these compressors make them a focus for energy efficiency projects [12].

Mine expansion

Mine expansion in South Africa is still on the rise. Mining groups have multiple expansion programmes in existing mining installations. The expansion programmes include mining footprint increase where the mining area is increased. This increase will ensure that more crews may mine throughout the mine. Combined with this is the increase in the amount of product excavated, and in turn the increase of ore extracted. The need to mine the highest grade of product increases the total product produced. During the process of expanding, the concentration of mining operations may move to these higher grade deposits.

The planned mining expansion programmes are extracted from annual reports of mining companies in South Africa. These mining groups include Anglo American, Anglo Gold Ashanti, Anglo Platinum, Gold Fields, Harmony, Lonmin and Rio Tinto. These groups do not restrict themselves to local operations, and they develop operations on promising sites world-wide.

Anglo American has a focus on growth explorations in copper, diamonds, iron ore, coal, nickel and platinum. Iron ore strategic growth projects include Minas-Rio Brazil and Kolomela South Africa. There is a focus on nickel mines in Barro Alto Brazil and there is also copper expansion in Los Bronces in Chile. Barro Alto nickel production has aimed to increase production by 36 000 tonnes which will ensure more than double the current nickel production. Les Bronces copper production is projected to increase by 200 000 tonnes per annum with a 30 year life span of the mine projected. Kolomela iron ore mine is estimated to reach a full production figure of 9 million tonnes per annum. Minas-Rio has a resource projection of 5.3 billion tonnes to support their expansion process. In 2011 a 75% year-on-year strategic growth programme was envisaged. The operational performance in 2012 ensured a 13% increase in the production of iron ore. Coal production guaranteed a 40% increase [13] [14] [15].

Anglo Platinum has a core focus on platinum, palladium and rhodium excavation. Operations include key mines in South Africa, Russia and North America. A platinum supply increase of 4.47% was realised between 2009 and 2010 and the increase in demand of 7.6% for the same period. Supply rose by 5.36% from 2010 to 2011 with the increase in demand of only 1.45% being achieved. Notwithstanding the minor increase, Anglo Platinum is still completing expansion plans on Modikwa and Kroondal mines in their South African operations. Bafokeng Rasimone Platinum mine (BRPM) shaft sinking project operations will ensure the life of that mine will be extended to 2051 [16] [17].

Anglo Gold Ashanti had a production of 4.51 million ounces (oz) in 2010. The production decreased to 4.33 million oz in 2011. During this year the excavation of ore reserves increased from 71.2 million oz to 75.6 million oz. This meant a concomitant increase in lower grade ore being mined. The mining group is planning to increase production by 20% by the year 2015 to a total of 5.4 - 5.6 million oz [18] [19].

Gold Fields has continuous expansion plans to ensure that production grows to 1 million oz by 2015. A 6% increase in their Australian operations lead to 659 000 oz being produced. The production is focussed on increasing the metallurgical plant capacity. Expansion plans will lead to improved output of 220 000 to 330 000 tonnes per month. Globally Gold Fields intends to achieve 5 million oz by 2015 [20].

Harmony has deepening and expansion projects on its Phakisa shaft. The expansion will ensure that the mine will operate at 2 400 meters and there will be an excavation of 72 000 tonnes per month. There is an increase in production on Doornkop, Kusasalethu and Tshepong mines. Feasibility studies on expansion are being conducted on the Hidden Valley facility. [21] [22].

Lonmin has plans for growth on multiple shafts. The sustained efficiency will be enhanced by expanding their K3, K4, Saffy and Hossy shaft. The aim was to markedly increase production, but due to the Marikana incident the opposite has been the case. Karee shaft had a 1.2% production decrease with Rowland, W1 and Newman had a combined decline of 23%. This action ensured that mine expansion now has a lower priority [23] [24].

Rio Tinto has growth plans for their magnetite operations. The feasibility studies for vermiculite are still being conducted and may lead to an expansion project. The magnetite production is projected to increase from 40 000 tonnes to 60 000 tonnes [25].

1.2 Problem statement

The expansion of the mines will result in higher compressed air use. Use will increase when more ore is excavated and larger number of drilling machines is used by crews. Compressed air networks will expand and increase the chances of leaks within the system. Cooling systems in the mine may be inadequate and compressed air will be used to cool working sections. This increase in compressed air use in the expanding mines will need the pre-implementation of strategies to lower power use. The need is thus to design compressed air networks to ensure sustainable DSM project with the projected mine expansion. With gold mining responsible for 47% of the mining sector, a key focus will be to design the system for expanding gold mines.

The study will focus on expanding gold mines within South Africa. A strategy will be devised to ensure that savings will be realised even with the mines' increasing production. Previous compressed air implementation projects will be investigated to ensure a variety of solutions that may be incorporated for the highest sustainable benefit. The implemented system should ensure sustainable savings. Sustainable savings will be determined by having a constant or increased savings month to month. This continued saving will indicate that the system implemented can achieve savings with minimal human interaction. Service level adjustment (SLA) of the baseline may be implemented to determine a new baseline with the increased production. This SLA will indicate the expected energy consumption if a DSM project was not implemented [26] [27].

The implementation of a DSM project will influence the operations of the system and it is of high importance to take the mine schedule into account. Any mining delays will surely be blamed on the DSM project and switched off. This is understandable seeing that the priority of the client is to increase the mining output. The symbiosis of lower energy consumption with production may increase the profit margin. Sustainability may be negatively affected by neglecting maintenance on DSM projects. This maintenance is in most cases not high priority of mining personnel. Maintenance contracts with specialised ESCo's may ensure sustainable electricity savings with large financial benefit. This sustainability is highly dependent on the human behavioural change toward DSM project and ensure successful implementation [28] [29] [30].

1.3 Dissertation overview

The dissertation will focus on designing and implementing a control system to ensure sustainable saving on an expanding gold mine compressed air system. A brief overview of the chapters is as follows:

Chapter 2: Compressed air use in expanding gold mines

The literature study will investigate mine expansion and compressed air savings methods. Sustainability of DSM projects and compressed air functionality within the mining sector are also discussed in Chapter 2.

Chapter 3: Methodology for sustaining energy performance on compressed air systems

A case study site overview is conducted in Chapter 3. The system design and preliminary control philosophy is presented with calculated and simulated project savings.

Chapter 4: Implementation and results

Project implementation is described in Chapter 4. Project difficulties and alterations with results are also laid out.

Chapter 5: Conclusion and recommendations

Conclusions of the project based on sustainability and mine expansion are presented, and the recommendations for system improvement and possible future work are outlined.

2. COMPRESSED AIR USE IN EXPANDING GOLD MINES

2.1 Introduction

The sustainability of a DSM project may be achieved by making use of multiple control methods. The compressed air systems, gold mine expansion and aspects which may decrease sustainability will be examined in this chapter.

2.2 Compressed air function within mining sector

Compressed air systems have multiple uses within the mining industry. The compressed air networks will be inspected from the supply and demand side of a compressor ring. The supply side review will focus on the compressors supplying the air in the system. Along the same lines, demand side equipment is described [31] [32].

Compressed air systems

A compressed air system is made up of multiple elements. These elements include compressors, compressor house or houses, intricate piping network and compressed air mining equipment. The compressed air ring may consist of a stand-alone compressor system or a compressed air ring. The stand-alone system has a single compressor installation. The compressor ring makes use of multiple compressor installations to supply a larger system with air [31] [33] [34].

A compressed air ring has advantages and disadvantages. The advantages include multiple control solutions, decentralized air supply and simplified maintenance that the compressors can easily be isolated from the system. Disadvantages include escalating costs of infrastructure and also the larger pressure drops on a vast air pipe system. Pressure differences are due to multiple tap off points from the main compressed air feed. A simplified mine compressed air layout may be seen in Figure 4 below [32] [33].

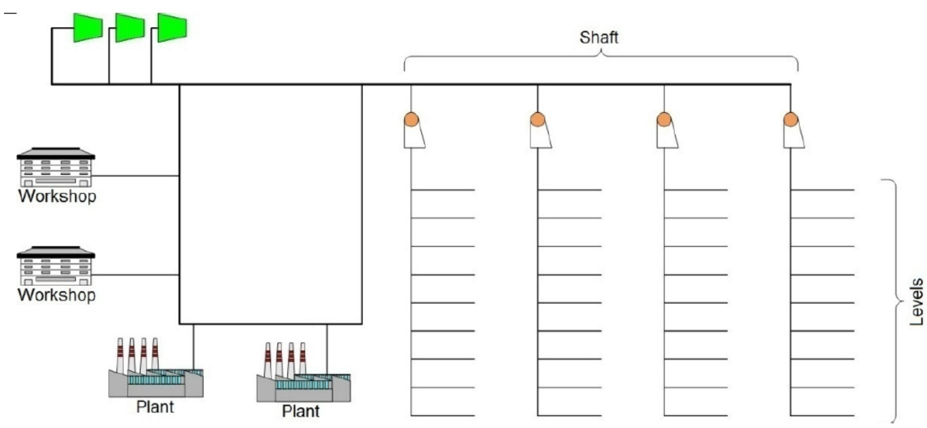


Figure 4: Simplified compressed air system layout [34]

Compressed air equipment may be dependent on either high or low air pressure supply. The low air pressure systems are used for ventilation and require between 50 kPa and 200 kPa. High pressure systems may supply as much as 700 kPa depending on mining equipment requirements [35].

Compressed air users

The compressed air is required for multiple applications within the mining industry. Compressed air is required for equipment, processes, and ventilated areas and also for artificial demand. The applications are as follows [31] [32] [34]:

ROCK DRILLS

The drills commonly used in South Africa are pneumatic drills. Rock drills are the main consumers of energy during the peak drilling shift. The highest demand for electricity is thus during this shift [32] [33].

MECHANICAL LOADERS

Mechanical loaders require constant pressure to ensure that equipment functions correctly and optimally. The loaders will cease to operate if only low pressure is supplied. The loaders will not be able to load ore from excavated panels and this hinders production [32] [33].

LOADING BOXES

Loading boxes are used to load ore in skips for transport within the mine. The skips transport ore out of the mine for processing. Low air pressure will hinder or stop loading boxes' functionality [32].

DIAMOND DRILLS

The development and expansion of a mine requires diamond drills. This development does not necessarily function within the mine drilling schedule and compressed air may thus be needed throughout the day [32] [33] [34].

AGITATION

The agitation process may require air pressure to ensure that mud and settling does not form under in the water dams. Open-ended pipes are used to ensure that the settlement does not form. Maintenance of these air agitation systems is lower than when using mechanical systems [32].

REFUGE BAYS

Refuge bays are used in case of emergencies. These emergencies may include gas leaks and fire. Refuge bays are pressurised to ensure that, in an emergency situation, clean air is supplied to miners. The chamber will have a positive pressure to ensure noxious gas does not form in the bay [32] [33].

VENTILATION

Open-ended pipes are in some cases used as ventilation in warm working areas. These areas need to be cool to ensure the correct temperature within the working environments. This cooling method is ineffective and so also constitutes an ineffective use of compressed air [32] [34].

The efficiency of compressed air equipment is low; this results in high electrical costs. The compressed air drills have an overall efficiency of 2% with efficiency of solutions in the range of 20 to 31%. The alternate solutions include electric, electro hydraulic and hydro powered machinery [34].

Alternatives to compressed air equipment

HYDRAULIC EQUIPMENT

Pneumatic cylinders used within the mining sector require high pressure. The possible replacement of these cylinders with hydraulic power packs will reduce the compressed air pressure requirements. Power packs as seen in Figure 5, make use of high pressure liquid, replacing the function of the pneumatic cylinders

Figure 5: Hydraulic power pack [34]

ELECTRICAL EQUIPMENT

Pneumatic valves have high pressure needs similar to the pneumatic loaders; but valves will cease to function under low pressure. These valves will open or close on failure for safety reasons, depending on the particular system. The control of these valves will thus no longer be sufficient for the control system. Pneumatic valves can be replaced by electric valves and these in turn ensure lower system pressure as the valves do not require a minimum air pressure to function. Control may thereby be retained. The control will be able to function in a low pressure environment. An example of an electrically-actuated valve may be seen in Figure 6 below [34].

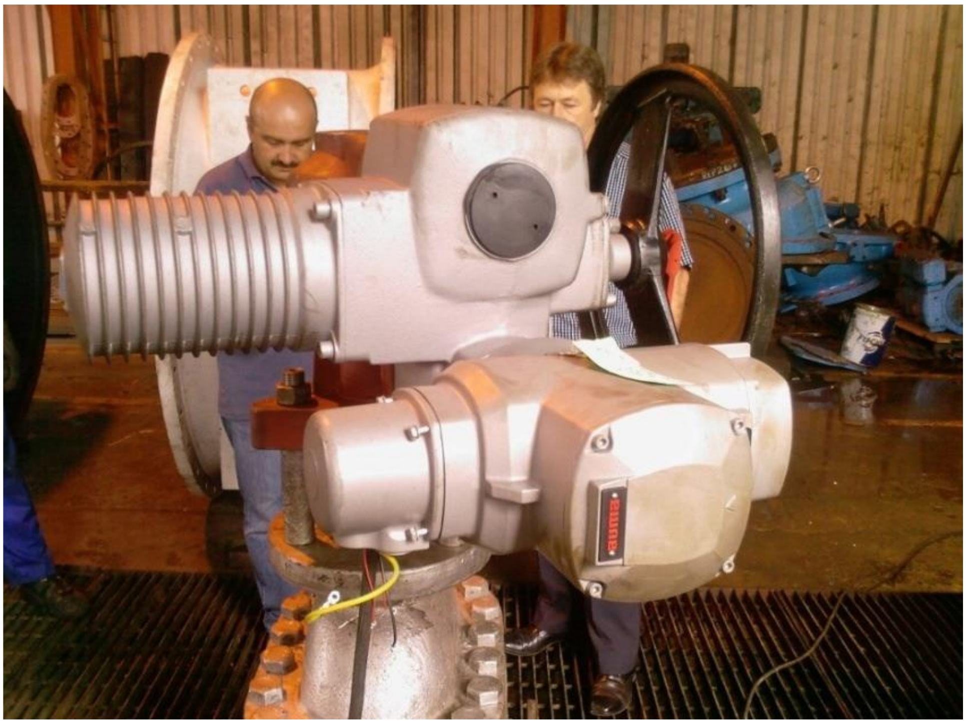


Figure 6: Electric actuated valve [34]

HYDRO HYDRAULIC EQUIPMENT

High pressure water systems are an existing implement in the mining industry. High pressure hydro power may be used for drilling. The combination of electric and hydro power will ensure an optimal solution. The use of hydro power does not only pertain to drills but also includes cylinders, valves and loaders [34].

ALTERNATE SYSTEM IMPACT

Short-term improvements on compressed air use are attained by the use of alternatives. The installation of these systems entails high start-up costs and low payback periods. The installation cost of hydraulic power packs range from R270 000 to R680 000. The payback period of the equipment does not in all cases seem viable and alternate solutions to improve compressor system efficiency have to be investigated [34].

2.3 Gold mine expansion

Mine expansion has an impact on compressed air systems. This impact on the system will have to be managed to ensure that a satisfactory sustainable system is implemented. The use of a sustainable system should not influence the production and expansion process.

Ore deposit

The expansion procedure of a mine is dependent on a range of aspects. The shape and size of the reef deposit to be mined will determine the method used to mine. Shapes may include:

- Stock and nest: Irregular in shape, but extend almost equally in all dimensions
- Column: Deposit of ore extending downward to form a column
- Sheet: Ore deposit is almost of constant thickness through two directions

The next factor is the thickness of the ore to be mined. Thickness is classified from very thin-, thin-, medium thick-, thick- and very thick deposits. These range from less than 0.7 metre and exceeding 20 metres. The angle at which the deposit is located together with the rock strength will significantly alter the mining method. Correct safety procedure has to be implemented to ensure rock falls do not occur [36] [37].

Mining equipment

The mining equipment used varies in size and application. Drills range from a standard 50 mm diameter to 200 mm diameter drills with the capacity of drilling up to 40 metres. Large capital costs are incurred in the procurement of mining equipment. Ineffective use of the equipment will affect minimal ore recovery and thus lower production. The effective utilisation of equipment will ensure quick excavation of ore and a faster return on investment (ROI). However, increased mining activity will result in the deposits being depleted faster [36].

The use of equipment in the mining- and expansion process entails several types of procedure. Equipment includes drilling, charging and blasting, clearing muck, haulage and hoisting. The progress of technology has ensured that the equipment used will be highly effective but they may entail high costs. The use of this equipment will ensure a highly efficient mine; however, this may curtail employment opportunities. The use of the equipment may not be deemed viable if the socio-economic situation of the mine is taken into account [36].

Ore value

The mining industry is oriented to ensuring high grade product is mined and that this activity is economically viable. Ore grade is a highly motivating factor in mining activity. Low grade ore, if easily accessible, will yield a high production, where high grade ore will be mined even in difficult situations. The market value of the mined ore will significantly impact the profit margin. The mining cost and selling price of gold are constantly compared to ensure that a financial viable mining operation is sustained [36].

The depth of the deposits will inevitably ensure that complications may occur. The deeper the ore deposits, the higher the cost. These costs include additional ventilation, support structures, drainage, hoisting and transportation of product and personnel. The presence of gases and water storages may become hazardous if relevant safety procedures are not undertaken [36].

Mining methods

The mining method chosen will be determined by multiple aspects. These aspects include the following and are the desirable output in the mining environment [36]:

ROCK FRAGMENTATION

- Effectiveness of the blast
- Facilities available to work on rock fragmentation
- Obstacle free environment

OUTPUT

- Effective use of rock face in terms of manpower, machines, equipment and supervision

RATE OF PROGRESS

- A faster rate of progress may ensure reduced cost and higher ore turnover

MAXIMUM RECOVERY

- High yield by a combination of grade and tonnage obtained

CLEAN MINING

- The product mined is mainly reef and less waste sent for production

EASE OF ACCESS

- The stoping method used should ensure easy movement of personnel, machines and equipment

ENERGY AND MATERIAL CONSUMPTION

- The optimal balance between energy use and material used. This energy can be in the form of ventilation, water supply, lighting and compressed air supply.

ORE HANDLING

- Ore mined should be removed for processing quickly and effectively

FILLING

- Once areas are finished with mining activity, effective filling and packing methods should be employed

ORE WINNING POSTURE

- Effective and safe stoping techniques should be implemented to minimise an unsafe working environment

The stoping methods to be implemented can be derived from analysing the ore strength, stoping class and deposit geometry. The correct stoping procedures will ensure quick progress in the mining environment. Procedures followed are in the same instances implemented on developing areas. Blasting and drilling form part of the development procedure to access the desired reef to be mined. The expansion will have to include the safety procedure to ensure the newly blasted area is safe for work. Additional instrumentation will have to be installed to test the strain and stress in the new environment. Support for these sections is installed to prevent rock falls. Critical mining service will also have to be installed within the developed area. The compressed air system needs to be extended for drilling. Ventilation is added with the new water supply, both for personnel and mining purposes. The additional infrastructure for development has a financial impact but also increases the base load of mining services [36].

2.4 Sustainability

Sustainability as defined by the Oxford dictionary is as follows: "able to be maintained at a certain rate or level" [38]. The desired effect of sustainability for DSM projects should entail constant or growing power savings. The central factor of a sustainable DSM project will therefore be measured by the level of savings over consecutive months. These projects may have multiple aspects that will ensure a success of a project (and the various aspects will be discussed below). The success of a DSM project is also being conceived as a cost-benefit analysis. The reduction in power use in a cost-effective manner may ensure a successful project [39].

DSM achievements

Ensuring that a project will either fail or succeed is connected to the sustainability of the project. Attempts to implement a project with a high success rate will have multiple aspects that may negatively impact on the project. The projects implemented have a focus on changing behaviour within an end-user or system. The DSM implementation has two respective foci to improve savings. The initial purchase of efficient equipment should ensure efficient electricity use on the part of an end-user. The next step is to install equipment incorporating an energy management system (EMS) to ensure continuous reduction in energy use [39].

The implementation of DSM projects makes use of both these steps. The systems are optimised to ensure efficient equipment use; systems are put in place to maintain the behaviour aimed at achieving optimum energy savings. The implementation of these systems is conducted by specialised ESCo's as has been pointed out above. The successful implementation of an EMS has multiple challenges that may be encountered.

The investigation phase of the project will propose a change within the system that may inconvenience the current system operators if it is not correctly addressed. This communication to the client is in some cases neglected and result that the EMS is shut down and savings will no longer be achieved. The client may be more cooperative if the following are addressed before the project is implemented [29] [39]:

MOTIVATING FACTORS

- Awareness of project to be implemented
- System capability
- System efficiency

ENABLING FACTORS

- Financial benefit
- Technical aspects of implementation
- Organisation resources implemented or the minimal implementation of resources
- Possible new skills development

REINFORCING FACTORS

- System feedback from experts
- System feedback from EMS
- System optimisation

The information being shared at the investigation and pre-implementation phases may ensure smooth project execution. Buy-in from the client is a critical part and ensures that the project will function correctly after the project has been handed over. The financial benefit is a factor that may ensure cooperation on the part of the client. The financial aspect includes the electricity saved and the added benefit of avoiding Eskom penalties. The buy-in by the client will ensure that the project has minimal risk during the implementation. [29] [39].

DSM project implementation has the potential to guarantee a large reduction in electrical use. These projects need to prove savings potential in the performance assessment phase. These savings are often hindered by changes in the business and operational environment. The changes in mine operations often move mining activity to previously off-peak time periods without the ESCo’s being informed. EMS will have the control philosophy as previously set up and this might possibly impair the mining operations. The impaired system functionality is then often labelled as the culprit and the system is shut down [29].

The priorities of the client are in most cases focused on the output or production of the facility. Production will have higher priority than the potential savings obtained by a DSM project. The increase of a few percentages in ore being produced may result in the EMS control being neglected. The financial impact of this will minimise savings or lead to additional costs being incurred. An optimal point between the electrical input cost and maximisation of production should be reached [4] [29].

Service level adjustment

True impact of any DSM project is measured by pre- and postimplementation power profile. This is measurement is assisted by constructing a preimplementation power baseline. The baseline is set up proir to ESCo intervention. An accurate set-up is needed to ensure that accurate savings may be reported on a DSM project. The baseline is set up and verified by an external Measurement and Verification (M&V) team [40].

The Service Level Adjusment (SLA) is a procedure implemented with the baseline setup to ensure that the baseline remains applicable over the lifetime of a project. SLA methods are implemented on the baseline to determine, what is known as, “what-it-would-have-been baseline”. Multiple scaling methods exist that will be defined by each unique project’s parameters. These scaling methods as applicable to compressed air systems will be discussed below [41].

FLOW RATE

Compressed air flow during the peak drilling shift is used in conjunction with compressor energy consumption. The air use during the drilling shift from 09:00 to 12:00 is used with pre-project implementation consumption. A linear correlation between these two factors is determined that will scale the applicable baseline. The new baseline is used to calculate the new savings for reporting purposes. Flow is a single independent parameter to be monitored and will be advantageous. The disadvantage will be if the compressed air system alters drilling operations and cause the SLA to be void [41].

PRODUCTION

Production can be correlated to compressed air use with high compressed air dependencies. The compressor energy consumption will be compared to production tonnes to determine the new SLA methods. Production data determined on a monthly basis is to be compared with the compressor power consumption. The baseline will then only be adjusted on a monthly basis and the daily impact will be difficult to obtain. Production data are available by mining operations and thus no additional information will be required to be logged. Production increase after implementation ensures a baseline scaling of 25% on projects [41] [42].

2.5 Impact of artificial demand on sustainability

The sustainability may be negatively impacted by an increase in artificial demand. The additional demand will ensure that additional compressed air has to be generated. Compressed air supply will in turn increase the electricity consumption of the compressors. Sustainable power savings and the loss of production are key factors that are needed to sustain a system. Production is a higher priority to the client. An artificial demand will lower the quality and pressure of compressed air to the system. This artificial demand will increase the base load of the system and may in severe cases require an additional running compressor to supply the system.

Air leakage

Savings achieved after the performance assessment phase of a project decreases without expert attention on site. The reduction in some cases has been as severe as 64% within a six month period. This decrease in project savings can be seen in Figure 7. Compressed air systems have documented losses between 35% and 50% through air leaks. The ineffective management of compressed air losses in these ranges will have a marked effect on power use within any compressed air system. Air leakage losses may well ensure that any DSM project will no longer be sustainable [28] [32] [43].

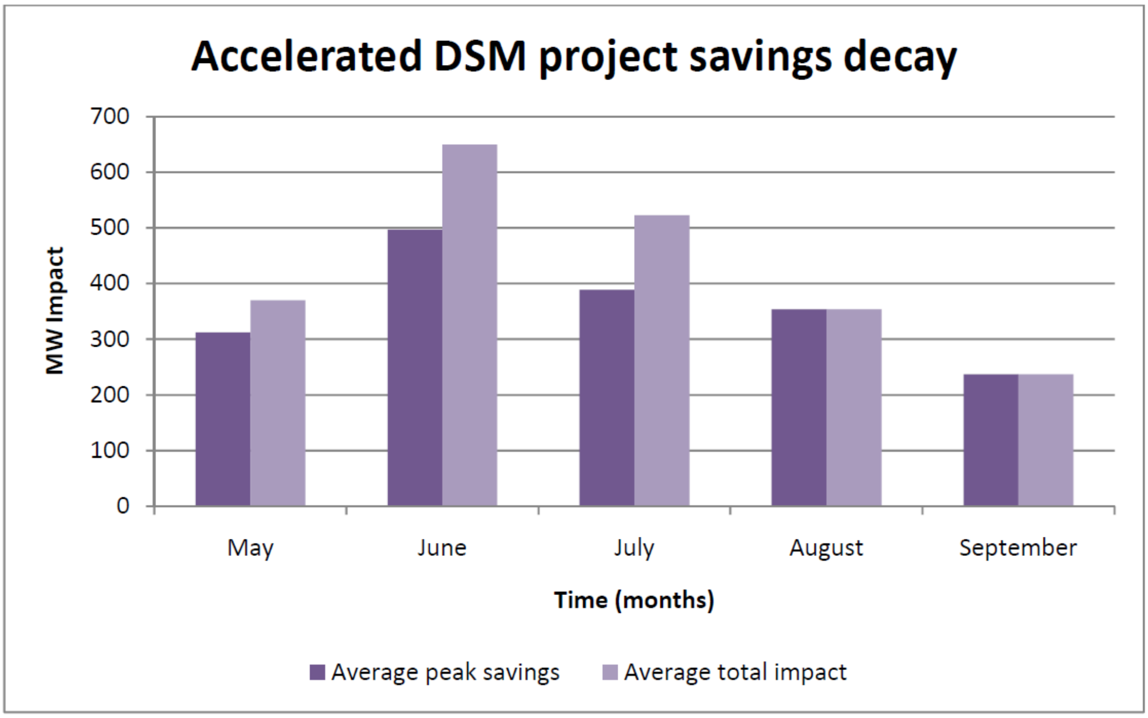
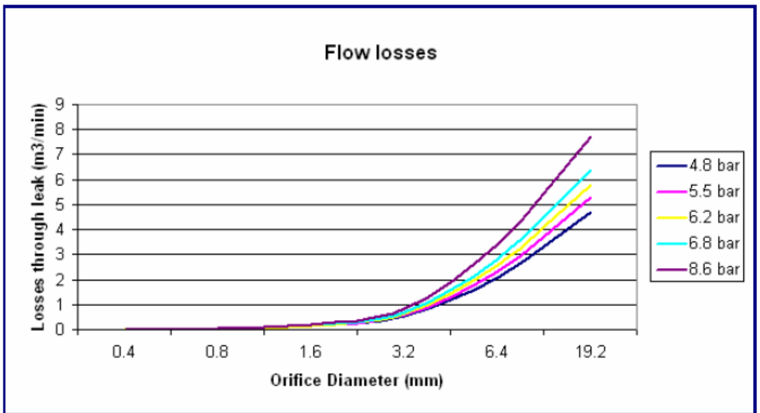


Figure 7: DSM project savings decay [34]

Systems implemented to rectify air leaks have either a focus on small or large leaks. Large leaks are heard simply walking passed the applicable leak. Small leaks are not as easily detected and require multiple systems to detect and estimate the air flow through the leak. These systems include ultrasonic detection, intelligent leakage detection, pigging, soapy water, tracer gasses and load/unload tests. The detection of these leaks is in most cases outsourced to specialised companies. These companies have client systems with leaks in excess of 20% of the installed capacity. Losses through an orifice with different pressure supplied are quantified in Figure 8 below. The financial impact, power wasted and financial impact may be seen in Table 1 overleaf [28].



Leakage (m^3/min)						
Presure (bar)	Orifice Diameter(mm)					
	0.4	0.8	1.6	3.2	6.4	19.2
4.8	0.00812	0.03248	0.13048	0.52136	2.0832	4.6984
5.5	0.00896	0.03528	0.14672	0.58128	2.3268	5.3
6.2	0.01008	0.04088	0.16016	0.6468	2.576	5.7848
6.8	0.0112	0.0434	0.17668	0.70616	2.8252	6.356
8.6	0.01344	0.05432	0.21448	0.8582	3.4216	7.714

Figure 8: Volume flow loss through an orifice [12] [32]

Table 1: Energy and cost impact of leaks (ESKOM 2010/2011 tariffs) [34]

Hole diameter (mm)	Area of leak (m^2)	Mass-flow (kg/s)	Mechanical energy (kJ/kg)	Power wasted (kW)	Energy savings (kWh/year)	Cost savings (ZAR/ year)
3	0.000007069	0.01	271.43	1.71	15 244.56	7 096.37
6	0.000028274	0.03	271.43	6.82	60 978.23	28 385.49
10	0.000078540	0.07	271.43	18.95	169 383.98	78 848.59
25	0.000490874	0.44	271.43	118.43	1 058 649.86	492 803.72
50	0.001963495	1.75	271.43	473.73	4 234 599.46	1 971 214.87
100	0.007853982	6.98	271.43	1 894.93	16 938 397.83	7 884 859.48
150	0.017671459	15.71	271.43	4 263.60	38 111 395.11	17 740 933.82
200	0.031415927	27.93	271.43	7 579.74	67 753 591.31	31 539 437.91

Audible leakage detection of large leaks is one of the easier methods to implement. The noise may often be heard by simply walking past a pipeline with an air leak. Increased leak size will ensure that a louder noise may be heard. This method is obviously ineffective for small leaks. Ambient noise however may also ensure that relatively large leaks not be detected [34].

Audible leaks are not often documented in client systems. A Compressed Air Leakage Documentation System (CALDS) has been devised for the mining industry to maintain DSM project savings. This system makes use of a handheld device to document crucial information of leaks within a compresses air system. This includes the following information [28] [34]:

- Location of leak
- Severity or size of leak
- Person investigating leaks
- Date of detection
- Previous leaks detected

- Flow rate of leak
- Financial impact
- Update of leaks repaired

The collected information is processed and used to generate a report. This report can easily be interpreted by management with the financial impact being quantified. Prioritising of each leak according to severity may also ensure the DSM project savings become sustainable more quickly. The larger leaks will have the highest impact on the system. The tracking of leaks detected and repaired will also indicate the positive impact of implementing the CALDS system. The focus of personnel behaviour is then on improving the current compressed system rather than increasing the capacity. [28] [34] [39].

Projects implementing the CALDS system ensured an additional 0.69 MW saving. The savings increased from 1.29 MW to 1.98 MW. Targeted savings are reduced by up to 34% where the client does not take ownership of the DSM project. The implementation of CALDS markedly improves the savings to 102% of the target [28] [34].

Illegal mining

Criminal mining activity has become a regular occurrence from about 1999. This mining activity started due to the struggle to obtain legal work in the society and the illegal mining is seen as an easy and appealing alternative. These mining activities are targeted on decommissioned mines, active mines and rock dumps. The activity may include the aggressive overpowering of equipment and working sections in active mines [44] [45].

Illegal mining has previously been seen as an act of trespassing. This has been changed and it is now regarded as organised crime. This shift in the justice system has occurred after mining corporations made it clear that the system comprises at least a five-tiered hierarchy. Mines experience the first tier with illegal miners or also known as Zama-Zamas. The illegal activity may include bribery, corruption, human trafficking, money laundering and several other illegal activities [44].

The mining companies are at a point where they can no longer handle the aggressive nature of the Zama-Zamas and they require assistance from security personnel and police. Illegal miners often carry firearms and plant explosives to hinder the attempts to eliminate them from the premises. There is the possibility of there being more than one syndicate on a given shaft. Rival crews may in some cases “wage war” to obtain a better working environment. The battle for the highest grade gold ensures that the mining company will either have to settle for a lower grade product or call in a specialist to repel syndicates [44].

Illegal sales in gold are estimated to deprive the mining industry of R5-billion a year. Mining companies incur the loss of company assets which include explosives, machinery, equipment and copper cables. This increase in crime ensures that additional security personnel are called in at an additional cost. Safety is compromised due to violence between competing illegal mining gangs. Mining personnel may lose their lives in the process leading to a loss of income of entire families [44] [46].

The illegal mining has far-reaching effects on multiple categories within the mining sector. The first impact as previously detailed is lost revenue. Abandoned mines targeted by illegal mining are initially scavenged for infrastructure which is then sold. The rundown mining complex is then used for the illegal mining activity. The environmental impact is large. The illegal mining activity is concluded with environmentally unfriendly techniques rendering additional waste. The discharged waste is freely cleared to any location. Harmful materials used in the extracting process will ultimately reach the water table and contaminate it; this may inadvertently harm a large number of people [45].

Such mining activity will ensure that additional mining equipment is needed on the shaft. The impact on the compressed air system will increase. Illegal miners do not have to work on mining schedule and they may work at off-peak time periods. These off-peak working times may coincide with Eskom peak times and cause financial harm. The areas mined may possibly be less ventilated than the mining company specifications. This poor ventilation is in most cases compensated for by the use of open ended pipes to ensure cool working conditions for the illegal miners. The use of air for illegal mining activity ensures that the base load of the compressed air is increased. This is an artificial demand [44].

Case study

The artificial impact is quickly appreciated when monitoring flow on a decommissioned mining level. Valves are used to limit flow on these levels in case the refuge bays need to be supplied. Standard level flow for one shaft was 3 000 kg/h and after the valve was altered by illegal miners has in some cases increased to 25 000 kg/h at a pressure of 560 kPa. The average flow on this decommissioned level would around 13 000 kg/h. The impact of this one level alone was the equivalent to 13 to 25% of the installed compressor capacity. The impact of the non-production level activity could be monitored by a flow meter. The installation cost could easily be covered by the savings.

2.6 Current control philosophy implemented

A control philosophy is a critical component in achieving savings on a DSM project. The control philosophy to be implemented on compressed air systems has multiple facets to maximise savings potential. Multiple implementation techniques on compressed air systems need to be investigated.

Supply side control

The optimal management for the control of compressors is one of the key focus points within compressed air systems. The compressor control system modification is common practice. Compressor control includes guide vane manipulation, load sharing and compressor selection. The start and stop on a compressor is the first step of control. This will ensure that a compressor may be started or stopped as demand requires. The automation process of compressors may also include the offloading potential. This offloading process may be used if demand is lowered for small period. The compressor running power may be lowered in this state to 20% to 30% capacity [33] [47] [48] [49].

The guide vane control ensures that compressed air flow is manipulated. Lower air supply in turn lowers the running power levels of a compressor. The control is most commonly implemented by making use of a Moore controller. This controller enables a common pressure profile or set point to be implemented according to clients' requirements. This pressure profile may be manipulated during the day depending on the shaft schedule. The controller is implemented in conjunction with a PLC. However the Moore controller has safety aspects to ensure the compressor does not surge. The surge state is caused when flow is reduced to such an extent that mechanical damage may ensue. The Moore controller will react to this state and increase flow to ensure a safe working condition. The dedicated function of the Moore controller will ensure that the reaction is faster than the PLC's capability [31] [33] [49].

The dynamics of a compressed air ring does not in every case consist of one compressor type and size implemented. Load sharing is a desirable control method within such a system. The Moore controller enables the system to have one central pressure set point. The controller will in turn control the guide vanes of all the available compressors to ensure the load is supplied by all available resources. Control of compressors guide vanes also be used within this compressor selection process. Guide vane control input may change with an offset to ensure the base load stays constant. The compressor selection process ensures that the combination that is the most efficient be used. This combination may include switching off a small compressor and simply running a high installed capacity compressor rather than both cutting back on guide vanes [33] [47] [48] [49].

Compressed air demand reduction

The mining industry, as previously mentioned, is highly dependent on compressed air. The need to lower the dependency on compressed air is one of the strategies previously implemented. Optimisation of the compressed air network may be obtained by implementing underground level control valves. This entails the air demand of underground level being lower, to ensure optimal control. This system incorporates a PLC, pressure transmitters and flow-measuring equipment. The control on the levels is highly dependent on the mining schedule. Control may be implemented in periods of low pressure requirement. The system has the additional benefit of being controlled once a level control has been put into place, leading to immediate savings [33] [43] [48].

The next step is the lowering the artificial demand within the system. The lowering of leaks in a large compressed air ring has a large impact. The implementation of valves will ensure that the leaks are supplied with lower pressure in off-peak time. Savings potential could reduce power use to between 10% and 23% if implemented. Implementing leakage detection has in cases increased project savings of between 34% and 102%. This saving is dependent on the size of the system and the severity of the leaks. The demand side is thus manipulated in the system to ensure that lower compressed air is needed [28] [43].

The pressure supplied within a compressed air system is done with the highest pressure requirements. Pneumatic loaders may be replaced by low pressure of non-pneumatic equipment and this lover compressed air requirement. The compressed air system in some cases also supplies air to a gold plant. Such plants require a high pressure with low flow to function correctly. The gold plant can however be isolated from the ring and a standalone compressor system be installed to supply the system [33] [43] [50].

The lowering of compressed air dependencies require additional infrastructure. Installation may be very expensive. This and the buyback period as obtained by the power savings need to be taken into account when a solution is proposed. The lifespan of the client's site or shaft will affect the choice of installation; in some cases the buyback period may be longer than the lifespan [43].

Auto compression

The compressed air rings within a deep gold mine are an intricate compressed air system. Pressure required on the underground levels needs to be constant to ensure the proper functioning of the mining equipment. The need for the high pressure in most cases entails high output pressure by the compressors. The discharge pressure of compressors is set to the underground pressure required. The discharge pressure does not in most cases take into account the auto compression that occurs within deep level mining [49].

Auto-compression of air in a system occurs with additional compression by means of the air weight. The depth of the mine will ensure that the auto compression will be higher. An average increase in pressure could be expected to be 10.25 kPa per 1000m deep. This increase in pressure has the potential to lower the discharge pressure of the compressor while sufficient pressure is still supplied to the mining sections. The lowering of compressor discharge will in turn lower the running capacity of a compressor [49].

Auto-compression in a shaft is highly dependent on the piping system used. The friction obtained due to pipe diameter restrictions will ensure the higher losses and possibly the loss of auto compression benefit. Increased air demand during peak drilling periods requires a higher air flow. This higher air flow will be compromised if pipes restrict the system. This saving of 10% due to auto compression in a high and low pressure ring may be achieved [49].

2.7 Summary

There are multiple solutions for controlling a compressed air system, depending on the infrastructure. A sustainable approach includes a control philosophy that integrates a mines’ expansion plan. Air leak and artificial demand rectification may a rapid compressed air base load reduction. The sustainability of a project after sign-off depends on the behaviour of personnel to implement and maintain the system.

Implementing compressor control with underground level control could be beneficial. Such proper control would lower the compressor discharge when not needed. The mine-specific level control schedule can reduce the demand for compressed air. Controlling artificial demand ensures a sustainable system.

3. METHODOLOGY FOR SUSTAINING ENERGY PERFORMANCE ON COMPRESSED AIR SYSTEMS

3.1 Introduction

The control methodologies that can be implemented were discussed in Chapter 2. Chapter 3 will cover the system design to ensure that a sustainable DSM project can be put in place. The current system is investigated to determine the infrastructure required to perform sufficient control. Preliminary design and control philosophy is discussed with a simulation to determine the potential for savings.

3.2 Compressed air system overview

The case study included three mines. Mine A, B and C's compressed air networks are interconnected underground. Compressed air is supplied to all three mines from compressors situated at Mine A and Mine C with installed capacities as laid out in Table 2.

Table 2: A case study of compressor installed capacity

	Mine A	**Air flow (CFM)**	**Mine C**	**Air flow (CFM)**
Compressor 1	Sulzer: 3 900 kW	25 000	Sulzer: 4 800 kW	30 000
Compressor 2	Sulzer: 3 900 kW	25 000	Sulzer: 4 800 kW	30 000
Compressor 3	Sulzer: 4 800 kW	30 000	Sulzer: 4 800 kW	30 000
Compressor 4	Hitachi: 4 800 kW	30 000	Sulzer: 4 800 kW	30 000

Mines B and C are actively mined while Mine A is only used as an engineering shaft. The dewatering system at Mine A ensures that flooding does not occur on Mine B. Compressed air is supplied to Mine B from Mine A through an underground compressed air pipe connection on level 55. Mines B and C are also connected through an underground pipe system on level 66.

The connecting pipes on level 66 were severely damaged by an underground explosion. These damaged pipes were sealed off with the result that compressed air could no longer be supplied between Mine B and from Mine C. As a result, both compressor houses now only supply one actively-mined shaft with compressed air.

Gold production at Mine C is presently at full capacity. As part of Eskom's DSM contracts, only one project may be implemented on the same energy consumers per site within a five year period. Since a DSM project has been completed at Mine C within the prescribed period, energy savings project investigations on compressed air was only done at Mine A and Mine B. Mine B is a recently developed shaft that has rapid expansion plans.

A simple overview of the compressed air system is shown in Figure 9 below. The compressed air valves are installed and can be seen in the figure below. The levels at Mine A have been closed off with the intention to lower compressed air wastage through leaks to old mining areas. Mine B has five production levels each with Northern and Southern expansions. The ore located in the Northern expansion is of higher grade than the Southern expansion and therefore the mining activity in the Northern sections are relatively higher. Mine C has an Eastern and a Western expansion.

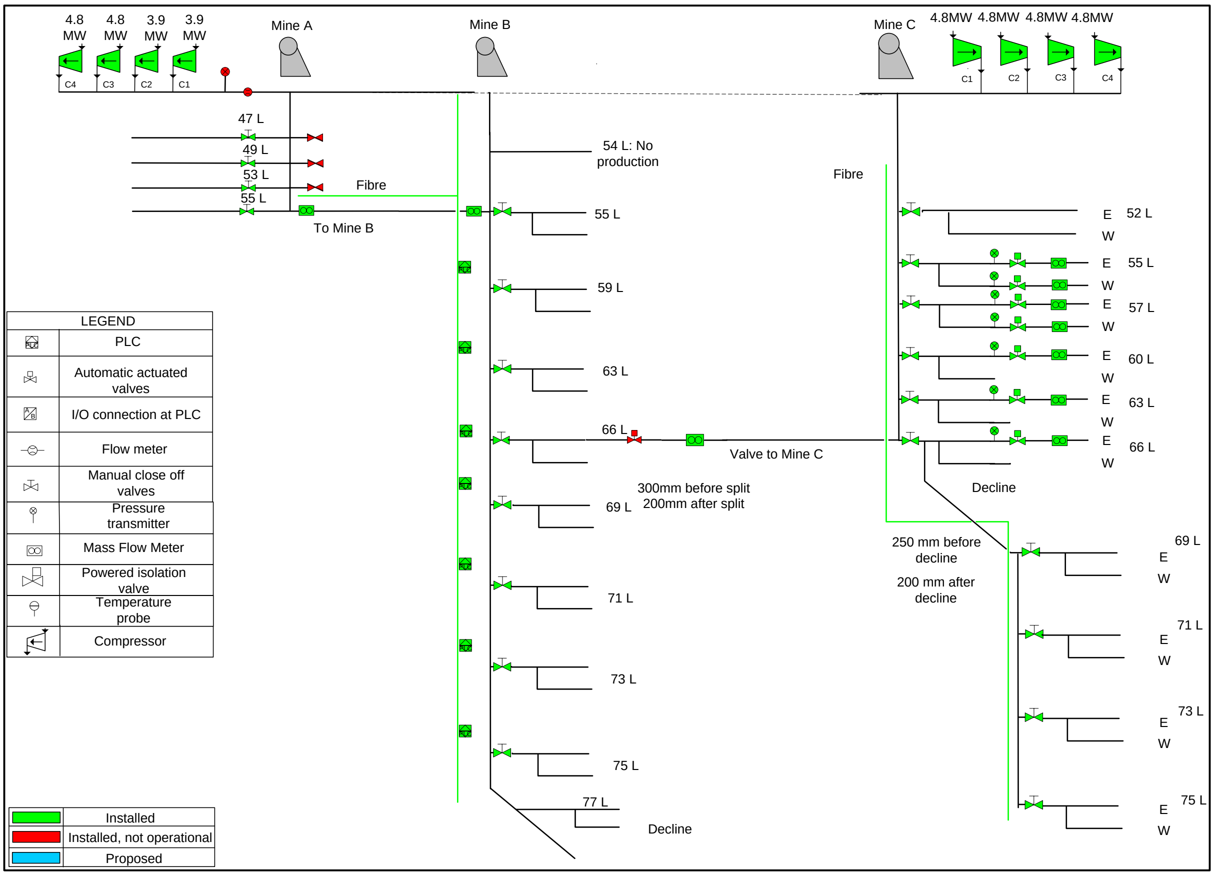


Figure 9: A simple overview of the compressed air system

Compressed air power savings will be achieved by implementing DSM projects on both mines. The aim of the DSM projects would be to control both the demand and supply side of the compressed air system. Compressors supplying compressed air are outdated and will have to be upgraded in order to ensure successful supply control. At the same time, the demand on mine B will have to be lowered. The lower demand will decrease compressed air demand which will lead to savings. Since compressors form part of one of a few large energy consumers on a typical mine, substantial energy savings can be achieved if savings on the compressors are obtained.

Power baseline setup

The power savings realised after the implementation requires a benchmark. This benchmark is realised via a baseline. The baseline is constructed before project implementation, and savings are measured against the baseline after project implementation. This power baseline was constructed by using power data recorded during a three month period. Only compressors 1 and 3 were operational during the baseline period. The installed capacities of these compressors are 3,9 MW and 4,8 MW respectively.

The power consumption of compressors 2 and 4 were not included in the baseline. Compressor 2 had starting up problems and it was used only as a backup compressor. Compressor 4 was also out of order and no plans existed for repair. Compressed air was thus supplied to Mine A and Mine B's compressed air network from compressors 1 and 3. The installed capacity of the two compressors has a total of 8,7MW with the total installed capacity of the compressor house being 17,4 MW.

The baseline was recorded from 16 February 2011 to 16 May 2011. Power consumption during this period is shown in Figure 10 below. The baseline pressure of the compressed air at Mine B is shown in Figure 11 below. Instruments used for mining are highly dependent on the compressed air pressure supplied to them. Delivery pressure is important and must be maintained in order to not hamper production. It can be seen that the pressure drops highly between 08:00 and 14:00 but the compressor power consumption is higher. This clearly states that the compressors are struggling to supply the desired pressure of the high usage equipment. The high flow used will increase the losses through air leaks in turn as well.

Knowing that most mining instruments can only function at pressures higher than 400kPa and by studying the pressure profile it is possible to determine different project control strategies. This will be discussed in section 3.3, Preliminary control philosophy.

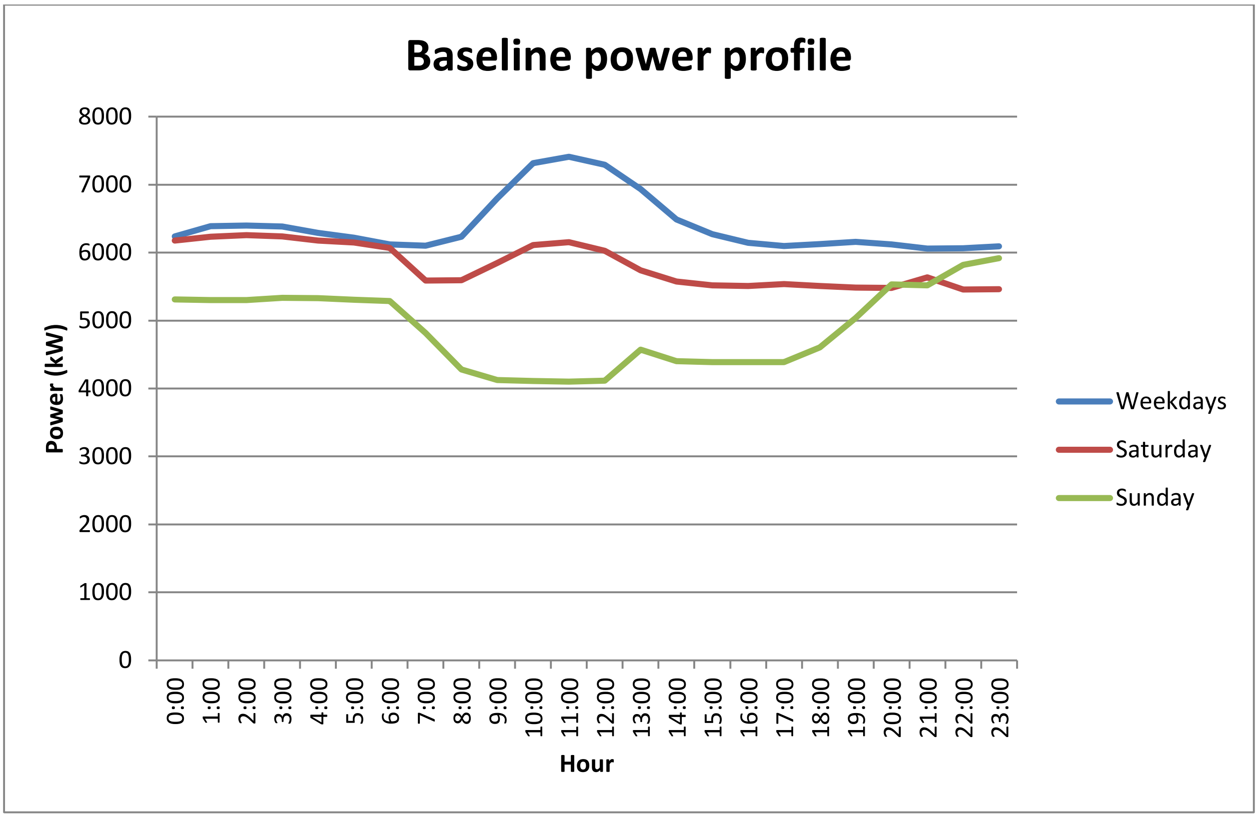


Figure 10: Baseline power profile

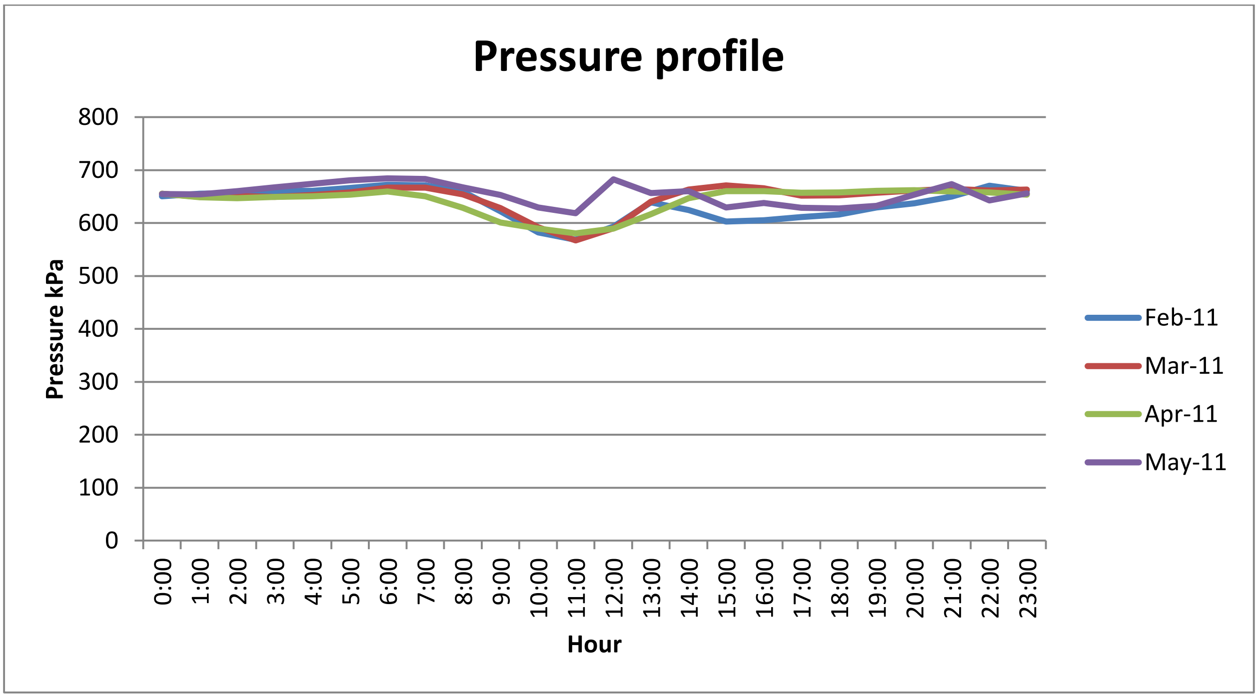


Figure 11: Pressure profile

Production increase

The production on mine B has not peaked and the rapid expansion programme will bring it close to full capacity. Long term plans of the shaft as previously mentioned were to significantly increase the production and mining sections. The estimated production increase is shown in Figure 12 below. The increase is estimated to be about 34% from February 2011 to August 2013.

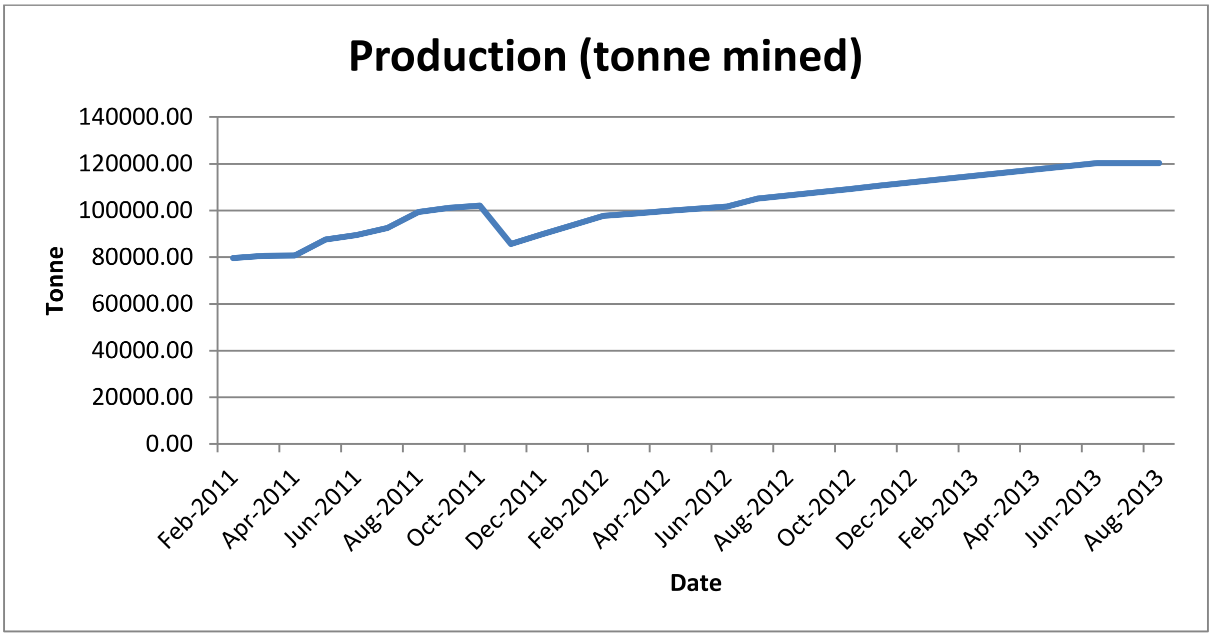


Figure 12: Estimated production increase

The additional mining and expansion will increase the compressed air use. This use is estimated for the same time period by mining personnel. The increase of compressed air is estimated to be in the same range as the additional tons being mined. Increase will thus require the compressors to deliver more air and in turn be consuming more electricity. The estimated compressed air use is shown in Figure 13 below.

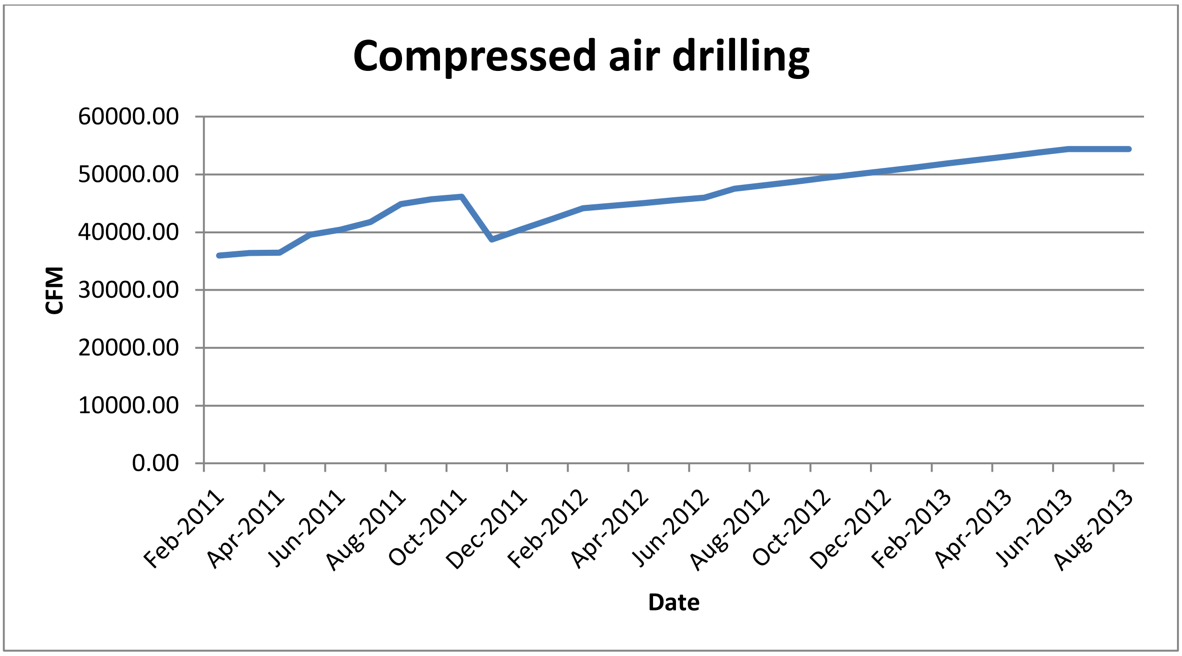


Figure 13: Estimated compressed air use

Estimated compressed air use includes leaks. The estimation of these leaks from the mine is in the range of 25% on the compressed air ring. The leaks will also have to be redeemed from the compressors and the estimated compressed air and increase the base load as shown in Figure 14 overleaf. The total installed capacities of the compressors are reflected in Table 2 on page 32.

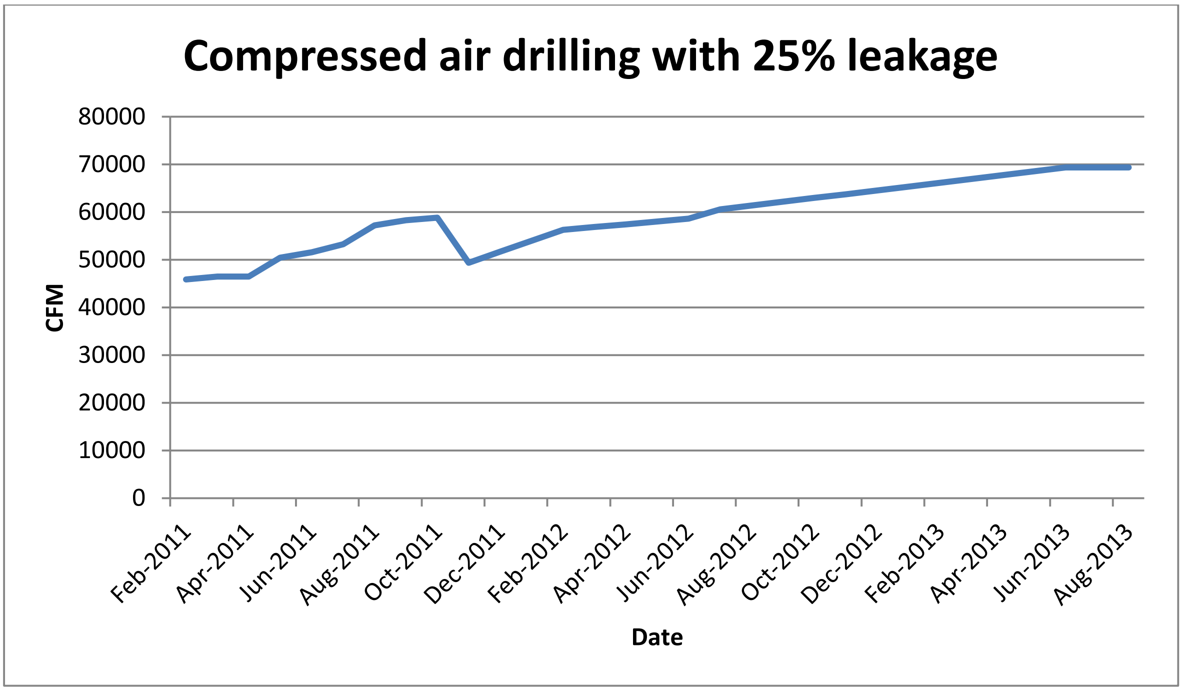


Figure 14: Estimated compressed air use including leaks

Compressors 1 and 3 were running before project implementation. The baseline compressors limit the minimum cutback of guide vanes and in turn the minimum running power. This compressor combination was used by necessity rather than an optimal compressor combination. Finances received by implementing a DSM project ensured that compressor 2 would be ready at installation.

The DSM project will grant compressor 2 running state and the potential for a new compressor running strategy. This strategy could increase the possible energy savings. These three compressors running combinations increase and make it possible to use compressors 1 and 2 with an installed capacity 7 800 kW. The current running combination of compressors 1 and 3 have a capacity of 8 700 kW. The compressor running capacities have to be investigated with the potential savings.

System flow

The compressed air estimation as received by the mine has the CFM requirements below 50 000 CFM without leaks. The smaller compressor's maximum delivery is 25 000 CFM each and they would supply sufficient air to the shaft. Air leaks in the system will on the other hand have a significant impact; they will have to be lowered for a successful tactic.

The acceptable norm of air leaks is 10% of the system and that is the current target. Loss through air leaks within the system will also be minimised by reducing the pressure on each level. The pressure profile in the preliminary design will lower the air leaks loss by an estimated 32% [28] [34].

Service level adjustment (SLA)

The production increase causes increased compressed air use. This increase has to be reflected with a scaled baseline. The SLA would be conducted by comparing production data from the baseline period to performance assessment over the same period, the correlation between production and compressor power consumption would have to be obtained. The project tracking would then make use of the correlation to obtain the new SLA baseline to determine the what-it-would-have-been baseline [41].

3.3 Preliminary control philosophy

The initial investigation was done to ensure that the mining infrastructure and working schedule may be better understood. There should be no negative effect on the mining schedule. The control philosophy is modified around the mining activities on the shaft. The financial implications of production losses are much higher than compressed air electricity cost savings. The mining schedule and intended control are shown in Table 3 below.

.

Table 3: System variable pressure constraints

MINING SCHEDULE [TIME PERIOD OF SET POINTS]	MINIMUM PRESSURE VALUE [KPA]
Peak drilling shift [08:00 – 12:00]	450
Cleaning [15:00-19:00]&[22:00-04:00]	400
Blasting 1 [13:00-15:00]	200
Blasting 2 (with cleaning) [15:00-17:00]	400
Off-peak 1 [04:00-08:00]	350
Off-peak 2 [20:00-22:00]	300
Mine personnel safety clearance [12:00 – 13:00 and 19:00 – 20:00]	400

The pressure available in the system during the baseline period is shown in Figure 11 above on page 36. This pressure in the system exceeds 650kPa through the shaft. The initial investigation showed that a large improvement may be obtained by lowering the pressure supplied to the mining sections. The combination of lower pressure demand on the levels would ensure that the compressors supply be lowered. The lower supply would in turn run the compressors at lower power levels.

The peak drilling shift requires 450kPa pressure be supplied on each level. Supply of 400kPa is required by drilling machines on each level. The safety factor of 50kPa has been agreed upon by the client to prevent no production losses. Within this time loading will also take place, which also requires a minimum of 400kPa.

Mine B expansion plan has two distinct routes to ensure the increase of mining activities. The first step is to increase the number of crews mining on the shaft. Additional crews required are taken from mine A. Mine A has gold available for mining, while the gold grade is however higher on mine B than Mine A. This increase will ensure that a larger area can be mined and in return a larger product be excavated. The second step is to increase the stoping area and dramatically increase the footprint of the mine. This expansion process will increase the exposed area for mining the desired reef.

The increase in mining activity ensured that the preliminary control schedule could no longer be used. Limited cages available for transport have led to an increase in mining times. The schedule is altered not only for longer mining, but development occurring throughout the day ensures an increase in air consumption. The development requires a fairly high pressure resulting in increased off-peak period pressure requirements. The initial off-peak period had a pressure set point to manage a positive pressure in the refuge bays. The pressure profile to be used is reflected in Figure 15 below. The profile will be finalised once implementation takes place.

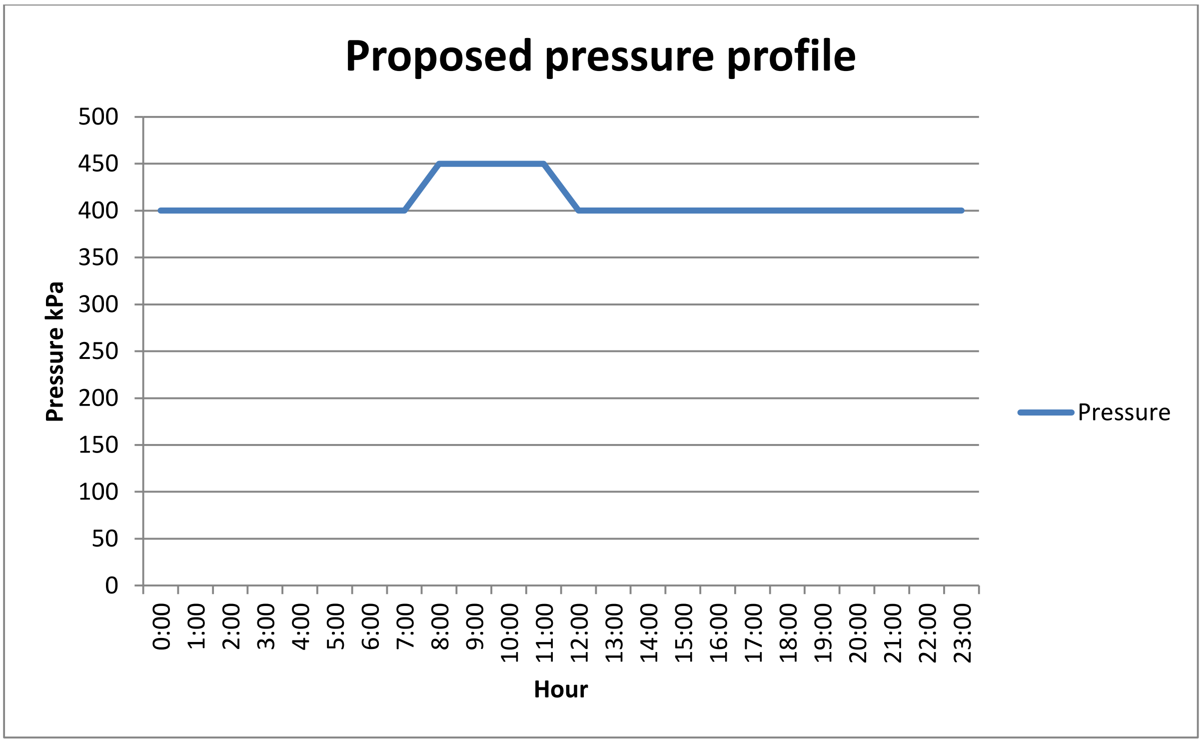


Figure 15: Proposed pressure profile

The level control valves have the set points initially set up to lower the demand from the initial baseline which exceeds 650 kPa. Preliminary set point values used could not function due to changes in the shaft schedule. The production increase altered the time schedule. Mine expansion plans had also taken into account the development work during off-peak time. The expansion ensured that mine air use increased.

The equipment used in development had a minimum pressure requirement of 400 kPa to function acceptably. Demand on the levels was thus lowered by making use of air valves from 667kPa to 450kPa maximum while taking into account the safety factor of 50kPa. This decrease of 32% will in turn have a marked effect on the compressed air supply. The supply of the compressor was initially set to have a discharge pressure of 600kPa. Auto compression in the system ensured the supply in off-peak time periods be raised to a maximum of 667kPa. Lowering demand in the valves increases the column pressure and also lowers the supply needed by the compressors.

The compressor should start cutting back on guide vanes to lower the compressor power use. Compressor supply pressure of 600kPa would be much higher than the required 450kPa system pressure. The discharge of the compressor should also be lowered to ensure an earlier cutback of the guide vanes, and the discharge pressure of each compressor should be lowered to at least 550 kPa.

3.4 Simulation

The air supply within the system is simulated before and after the installation of equipment. This simulation will indicate if the air flow within each section is sufficient. The simulation is first conducted with the initial pressure readings in conjunction with the compressor kW readings to determine the flow within the compressed air system. Simulation is modified to include the control equipment to ensure effective service delivery.

The pressures simulated within the system are done with the initial investigation pressure requirements. Simulation is completed for the pressure supplied on the levels for 450kPa (Figure 16) and 300kPa (Figure 17). The discharge pressure of the compressor is also lowered to determine the effect on the system.

The planned mine expansion process is to increase the pipe size to the Northern and Southern expansion from 200mm to 300mm pipes. These pipes sections will thus be installed from the station and split into two 200mm pipes. The installation plan will be completed three months before performance assessment.

The purpose of the intended pressure profile is to reduce the workload of the compressors. Workload on the other hand should not influence the pressure available on the production levels. The production should have sufficient pressure to run all the necessary equipment. Simulation uses the flow and pressure distribution within the system.

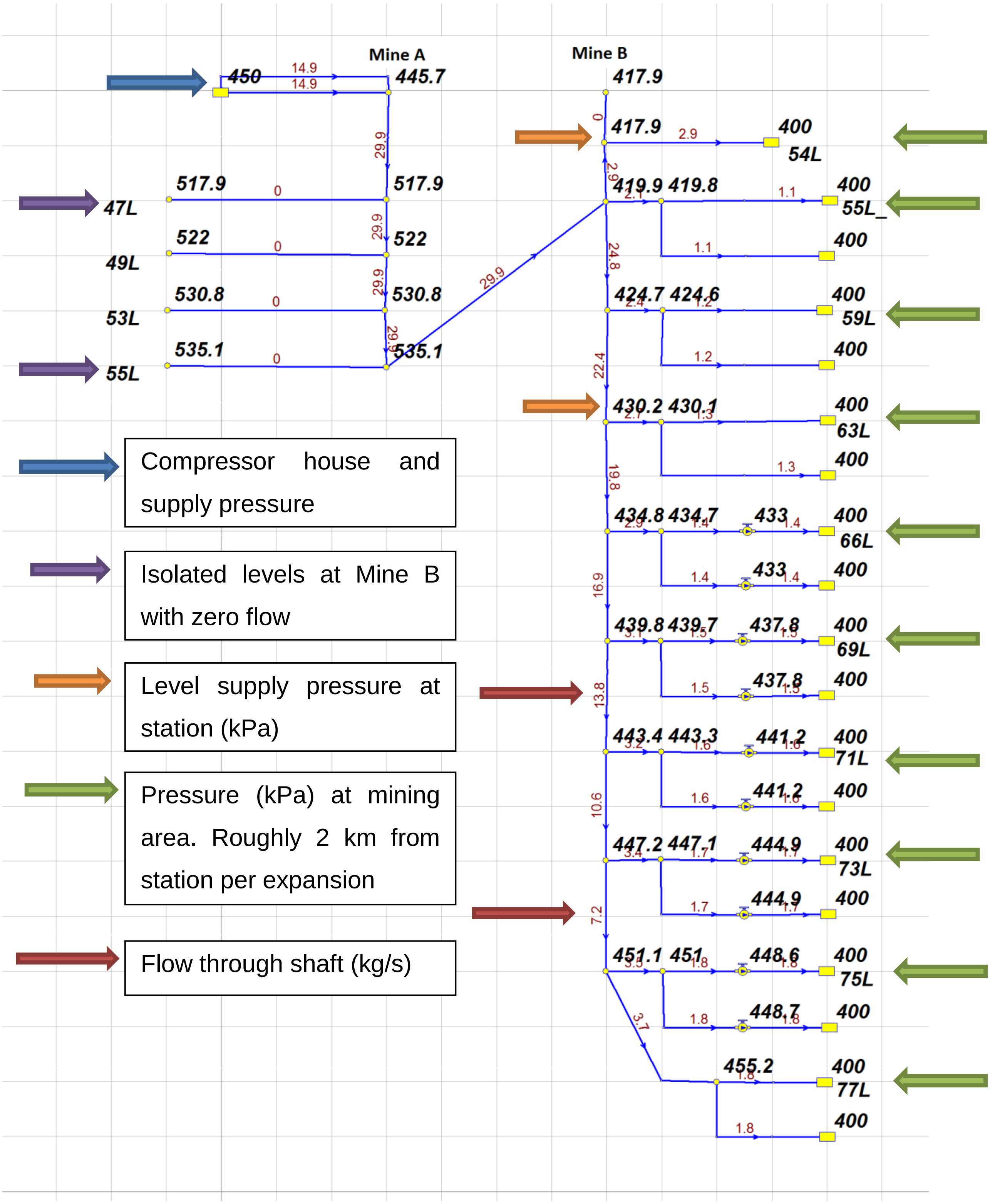


Figure 16: 450kPa pressure discharge simulation

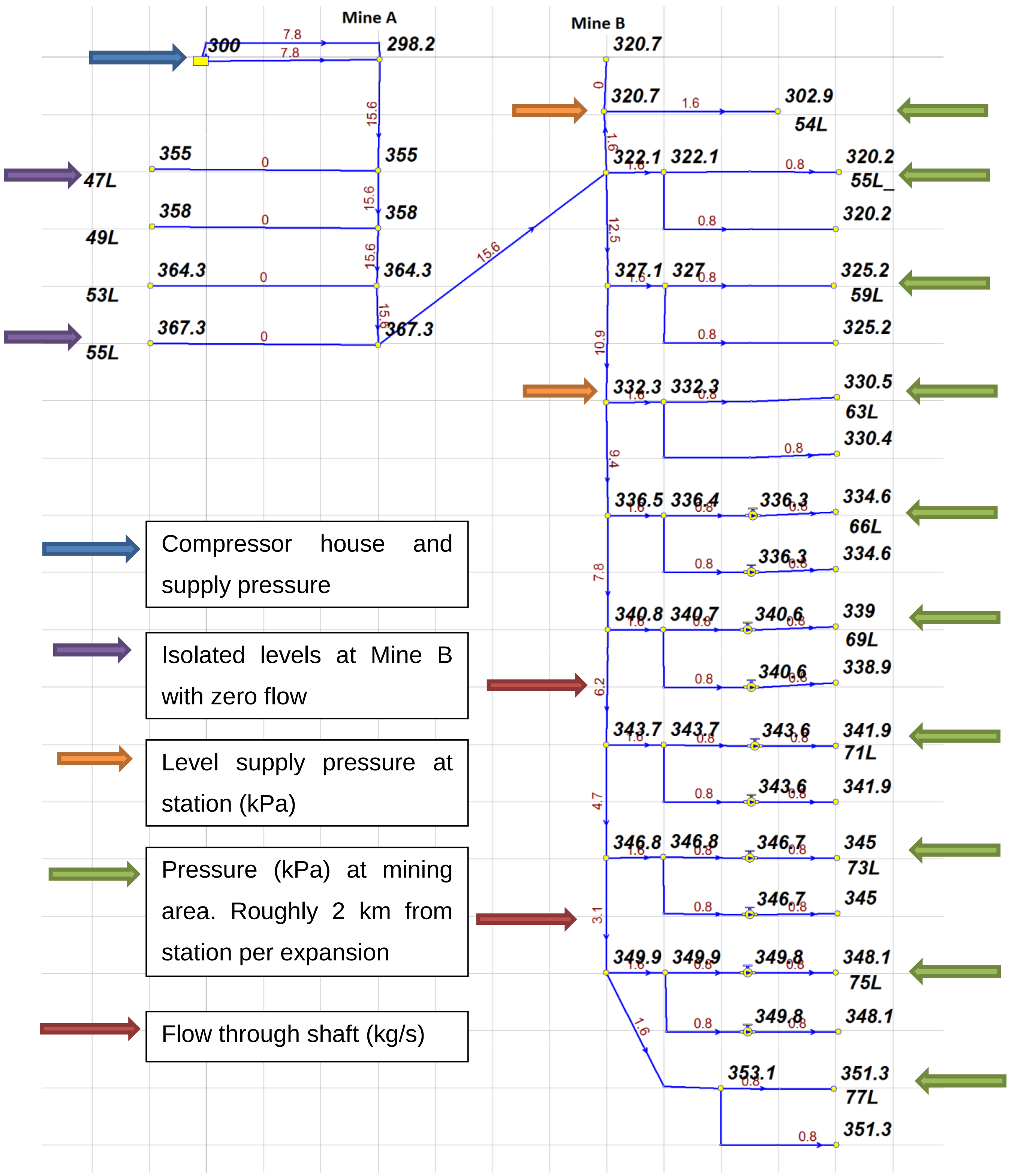


Figure 17: 300kPa discharge pressure simulation

The pressure has sufficient distribution to all levels as seen in Figure 16 above. Pressures at the mining areas are in acceptable ranges for mining equipment function.

Flow is simulated with current flow reading and a 20% safety factor for mine expansion. Simulation is set up with pipe diameters, distances and compressor outputs according to the initial control philosophy. The 300kPa supply from the compressors will not deliver sufficient flow and pressure to the mining areas. The simulation with the calculated savings confirms that the project is viable and that installation of equipment may commence.

3.5 Calculated saving

The potential savings had to be calculated to determine the impact from the pressure set points available. Savings are calculated from the initial baseline pressure and power data. The lowering of pressure has in turn a theoretical reduction in compressor power use that will be used. This calculation will indicate the potential savings and will be compared with the actual savings after project implementation.

The calculated savings will not take into account the minimum running capability of the compressors but only the kW required for the delivery pressure. Potential savings are calculated for each hour as shown in Table 4 below. The average for peak clipping (grey cells) and energy efficiency is also identified. Calculations are completed by correlating kW running status with pressure supply. The lower pressure profile has a theoretical lower running power which is used for average savings calculations.

Table 4: Calculated savings

Time	Pressure (kPa)	Saving (kW)	Time	Pressure (kPa)	Saving (kW)
00:00	400	1578	14:00	200	2414
01:00	400	1582	15:00	400	895
02:00	400	1580	16:00	400	876
03:00	400	1572	17:00	400	782
04:00	350	2003	18:00	400	763
05:00	350	2021	19:00	400	763
06:00	350	2026	20:00	300	1562
07:00	400	1622	21:00	300	1523
08:00	450	1225	22:00	400	1081
09:00	450	1170	23:00	400	1484
10:00	450	1077			
11:00	450	981		Energy efficiency	1528
12:00	450	1188		Peak clip	763

3.6 Preliminary design

A preliminary site audit was conducted to determine the state and availability of the installed infrastructure and equipment. This had to be done in order to compile a project control philosophy and infrastructure requirements. The audit revealed that the present compressor control infrastructure at Mine A was out-dated and inadequate. The compressors, and especially the compressed air supplied from the compressors, needed to be monitored continuously in order to ensure the ample supply of compressed air. Proposed infrastructure includes monitoring, control and safety equipment. To ensure that equipment would be sufficient a flow analysis and simulation were conducted.

The flow analysis and simulation were completed in order to determine the feasibility of both the choice of proposed hardware as well as the proposed control philosophy. From the simulation results it was determined that the compressed air system will be fully functional if only two 3.9 MW compressors were used. Compressors 1 and 2 are in a working condition with project implementation, and since these compressors will be able to supply sufficient compressed air, and new control equipment will only be installed on these two compressors. Due to budgetary constraints other compressors could not be fully upgraded.

The current setup therefore does not provide a supply buffer if the mine undergoes future expansion. All upgrades made, except for the physical upgrades, will thus make provision for future compressor upgrades to be added to the control system. The mine is planning to automate and upgrade compressor 4 at some point in the future.

Compressors 1 and 2 are both Sulzer compressors and were manufactured in 1974 and 1977 respectively. Due to the old age of these compressors major compressor upgrades were required. The new monitoring instrumentation, PLCs and control equipment included all of the necessary upgrades. It was furthermore planned to complete a full compressor and HT breakers service after the installation of the upgraded equipment. The installed equipment will allow the compressor to be controlled according to the underground compressed air demand. Newly installed equipment and sensors will also ensure a higher level of safety when in use.

Control and monitoring equipment are both needed. Equipment will be used to lower the air use within the system, especially during non-production hours. Installation will consist of control valves, pressure transmitters, a temperature transmitter and air flow meters. A control and monitoring PLC will also be installed to enable system control. The valve will have a PID controller to manipulate the downstream pressure to a specific set point. The proposed pipe installation and configuration may be seen in Figure 18 below.

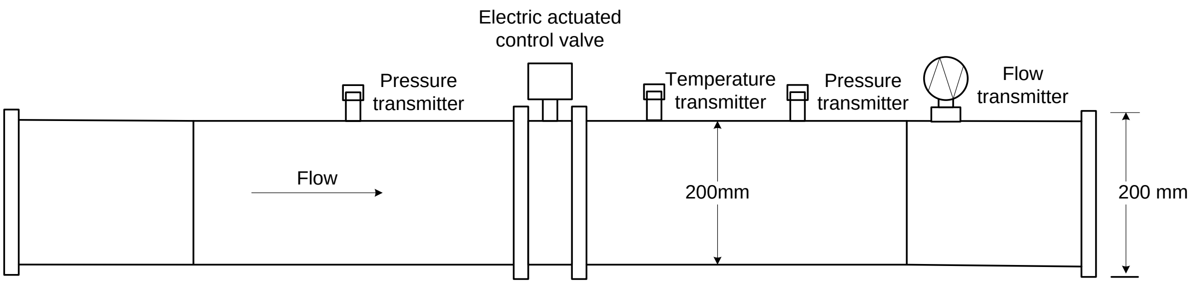


Figure 18: Proposed pipe installation and configuration

Because of budgetary constraints a volumetric flow meter instead of a mass flow meter will be installed. The functionality to convert the volumetric flow to mass flow also required the installation of a temperature- and pressure transmitter.

The initial design included the installation of the control valves at the station to control the entire level with one 300mm butterfly control valve. The investigation revealed that the air demand may be lowered by employing control valves. Southern expansion mining should decline due to higher grade available on the Northern expansion. This lower demand will ensure that stricter control be implemented here. The need is to implement a control on each individual expansion. By implementing a separate 200mm valve on a section, a large pipe section pressure may be lowered when not needed. The mine equipment to be installed can be seen in Figure 19 below.

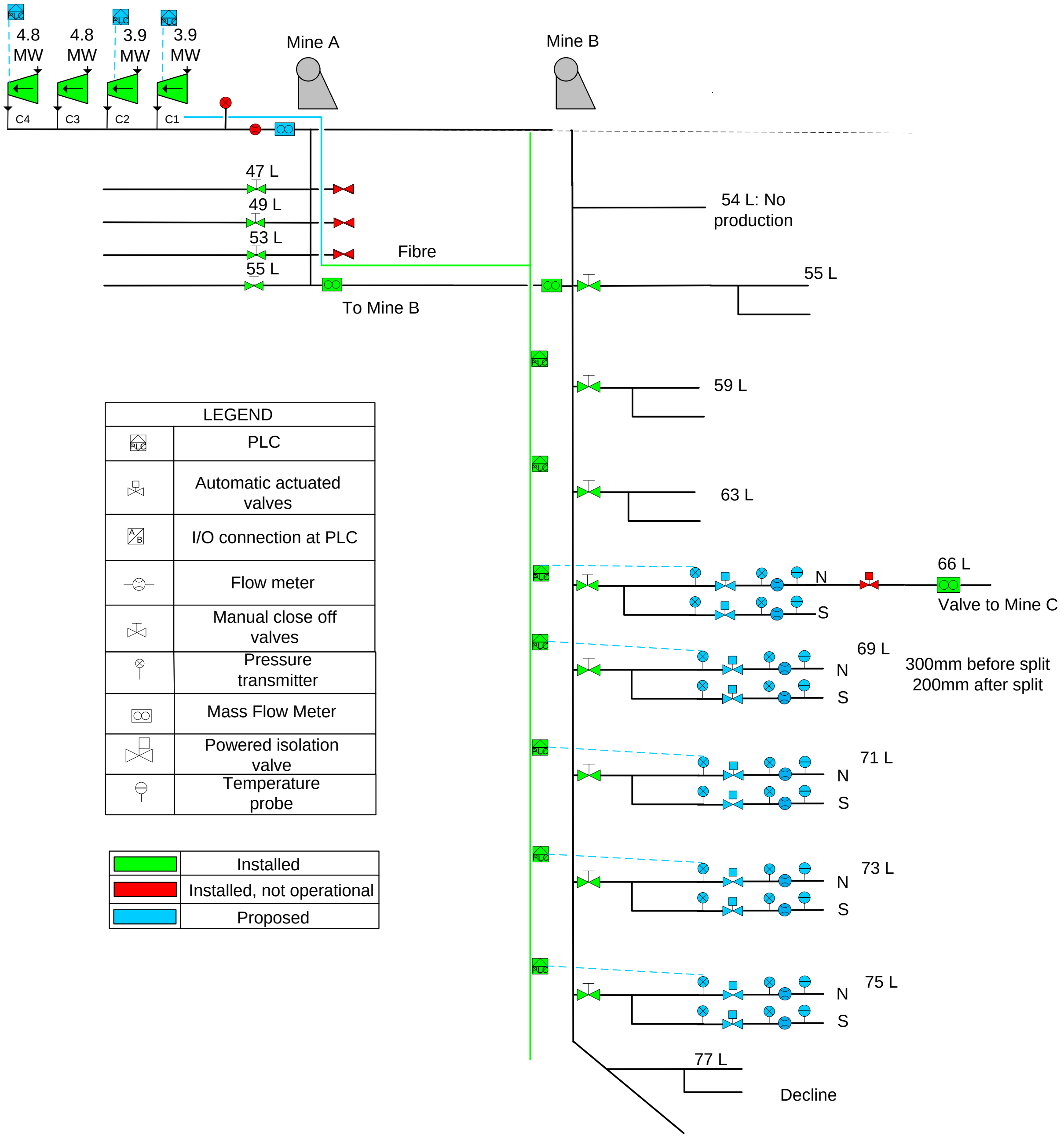


Figure 19: Installation layout

3.7 Summary

The control and implementation of the two smaller compressors should be a viable option in supplying the system. It will be beneficial to use valves for demand side control. The simulation revealed that sufficient distribution of compressed air could be obtained with the compressor sequences. Energy efficiency calculations showed that a saving of 1.528 MW could be obtained and a peak clip of 0.763 MW could be viable. Compressor sequence changes and switch off during peak Eskom periods lead to increased savings. The targeted savings for energy efficiency was 1.5 MW and with compressor switch of a 2.4 MW a peak clip was expected. The peak clip target is much higher than simulations, due to optimal compressor running sequences that will need to be investigated. The optimal use of the compressors or switch off may ensure that the 2.4 MW target be reached. In section 4 the implementation of the design and the final control philosophy is discussed.

Simulation has indicated that the planned pressure drop of the compressors will still supply the needed 400 kPa to the levels. The increase of 20% meets mine expansion plans. This scenario is feasible and sustainable during and throughout production increases.

4. IMPLEMENTATION AND RESULTS

4.1 Introduction

The preliminary design and control philosophy is complete and awaits implementation. The implementation and deviations from the initial design will now be discussed. The results obtained are stated with design and test concluded during the implementation process.

4.2 Implementation

The demand side installation was completed with the mine preference of equipment. The use of preferential equipment will allow mine personnel to maintain general equipment and also faulty equipment. Faulty equipment can be fixed if technicians are familiar with it. The mine asked for the following equipment to be installed (See Table 5 below).

Table 5: Equipment specifications

Equipment	**Specified**
Flow meter	Endress+Hauser
Pressure transmitter	Wika or IFM
PLC	Allen Bradley (Control Logix or Compact Logix)
Temperature probes	None specified
Actuator	Auma electric actuators

Installation of this equipment can only take place during off-peak time periods since the compressed air has to be isolated. The air is shut off with an isolation valve. The installation can take up to eight hours if all the work is done underground. The work includes removing of existing pipes and the construction of new sections. Such time is only available on non-working Sundays. This process had to be speeded up by manufacturing the pipe work on surface, and then lowering it to the levels. A two hour installation is possible with surface preparation and it could be done during mine off-peak hours.

The underground installation was scheduled to be completed within 10 working days if each expansion could be installed on one working day. There is an expected lead time of six weeks. The combined lead and installation time could ensure a two-month valve installation time. A fibre optic communication cable was installed on the North/ South expansion. This communication was used as instrumentation cabling proved inadequate over these distances. The distances to the Northern and Southern expansion are indicated in Table 6 below.

Table 6: Distance to split installation

Level	Distance to split (m)
66	93
69	144.6
71	425.1
73	603.6
75	709

The communication is needed to communicate set points to the control PLCs of the valve location points. Additional information available will also be transmitted by the fibre communication network. The PLC installed can on the other hand still control equipment if network communication is interrupted. Control will take place on the last known control parameters before communication loss. This control will not be to full control philosophy specification, but will ensure that a level will not reach pressures exceeding a maximum threshold. Limiting the pressure will ensure that savings will still be achieved even if communication fails.

Installation difficulties

The supply side implementation on the compressors had several setbacks. Delivery time on valves and flow meters increased. The first compressor to be automated could not run before installation as it had technical difficulties. Difficulties arose, including outdated HT breakers, faulty wiring and equipment and also because the incorrect excitation cable was ordered. So installation took longer than six weeks.

Blow-off valves are used to quickly increase the flow of the compressor when it enters a surge state. The surge occurs when guide vanes are limiting flow into the compressed air system. The blow-off valve will open an outlet of the compressor to the surroundings. The lead time for their order was eight to nine week, but it only arrived after 22 weeks. Blow-off valves form part of the safety system and should not be compromised; the installation could not commence without them.

The communication within a project is of utmost importance to ensure the installation and integration of teams. Unfortunately this was not always the case between the contractor- and mine personnel. The contractor time schedule did not always overlap with mine personnel working hours. The mine workers could not work overtime just to accommodate these issues and the contractor stopped work for these specific days. This led to multiple small delays in the process.

The miscommunication resulted in delays on the electrical revamp of the compressor. HT breakers rewiring and signals required by the new PLC system were not taken into account in the design. The new excitation cable was initially not ordered and the position of installation was not documented before the old cable was removed. Commissioning of the compressor was severely delayed when rewiring had to be done several times.

The mechanical measuring instrumentation had to be mounted on the compressor. Fitment of the equipment had to be drilled and tapped on the compressor to be mounted correctly. The mine could only complete this when they had no other higher priorities.

Production increase

There was production increase from 2008 to 2010 of 83% on milled volume. Using the higher grade Northern expansion section led to an 8% improvement in ore grade which in turn contributed to 98% increased gold produced from 2008 to 2010. This increase is directly linked to the build-up strategy and expansion of Mine B [22].

There was an increase of 14% milled ore with a 13% ore grade improvement leading to a 29% overall increase gold yield in the 2011 financial year. The build-up strategy ensured a higher grade mined in 2012 with a proved grade of 6.24 g/t to the previous 4.55g/t. This is an increase of 37% year on year with an expectation of a further ore grade increase. The increase in gold production can be seen in Figure 20 [21] [51].

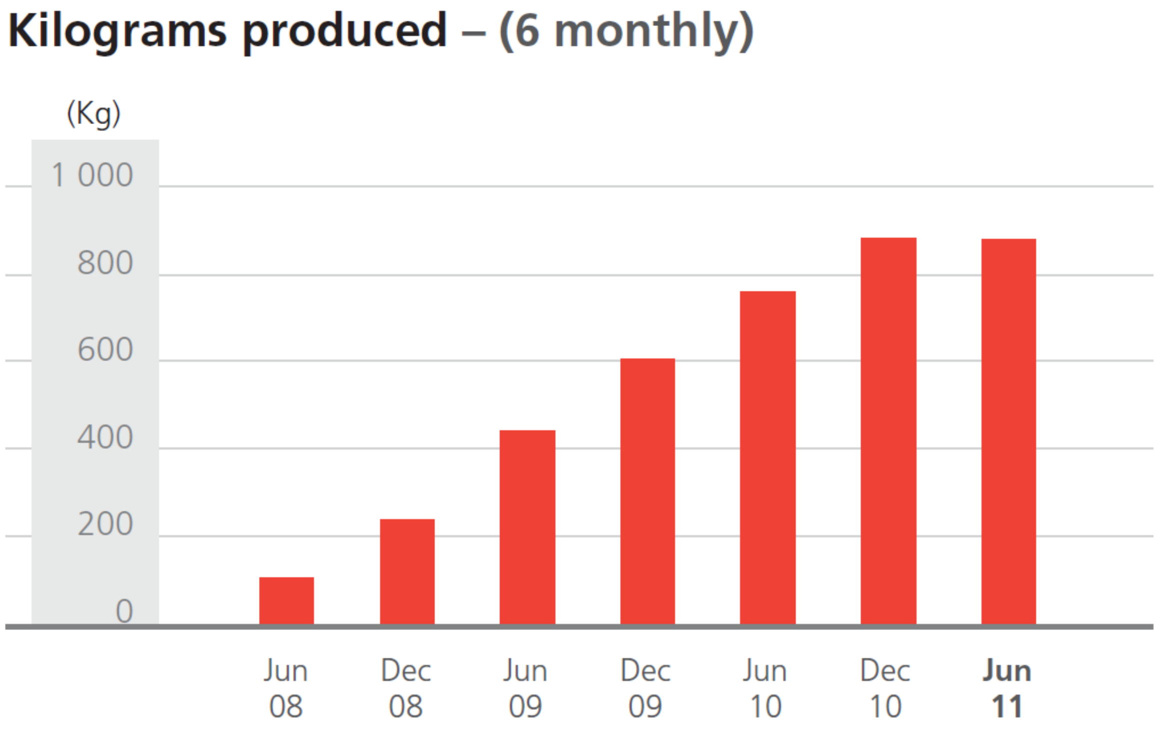


Figure 20: Gold production June 2008 - June 2011 **[21]**

Control philosophy

The original control philosophy used was of a Real-Time Energy Management System (REMS). The system is designed to control the underground level pressure and incorporates the capturing of key information. This information includes the pressure on the levels, air flow and a pressure set point for each level. The flow graph of the levels was included in the design. Daily flow statistics were also included to ensure an easy daily comparison. The layout of the REMS platform can be seen in Figure 21 and Figure 22 below.

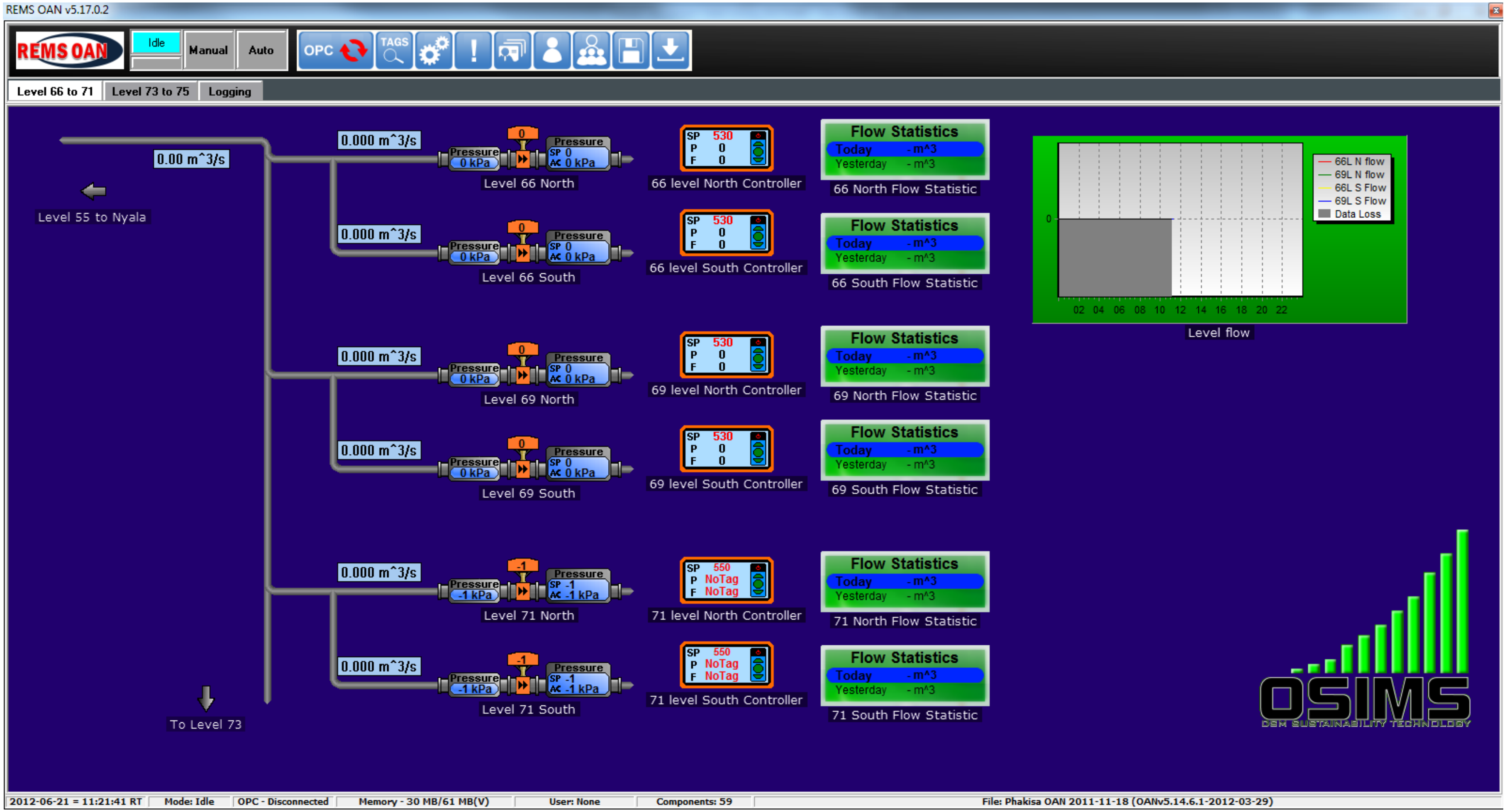


Figure 21: Initial REMS design for levels 66 to 71

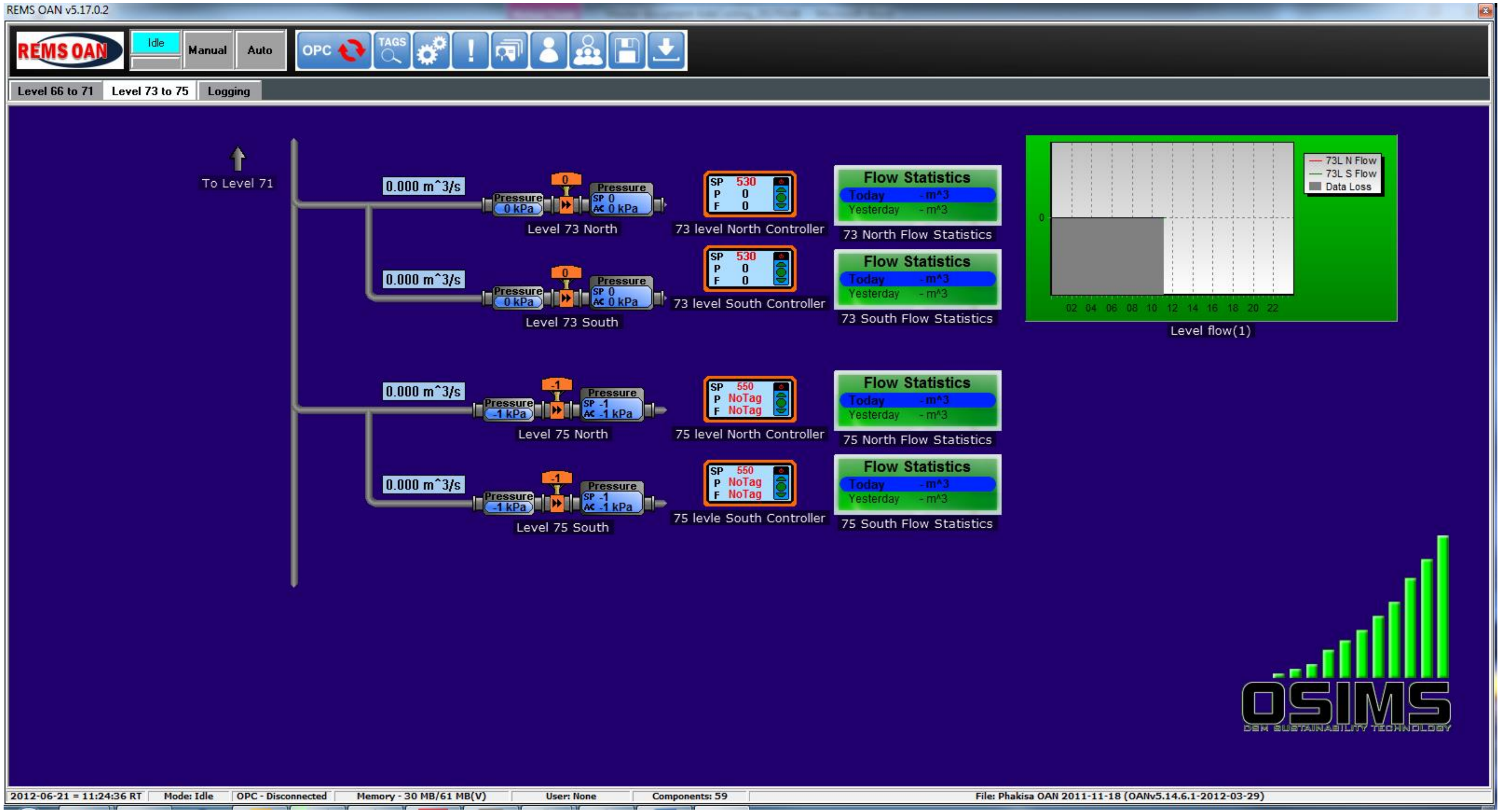


Figure 22: Initial REMS design for levels 73 and 75

The initial design had critical items for underground level control. This control is crucial to achieve the power savings within the compressed air system. The valves on the other hand had multiple control modes which may inhibit the control, and in turn, the savings. The valve could be set in a manual mode which would not control the valve according to the control schedule. The physical valve could also be set to manual mode and not remote control which has the same effect. There were valves that also got stuck in fully open position and so could not be controlled. These states of control information were not included in the initial design of the REMS platform. There was a need to increase the information available for the technicians in charge of maintenance. As stated by Sir William Thomson: "If you cannot measure it, you cannot improve it." The final REMS platform with the additional information can be seen in Figure 23 and Figure 24 below [41].

The system modification included additional information and alarms if the valves' control state was altered. The output position from the PLC to the valve was included with valve position feedback. The output may be used to verify that the control from the PLC is correct. The manual and automatic PID state is shown. This control will be disabled if in the manual mode and thus an alarm is triggered and an additional email is sent to the maintenance team [4].

The physical valve has a remote selection toggle switch which can be vandalised and resulting in loss of control. A remote selection alarm has been included together with an email to the maintenance team. The alarm can only be switched off at the remote section. This problem occurred multiple times and the toggle switch was removed to ensure the selection stays on automatic control. Similarly the valves getting stuck in fully open position lead to an alarm. The maintenance team can solve the problem cycling the valve by hand.

Figure 23: Final REMS design levels 66 to 71

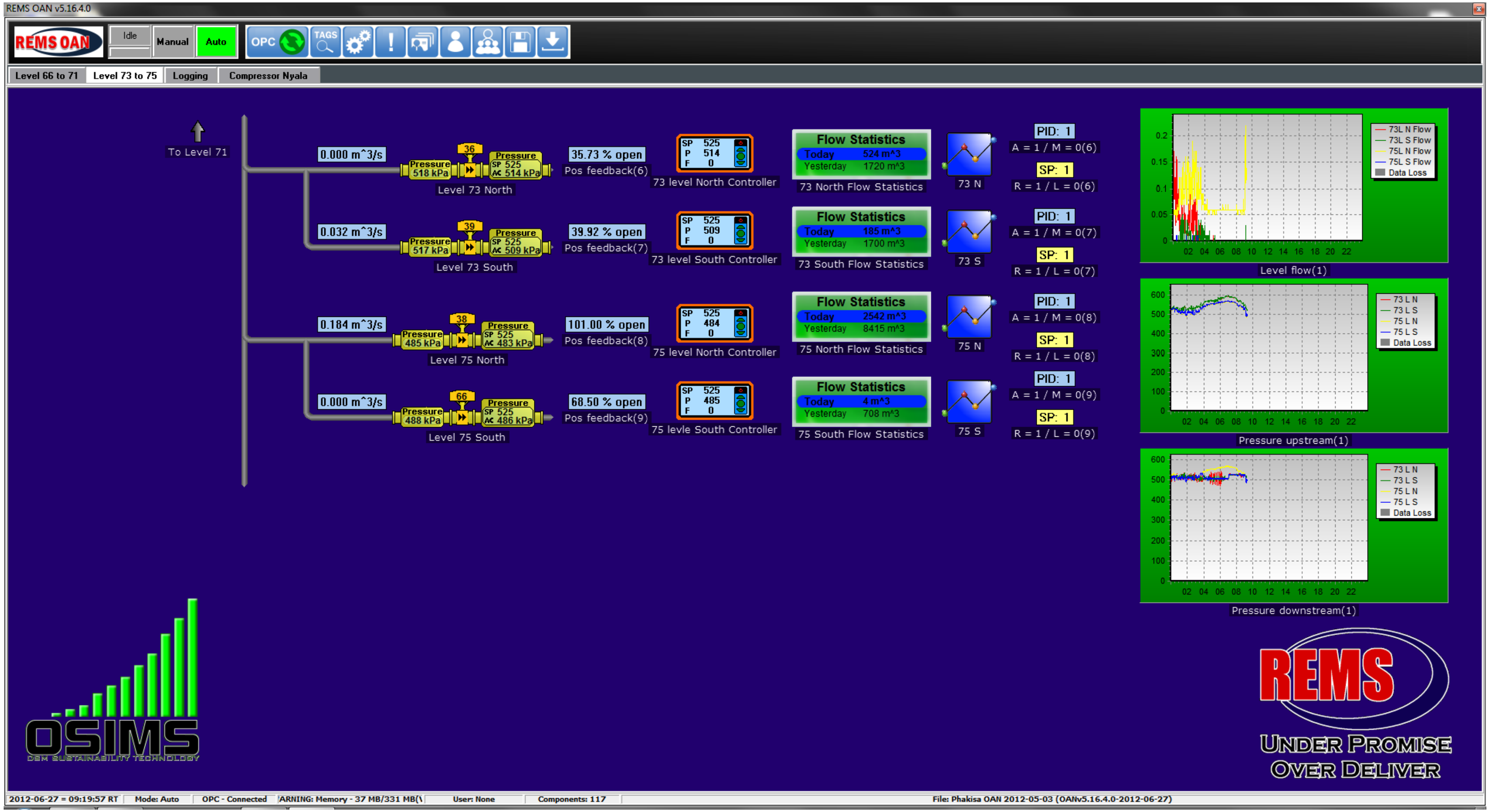


Figure 24: Final REMS design level 73 and 75

4.3 Results

Performance assessment

The performance assessment period was scrutinised to ensure the maximum saving could be achieved with the installed equipment. This period had control malfunctions, but personnel solved these problems quickly. The period after the performance assessment will allow that mine personnel had to take control and responsibility for the savings. The mine only rectified faults slowly over this time. Level control on 50% of the ten expansions was lost within two weeks after responsibility was shifted to the mine. The information of the control malfunction was emailed to all appropriate parties immediately. Control was lost on 20% of the expansions by means of remote selection on the valve. PID on 20% of the levels was set to manual and one level had a vandalised pressure transmitter.

Mining personnel changed pressure requirements from the initial investigation from 450 kPa to 540 kPa. The pressure profile derived from testing after equipment installation showed that this 540 kPa requirement can be lowered during the day. Off-peak times within the time schedule have shifted due to the expansion plans on the shaft. There is no longer an off-peak time because of development and longer mining shifts. Tests concluded that lower pressures are sufficient during certain periods of the day. The pressure required is much higher than the initial pressure profile shown in Figure 11. Pressure requirements are altered to fulfil the shafts requirements and the pressure profile from the test is reflected in Figure 25.

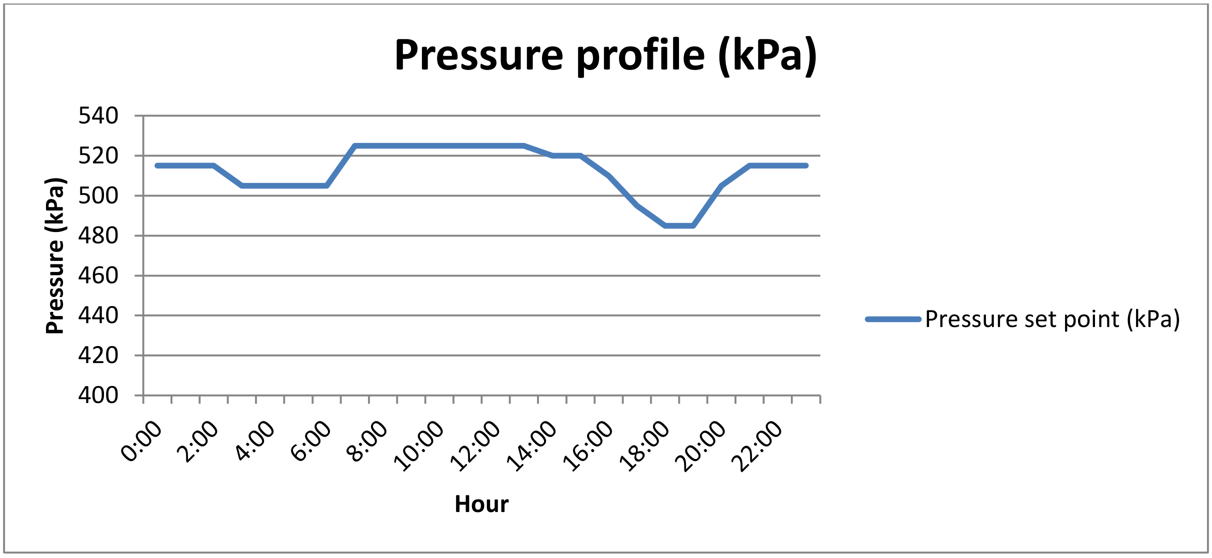


Figure 25: New pressure profile

The performance assessment time frame was March 2012 to May 2012. This time period was used to prove that the system is functional and that maximum savings could be achieved. The load reduction within this time period can be seen in Figure 26. The control has a significant contribution in lowering the profile for the entire day.

The compressor savings achieved during this time is calculated for the daily energy efficiency and peak clip component. Savings increased over the performance assessment months. The control philosophy alterations and mine personnel buy-in to the project contributed to the increase in savings during this period. The energy efficiency has increased by close to 50% from March 2012 to May 2012. The peak clip increase for the same period has increased 63%. The energy savings for the performance assessment may be seen in Figure 27. Peak clip savings are not that easily visible as the compressors were not switched off during performance assessment. The level cut back ensured savings were achieved during this period.

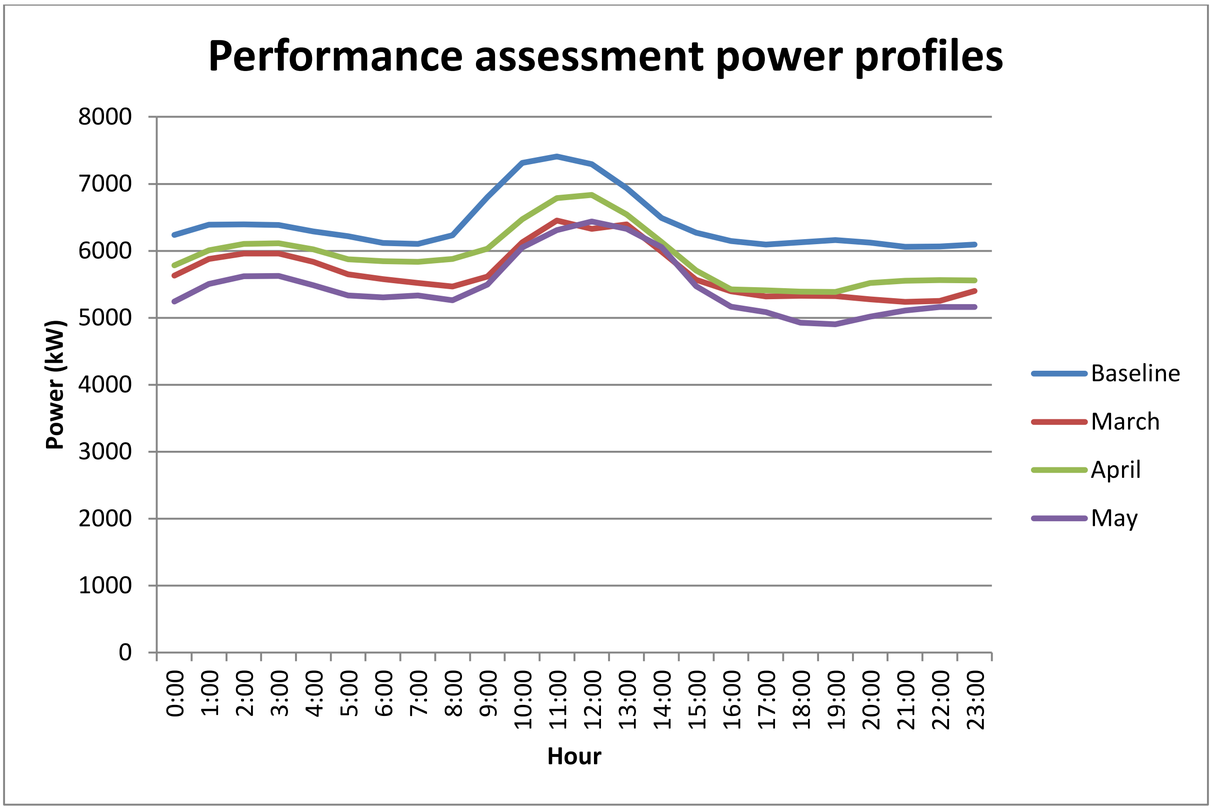


Figure 26: Performance assessment weekday power profiles

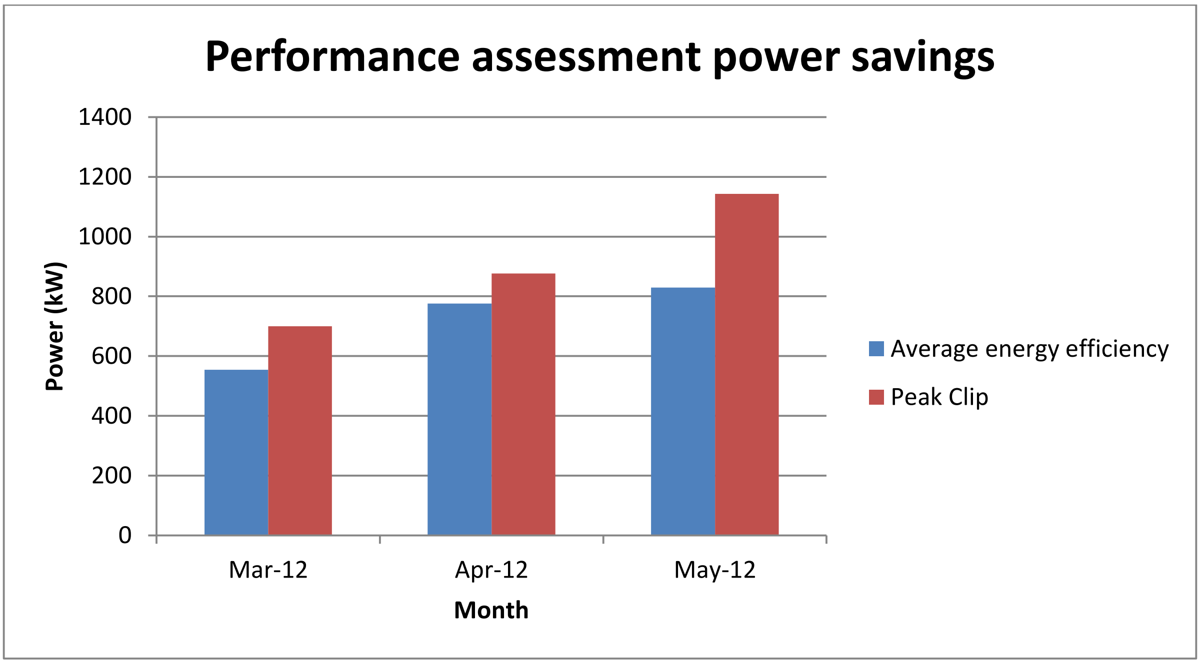


Figure 27: Performance assessment power savings

The initial running combination of compressor 1 and 3 before valve manipulation was possible on the levels. Compressor power use was close to that of the baseline period. This offset indicates that the baseline is still accurate a year after measurements. The power use is indicated in Figure 28. This running sequence was used before project implementation.

The project goal of attempting to run compressor 1 and 2 is realised after the compressor 2 automation completion. The time period before compressor 1 could be automated ensured the testing of this potential running sequence. Power use dropped significantly from the baseline, as predicted. The increased production during compressor commissioning ensured smaller savings than expected. The power use increased slightly with the implementation of level valve control. The power consumption of the pair is shown in Figure 29.

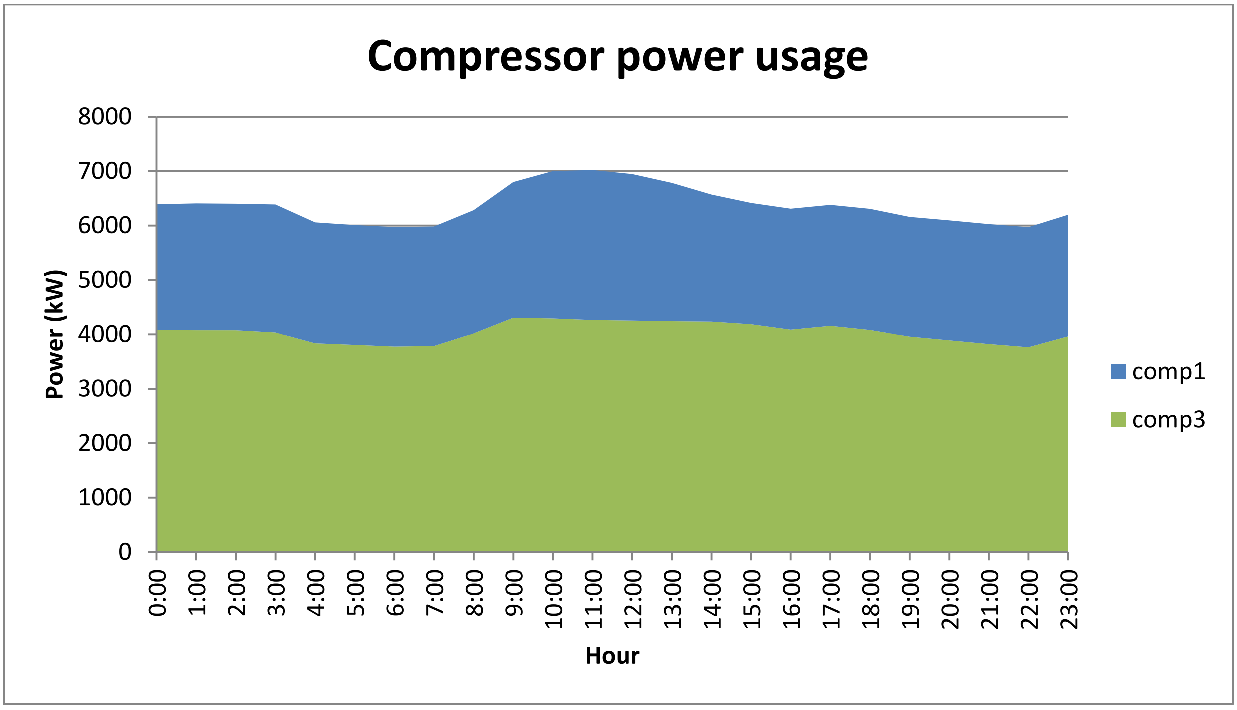


Figure 28: Compressor power usage before valve control

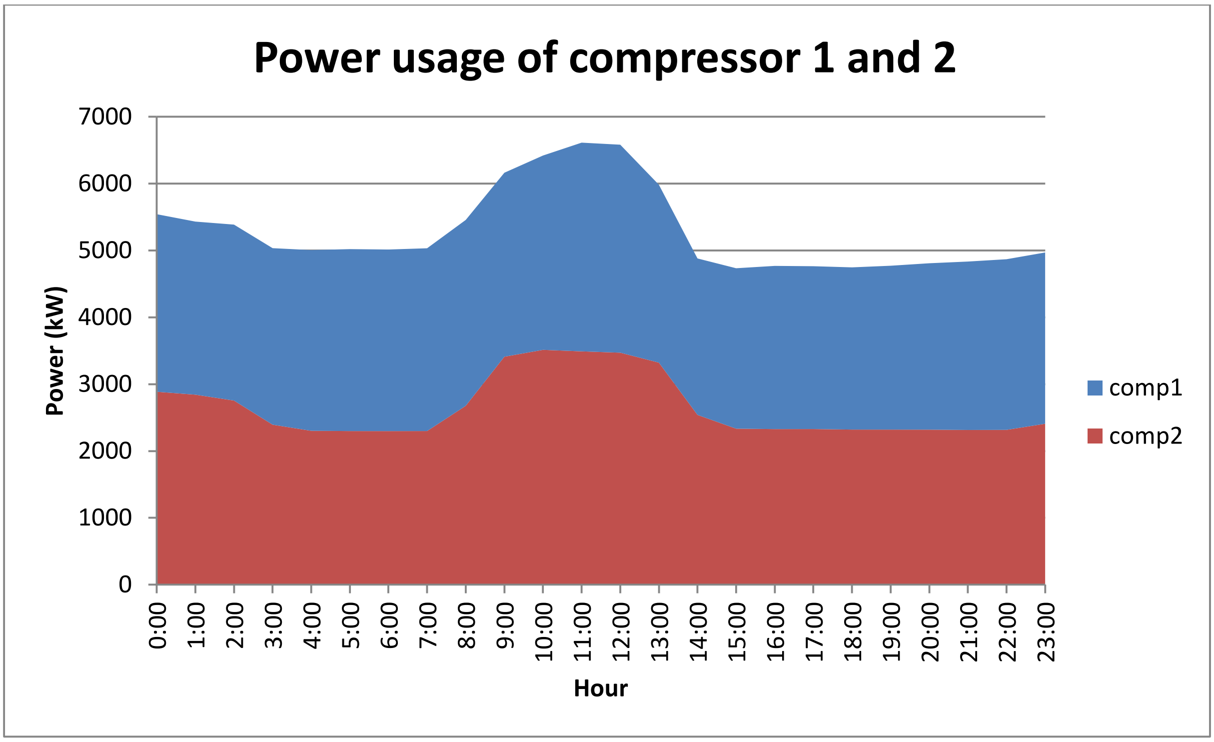


Figure 29: Power use of compressor 1 and 2

The test of having compressors 1 and 2 running as a sequence was proven to be successful. Compressor 1 had to be automated next and compressor 2 and 3 had to be run during this time period. The combination of the two compressors had a higher running capacity, but a strategy had to be devised for optimal savings during this time period. The running power of these compressors can be seen in Figure 30.

The initial step to have separate discharge pressures where set on 540 kPa for compressor 3 and 517 kPa for compressor 2. The pressures were used with trial and error for maximum cutback. The second step to take is to attempt switching off one of the two compressors during peak-time. Tests had to be conducted in an attempt to switch off each to see if the pressure in the shaft could be sustained.

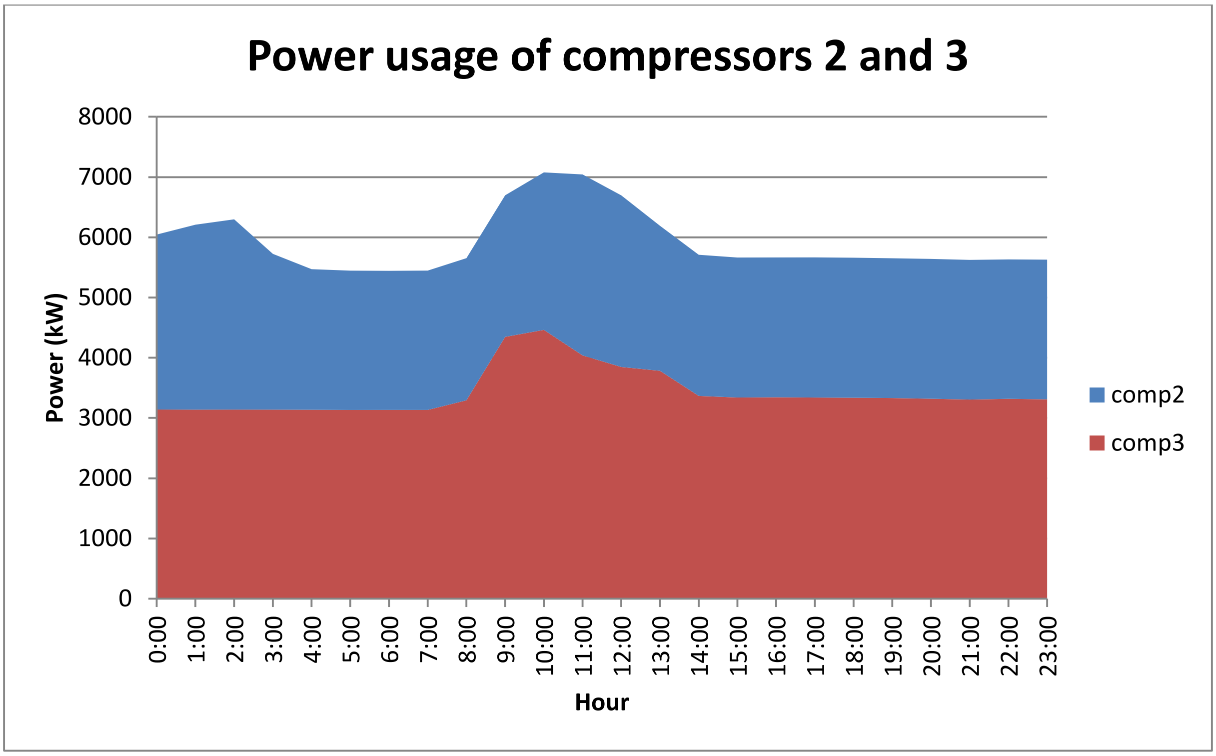


Figure 30: Compressor power use of compressor 2 and 3

Compressor running capacities

The savings of the project can only be maximised by taking into account the minimum running capacity of the compressors. The first performance assessment month showed mine personnel reluctant to change of the compressor discharge pressures. The compressors' average day profile is shown in Figure 31. The compressors discharge will ensure that power use is kept to a minimum and increase savings.

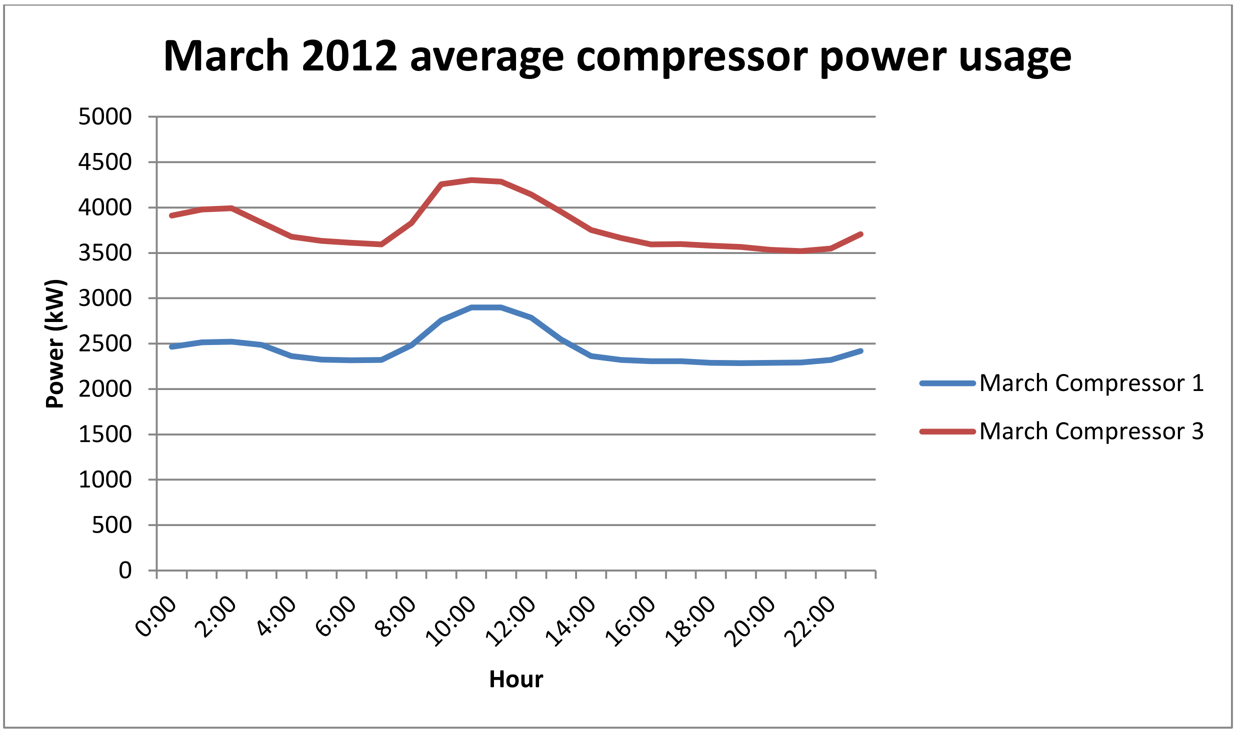


Figure 31: March 2012 average compressor power use average

The compressor discharge within this performance assessment month was set to 600 kPa on compressor 3 and 550 kPa on compressor 1. This difference in compressor discharge is to ensure the compressors' guide vanes cut back out of synchronisation. Pressure discharges were working separately due to no common control between compressors. The minimum running power due to compressor cutback obtained during the day profile is 2286 kW for compressor 1 and 3520 kW for compressor 3. This compressor discharge pressure ensured much higher pressures than were required underground. Auto-compression in the system also increased the pressure underground to over 670 kPa. The discharge pressure was thus lowered on both compressors for April 2012. The compressors' average daily profile can be seen in Figure 32.

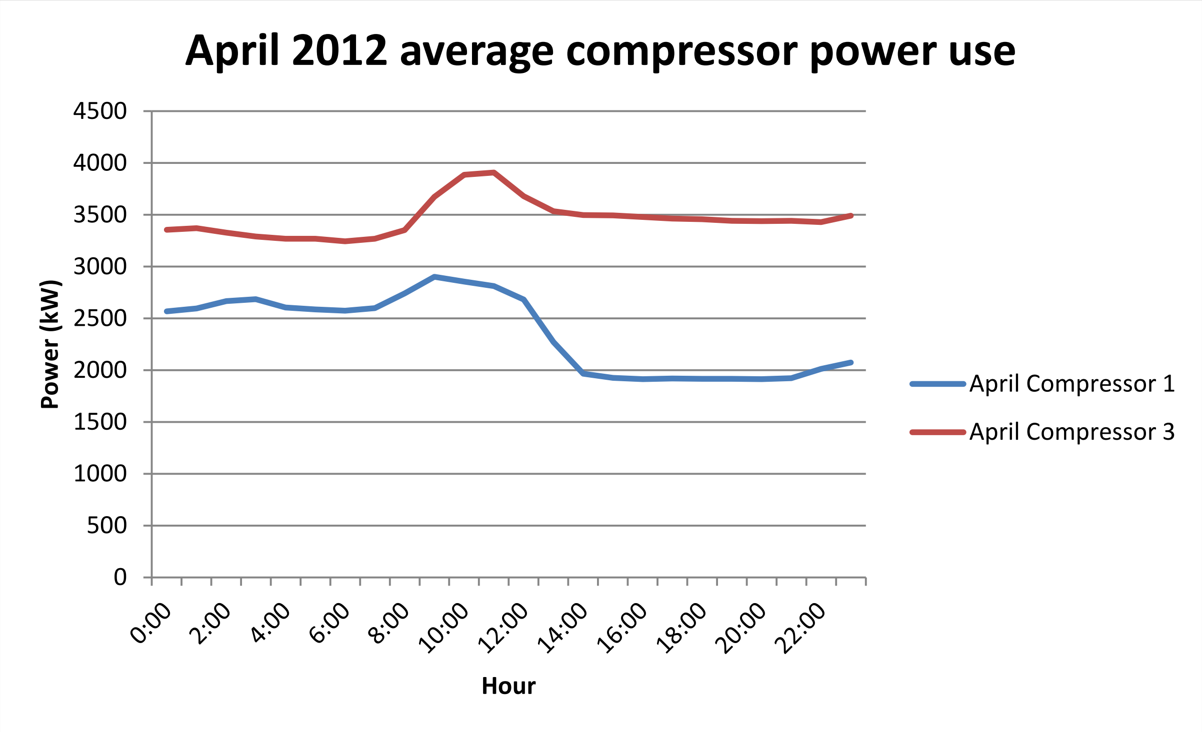


Figure 32: April 2012 compressor average power use average

The discharge pressure decreased from 600 kPa to 550 kPa for compressor 3 had a significant effect on power consumption. The discharge on compressor 1 was decreased to 530 kPa from the initial 550 kPa. This change in discharge pressure ensured that the minimum running capacity of compressor 1 could be reduced to 1913 kW and compressor 3 to 3243 kW. The discharge pressure ensured a cutback on power consumption of 427 kW within this time period.

Compressor 3 peak clip verification

The peak clip component may be maximised by switching off a compressor. A compressor drop test had to be conducted to see whether compressor 3 would be able to sustain the pressure within the system during peak time. The test will be conducted for the time period 18:00 to 20:00. The level pressure was initially lowered to 400 kPa before the switch off of compressor 2. Pressure on the levels was lowered to increase the column pressure until the compressor guide vanes could fully open. The guide vanes will open to sustain pressure when compressor 2 is switched off. The pressure on the levels will be gradually increased to ascertain which pressure could be supported with a high column pressure. The results are shown in Figure 33 and Figure 34 below.

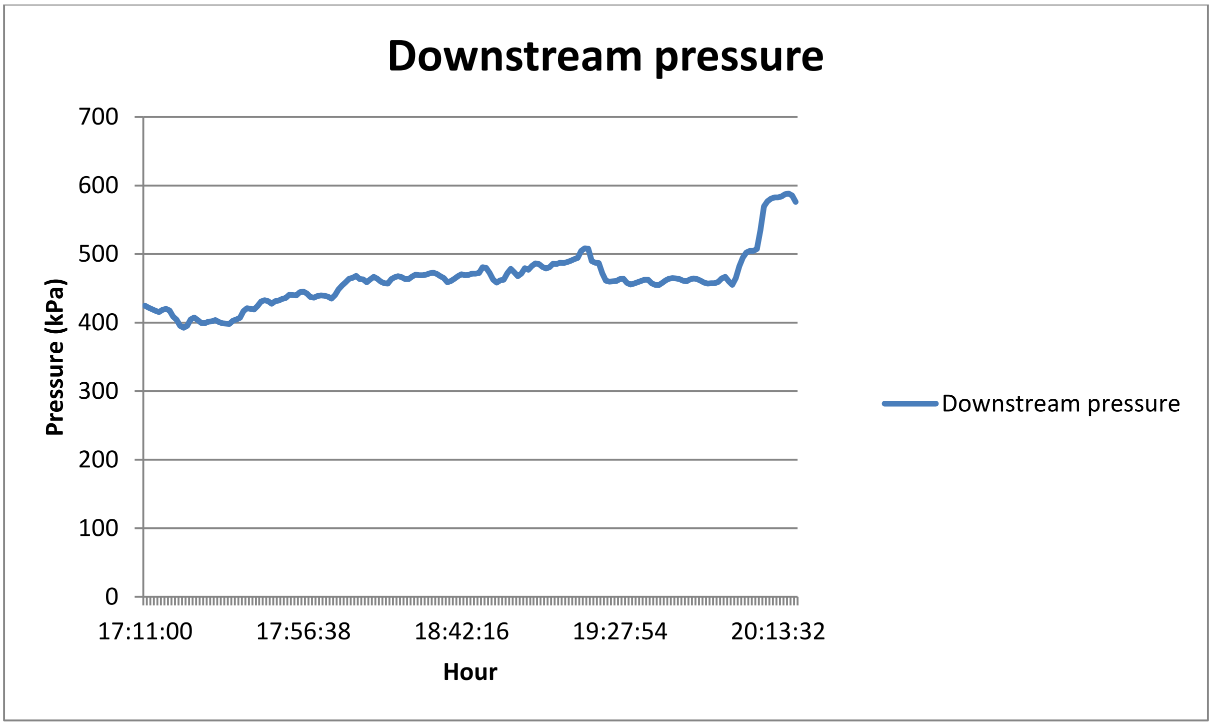


Figure 33: Downstream pressure compressor 3 peak time

The compressor had the capacity to supply an average of 495 kPa to the levels while sustaining a column pressure of 554 kPa. This test indicates that the compressor will sustain the pressure during peak time. The compressors' guide vanes fully opened and used 4382 kW during this time period. The result of the peak clip obtained was a savings of 1782 kW on the baseline.

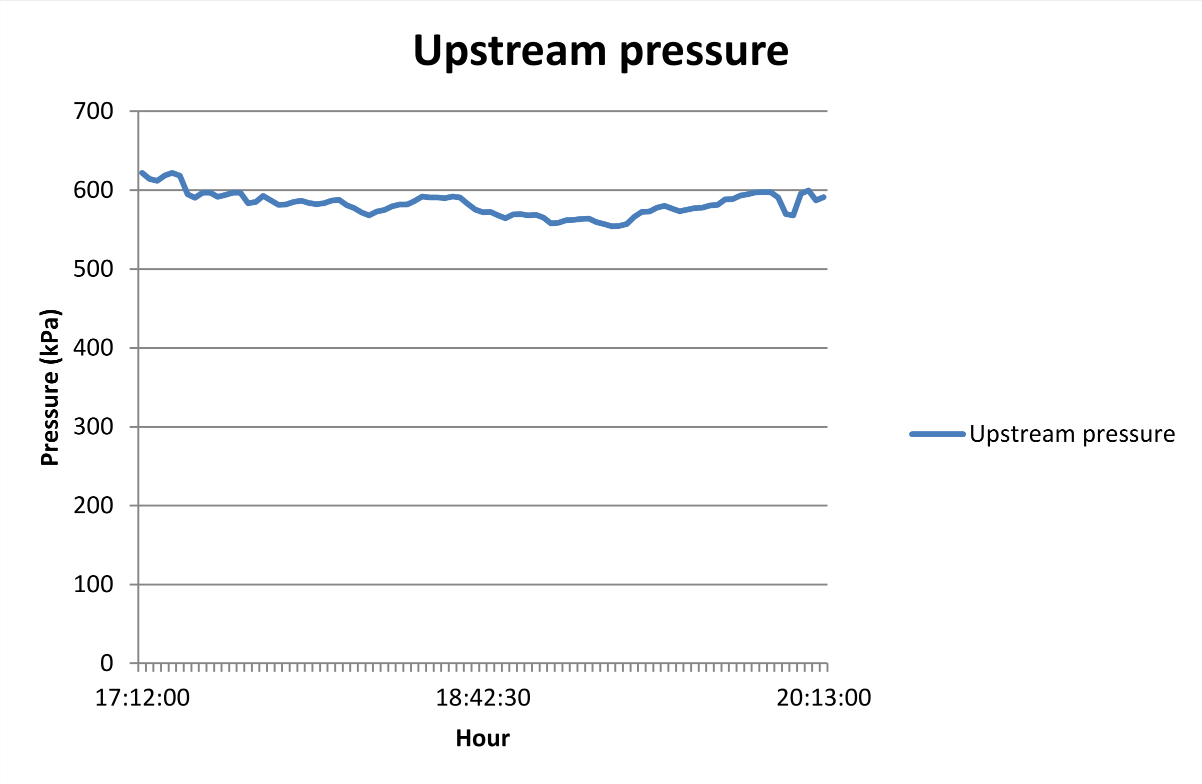


Figure 34: Upstream pressure compressor 3 peak time

Compressor 2 peak clip verification

The test is conducted to ensure that compressor 2 would supply sufficient air to the system in the same manner as the compressor 3 peak clip. The test would clarify the concern whether the smaller supply capacity of the compressor could sustain the system pressure. The time frame is altered for safety reasons and would have to be aborted if the compressor could not sustain sufficient shaft pressure. The starting time for the test was before 17:00 to ensure enough time to start compressor 3 if the pressure could not be sustained.

The downstream pressure on the levels is controlled to 400 kPa before the compressor switch off. Pressure on the levels stayed constant until the shaft pressure dropped to below 450 kPa. The pressure to be sustained would have to be at least 470 kPa to ensure the loading boxes on the column is functional. The test had to be aborted and a compressor 3 started. Trend of the pressure is seen in Figure 35 and Figure 36.

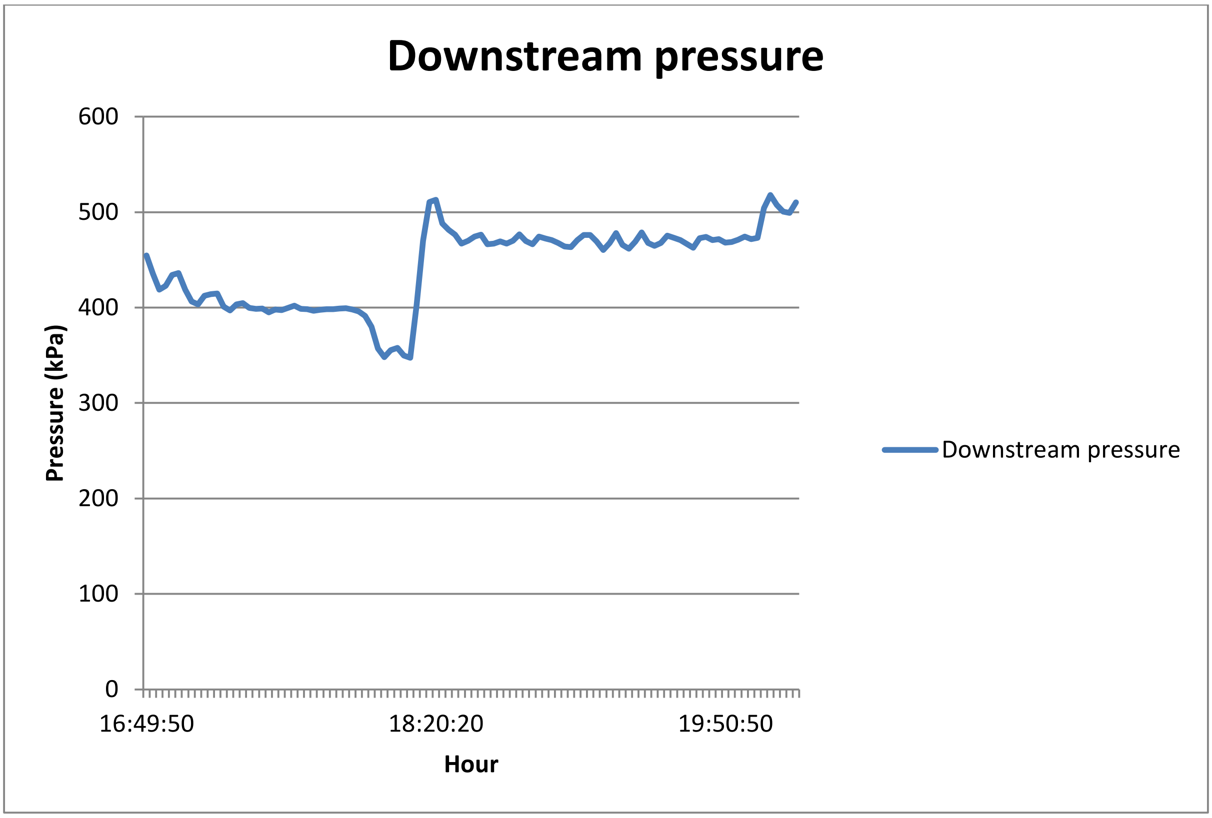


Figure 35: Downstream pressure compressor 2 peak time

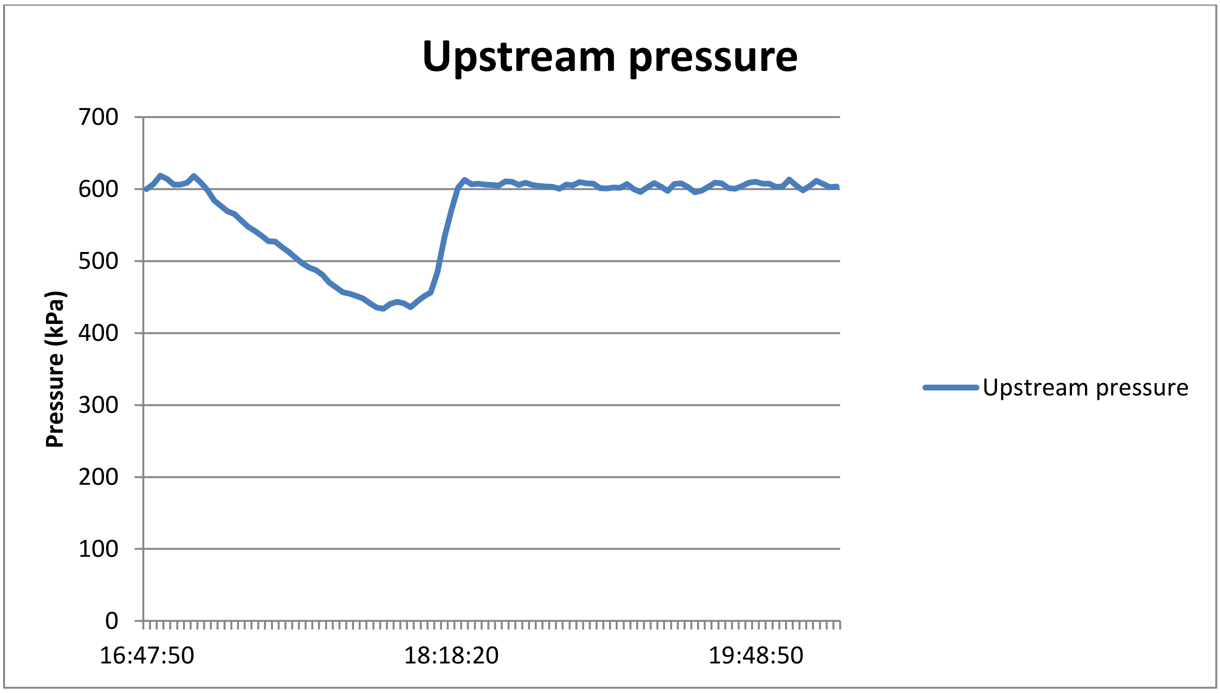


Figure 36: Upstream pressure compressor 2 peak time

The second test indicated that compressor 2 could not sustain the pressure requirements for peak time. The only viable option was to run compressor 3 at this time. The next step was to investigate the running sequences for optimal energy savings.

Compressor control optimisation

The initial running sequence used of compressor 1 and 3 limited maximum possible savings and compressor cutback. Initial investigation of the project was planned to run compressor 1 and 2 to ensure a maximum saving. The savings would increase as compressors 1 and 2 had a lower minimum running capacity. The compressor 2 implementation ensured the combination became available. Compressor sequences being run could now be compared. The comparison can be seen in Figure 37.

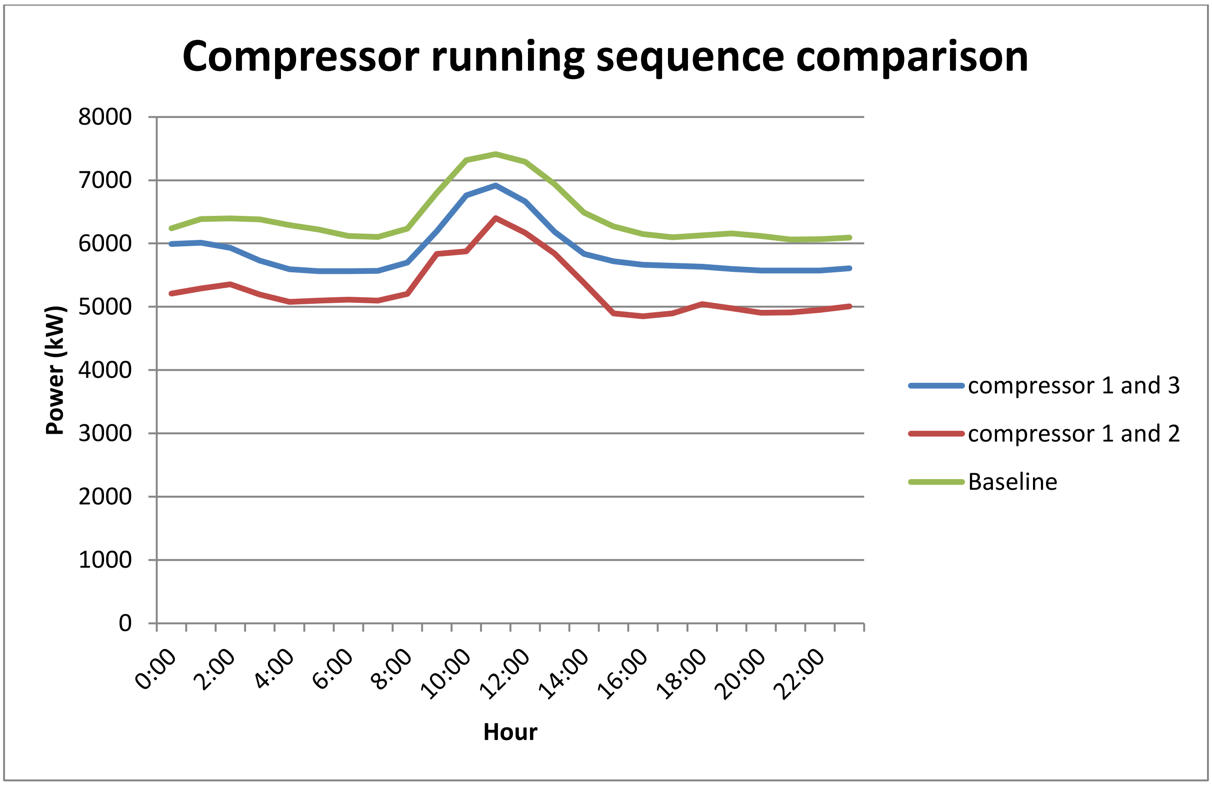


Figure 37: Compressor running sequence comparison

The average daily peak clip difference between the sequences caused an additional saving of 607 kW with the energy efficiency of 592 kW. Pressure supplied underground would still be sufficient while using compressors 1 and 2 combination. The next step was to investigate the financial implications for these running sequences.

4.4 System optimisation

Peak clip and energy efficiency comparison

The compressor running sequences can be compared to ensure a larger financial benefit for the mine. These available sequences can be seen in Table 7. The sequence power consumption will determine what strategy and control will be followed.

Table 7: Compressor running sequence

Compressor sequence	Compressors used
1	Compressor 1 and 2
2	Compressor 1 and 3
3	Compressor 2 and 3

The first sequence has the lower running capacity and makes use of the two smaller compressors. These compressors will not be able to be switched off as the pressure in the shaft cannot be sustained. This test is conducted with Compressor 2 peak clip verification. The compressors will have to run throughout the day and focus on the entire day energy efficiency without a maximum peak clip component.

The second and third sequence will function the same seeing that compressor 1 and 2 is similar. Running capacities of the compressors are in the same range and will be seen as one solution. The running capacity of these sequences is higher than the first solution. A compressor will have to be switched off during peak times to ensure the maximum saving. The use of compressor 3 for peak time can sustain the pressure within the shaft as shown in Compressor 3 peak clip verification. These sequences will focus on a higher peak clip with a smaller focus on energy efficiency.

The different sequences have an average saving for the peak clip and energy efficiency components during the day. These average savings can be seen in Table 8. The financial impact of this is stated in Figure 38.

Table 8: Energy savings comparison for compressor sequences

Compressor sequence	Compressors used	Peak clip (kW)	Energy efficiency (kW)
1	1 and 2	1502	1153
2	1 and 3	1785	758
3	2 and 3	1785	758

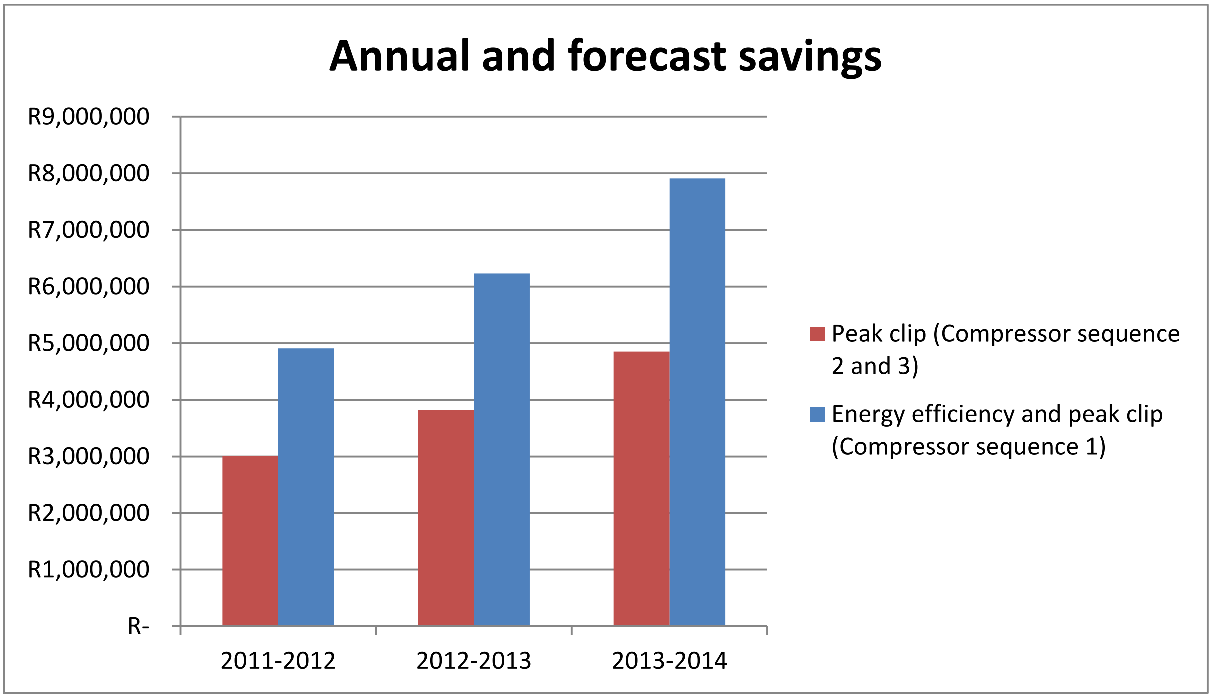


Figure 38: Annual and forecast savings

The cost comparison has an R 1 900 000 higher impact by focussing on energy efficiency and peak clip than just the peak clip component. Two smaller compressors were deemed viable with the 2011/2012 electricity costs. The forecast shown has an estimated electricity increase of 25% per year and the savings' potential of each solution. The two control strategies has a dramatic savings difference with the additional benefit of being the more practical option. The compressors do not have to be started after the peak time and do not need an electrician for the starting process. A suggestion was made to the mine to rather run compressors 1 and 2 for a larger financial benefit from the DSM project.

Weekly drop test

The air leaks had a dramatic effect on compressed air within a compressed air ring. Air leaks within the system are acknowledged by management, but not rectified. Open ended pipes are used for cooling is not sealed after the working day. This cooling is used, as the cooling on the shaft is of substandard. Fridge plants installation to decrease the temperature within the shaft is a separate project. This project will only be completed after the compressed air project performance assessment is concluded. Once the fridge plant is fully functional the compressed air use should be lowered for cooling purposes.

The levels with the highest leakage had to be confirmed to inspect and hopefully fix the leaks. Leakages were tested by performing a drop test on each of the expansions. The pressure measured on a level was noted before the test. The valve was closed for five minutes and the pressure reading documented. The ideal results were to have a high pressure that indicates minimal leakage after the expansion valve. The test was conducted on a Sunday afternoon with no mining activity on the shaft.

The air leakage within the system had to be tested to have some measure of the system to minimise the losses. Tests should be conducted initially and attempts to repair them may be quantified with a test periodically. The test results can be seen in Table 9 and Table 10. The test will have the following steps:

- Supply constant pressure to levels and document pressure and valve position
- Close valve
- Document pressure after 5 minutes
- Open valve and set to automatic control

The results obtained should easily show the levels affected the worst by air leaks. Desired results after 5 minutes will be to have a high pressure which will show a good pressure vessel in an off-peak time. Communication loss has ensured that some readings could not be taken and test has not been conducted on the applicable levels.

Table 9: Drop test 1

	Pressure (kPa)	**Valve position (% open)**	**Pressure after 5 minutes (kPa)**
66 N	503	13.4	29
66 S	499	10	375
69 N	497	1.9	454
69 S	504	13.3	289
71 N	Communication loss	HMI restart required	
71 S	Communication loss	HMI restart required	
73 N	Valve on local control	Switch on valve	
73 S	503	15	248
75 N	503	12.8	249
75 S	498	14.4	255

Table 10: Drop test 2

	Pressure (kPa)	Valve position (% open)	Pressure after 5 minutes (kPa)
66 N	Communication loss	HMI restart required	
66 S	Communication loss	HMI restart required	
69 N	504	3.4	404
69 S	560	16	254
71 N	486	16.4	263
71 S	469	14.3	118
73 N	490	13.7	286
73 S	523	15.8	189
75 N	Communication loss	HMI restart required	
75 S	Communication loss	HMI restart required	

The information obtained from the drop tests showed the dramatic loss through air leakages on the levels. System equipment downtime has also ensured that some of the measurements could not be taken. The system equipment malfunction was also brought to the attention of mine personnel. The results indicated a severe air leak on level 66 North. The levels could be prioritised and leaks can be inspected and rectified. Additional sustainable savings could be achieved by rectifying the leaks.

4.5 Project sustainability

Responsibility shifts to the mine

Project sustainability is demonstrated when savings continue to be shown after the performance assessment period. The project is then on automatic control with REMS controlling the system with the optimised control philosophy. The responsibility then shifts to mine personnel. From personal experience it is evident that the shaft engineer has the drive to maximise the savings on the shaft. A compressor were switched off as soon as one was not needed when approaching peak time. This ensured a maximum peak clip for that time period. The power trend and baseline can be seen in Figure 39 below.

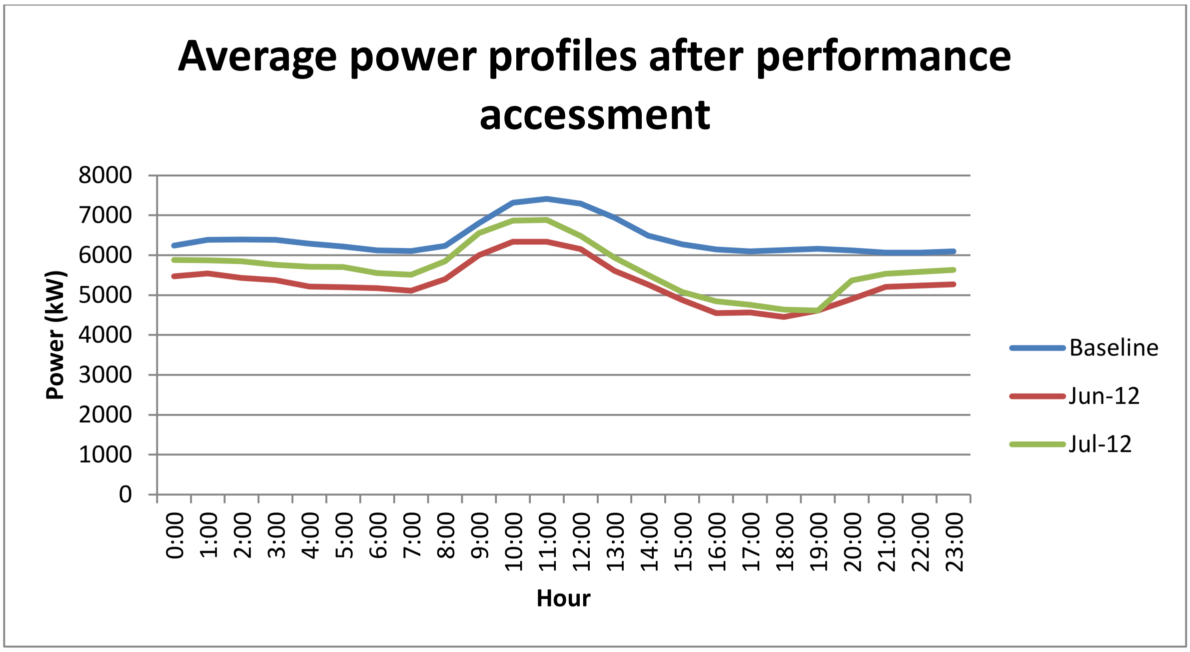


Figure 39: Average power profiles after performance assessment

The monthly savings through performance assessment increased. The increase during this period was due to mine personnel buy-in on the project longer than had been expected. Compressor installation and control took longer than expected and optimal running sequences could not be used. The compressors had an optimal running sequence in June 2012 with the two smaller compressors. Maximum savings are achieved for energy efficiency and peak clip component.

The automation of compressor 1 started in July 2012. The running sequence of the compressors was reverted back to compressor 2 and 3. This sequence required the mine to switch off a compressor during peak time to maximise the savings. The energy efficiency savings are less than previous months with a higher peak clip savings than previous months. The power savings can be seen in Figure 40. SLA during the performance assessment and subsequent months indicates what should have been saved with the production increase taken into account.

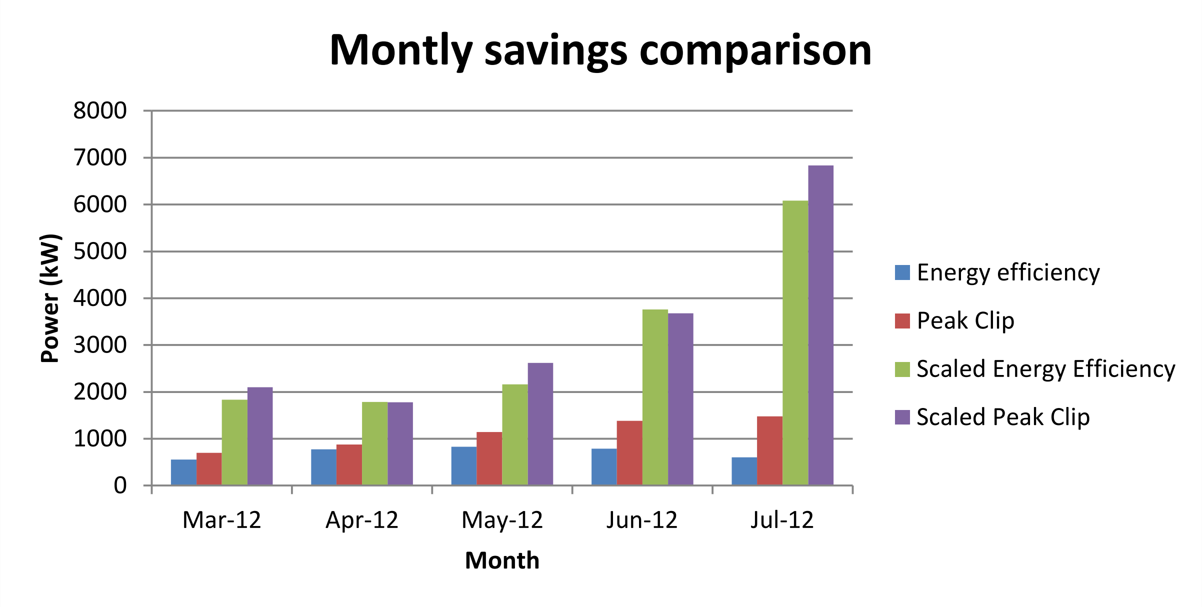


Figure 40: Power savings after performance assessment

Financial impact

The financial impact of the savings if sustained could have a marked daily effect. The monthly average saving is calculated for the daily financial impact and may be seen in Figure 41. The daily savings is calculated for the winter and summer rate on Eskom tariffs. Savings could vary from R4 600 to R13 500 for the power profiles. The power profiles calculated are for performance assessment time period and after mine personnel took responsibility of the system.

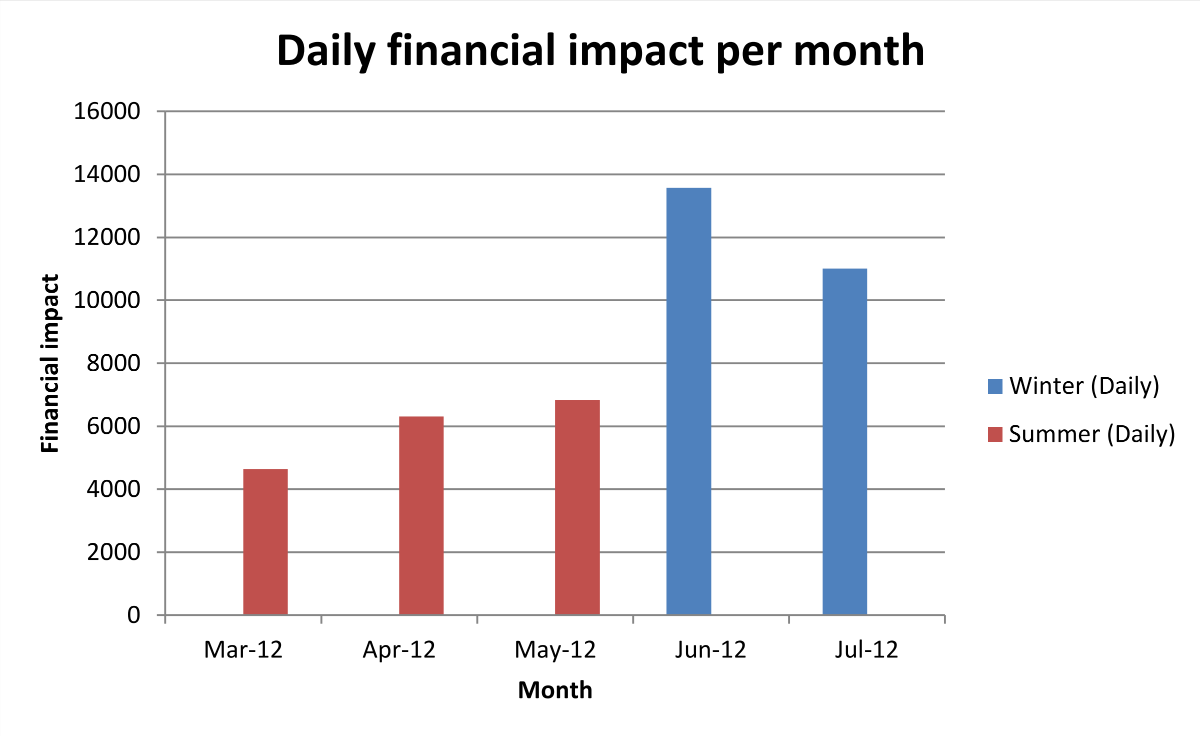


Figure 41: Daily financial impact per month

4.6 Conclusion

The implementation process varied from the original design. Minimum pressure control on the levels increased from preliminary design. This increase was caused by mining activity changes during the mine expansion process. The control of the system still had the potential of achieving a sustainable saving during performance assessment and after.

The savings achieved, as seen in Figure 40 below, are an increasing energy efficiency trend with a fairly constant peak clip. Compressor automation had unfortunately ensured that the running sequence of compressor 1 and 2 could not be used in the two months after performance assessment. This sequence had been deemed viable and sufficient during testing of this sequence. The peak clip was maximised by switching off a compressor when it was not needed.

This mind-set change of the mine ensured a maximum peak clip saving to be realised as well. With the performance assessment, the full SLA peak clip saving was not realised. Peak clip saving of 2.165MW was reached of the 2.4MW saving. The energy efficiency component had over-performed expectations with 1.944 MW. The verified savings can be seen in the Appendix A.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The gold mines within South Africa account for 47% of the mining industry with 17% of their power consumption accounted for by compressed air. With mines expanding and increasing compressed air use this is the ideal system to attempt energy savings potential. Designing a compressed air system with the capability to lower demand and supply side ensures efficient controllability. Sustainable energy performance may be achieved on an expanding gold mine as seen in the case study.

Several aspects limit sustainability. Cooling in the mining using compressed air will limit the savings potential. Improving cooling systems will lower the use of compressed air for cooling purposes. Air leaks constitute an artificial demand. Closure of these leaks will improve sustainability. In severe case the leaks may lead to using 40% of the compressed air system. Illegal mining activity will also strain the compressed air system and should be controlled as far as possible.

Maintenance of equipment and EMS is of utmost importance. When equipment malfunctions the system is not fully functional. Sustainability of the EMS will decline and minimal saving achieved. By ensuring that correct technical personnel are notified on equipment failure, the system will be rectified quickly. Maintenance contracting by a dedicated professional company will ensure that the EMS control will be kept up to date.

Tracking to prove sustainability over a 5 year timeline we will find the impact of the project will have a sustainable trend. This trend is determined with the months that follow the project implementation, performance assessment and hand over. The SLA implemented will take into account the production increase and the baseline what should have been needed before the project implementation. The project savings for the months following the project have a trend to stay above the targeted savings. Savings with the target and production can be seen in Figure 42 below. The SLA has a marked effect on the scaled savings for September 2012. Savings for these months are above the targeted savings. The SLA and system implemented proves that sustainable savings may be achieved for the 5 year period as required by Eskom.

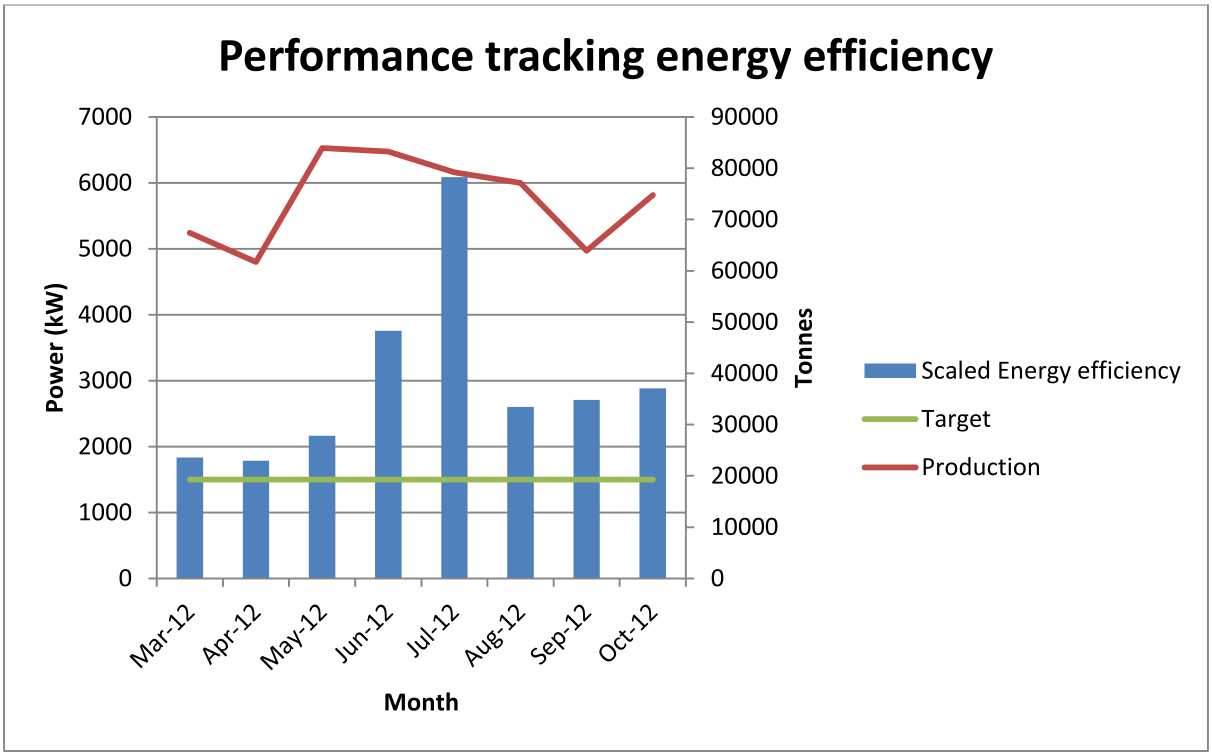


Figure 42: Performance tracking energy efficiency

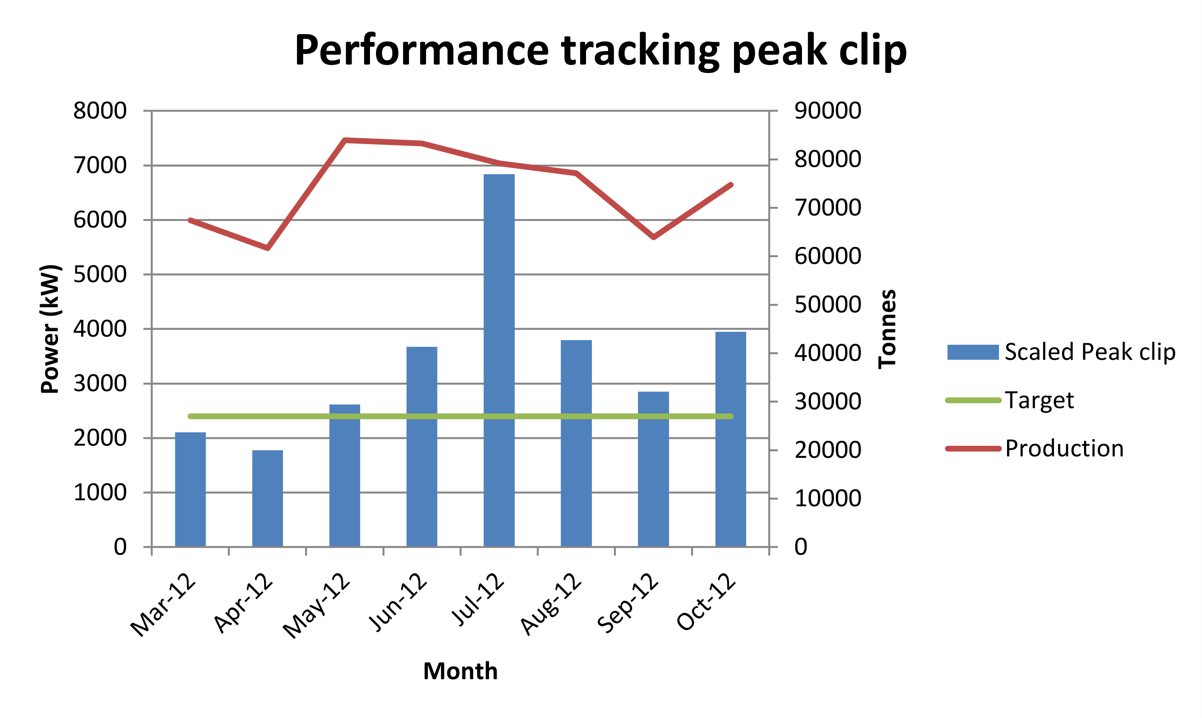


Figure 43: Performance tracking peak clip

Production increase and fluctuations had a significant effect on the SLA from performance assessment and the months to follow. During performance assessment (March to May 2012) the full and optimal control was not available. The savings achieved in this period was lower than target (2.4 MW) for the peak clip and energy efficiency outperformed the target (1.5 MW). The savings increased after full system functionality was available and the client had full buy-into the project. The months after performance assessment have an increasing savings trend due to this optimal control and support from the client.

SLA during this time with increased savings achieved ensured that all months after performance assessment were above target. The system proves that with production fluctuations the SLA used indicates above-target savings. Sustainability after performance assessment has been proven with constantly having savings above the target. The system implemented has ensured that sustainable savings can be achieved on an expanding gold mine.

5.2 Recommendations

The dedicated leak detection team or Air Wolf team will greatly increase the air leak detection. With dedicated mine personnel for these teams, compressed air systems leaks will be investigated frequently. The impact of leak repair may in severe cases save more than the salary required by the team.

The pneumatic equipment should systematically be replaced with higher efficiency equipment. With efficiency of pneumatic equipment in some cases being less that 10% an increase to more than 90% could be expected. By converting a level to only non-pneumatic equipment, the level may be completely isolated from compressed air. Air leaks will be lowered within these sections if isolated. This isolation may however prove difficult for refuge bay safety purposes.

The mining expansion is of importance to increase production but not in all cases will energy savings be taken into account. Financial planning to develop these systems is neglected. DSM funding ensures that these savings and system development may be obtained. This same procedure may be used on mines that do not have sufficient capital to install these systems and make use of DSM funds. The mines will not have to expand to achieve these savings.

Mine design for expansion has possibly room for improvement by integrating a sustainable approach. These expansion plans will require compressed air distribution to be extended as well. By actively designing the compressed air system with needed equipment, the control of the air supply can efficiently be controlled. Installation could take place during pipeline expansion to limit the system downtime. The system could be controlled immediately and have minimal missed savings opportunities. Additional monitoring equipment will be able to monitor compressed air use. Wastage within the system can be identified and managed efficiently.

Mining groups do not in all instances have a dedicated energy engineer on each site. These engineers are strictly focused on achieving maximum savings on site. The cost benefit of employing an energy engineer on each shaft should be investigated to determine its viability. The mining group in this study has a supervisory energy savings group that cannot always focus on every small detail on a shaft. The employment of shaft specific personnel may also increase sustainability of DSM projects.

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APPENDIX A

i. Peak clip MAD savings certificate

Eskom	M&V Measurement Acceptance Date (MAD) Certificate	NEC Contract No: 4600040073

DSM Project Title:	Nyala Compressor Manager	
DSM Project Number:	2010066	
Short Description of DSM Project:	Implementation of a Real Time Energy Management system (REMS3 CM) and an On-Site Information Management System (OSIMS CM) on the compressed air system of Nyala Mine.	
ESCo for DSM Project:	HVAC INTERNATIONAL	
M&V Team for DSM Project:	NWU	
Contracted MWs (as per NEC):	2.4	Per month
Actual MWs achieved as per assessment:	2.165	Per month
% of original contracted (MW) value	90%	

Date of M&V Completion:	June 2012
Duration of M&V assessment:	3 Months

It is hereby certified that the M&V Performance Assessment period for the abovementioned DSM project has been completed and that the performance is as given in the attachment to this certificate.

- The new target for the customer is **2.165 MW**.
- The customer officially takes over the system from 1 July 2012 for the next 5 years.

Signed at WELKOM on 2012/06/09 ~~20~~

Who accepts the MW performance of the project as given above and in this report	
ESCO	CLIENT
Name (Print)	Name (Print) F.W. VAN ZYL
Sign	Sign

Who accepts the MW performance of the project as given above and in this report	
ESKOM DSM (Project Manager)	ESKOM DSM (Sector Manager)
Name (Print)	Name (Print)
Sign	Sign

* Delete if not applicable
Annexure "A" – Signed Implementation Completion Certificate
Annexure "B" – M&V Performance Assessment Certificate

Eskom M&V Measurement Acceptance Date (MAD) Certificate Page 1 of 1

ii. Energy efficiency MAD savings certificate

Eskom | M&V Measurement Acceptance Date (MAD) Certificate | NEC Contract No: 4600040073

DSM Project Title:	Phakisa Optimisation of Air Networks	
DSM Project Number:	2010069	
Short Description of DSM Project:	Implementation of a Real Time Energy Management system (REMS3 OAN) and an On-Site Information Management System (OSIMS OAN) on the compressed air reticulation network of Phakisa Mine.	
ESCo for DSM Project:	HVAC INTERNATIONAL	
M&V Team for DSM Project:	NWU	
Contracted MWs (as per NEC):	1.5	Per month
Actual MWs achieved as per assessment:	1.944	Per month
% of original contracted (MW) value	130%	

Date of M&V Completion:	June 2012
Duration of M&V assessment:	3 Months

It is hereby certified that the M&V Performance Assessment period for the abovementioned DSM project has been completed and that the performance is as given in the attachment to this certificate.

- The new target for the customer is **1.5 MW**.
- The customer officially takes over the system from 1 July 2012 for the next 5 years.

Signed at WELKOM on 12/6/2012 20 12

Who accepts the MW performance of the project as given above and in this report	
ESCO	CLIENT
Name (Print)	Name (Print) F.W. VAN ZYL
Sign	Sign

Who accepts the MW performance of the project as given above and in this report	
ESKOM DSM (Project Manager)	ESKOM DSM (Sector Manager)
Name (Print)	Name (Print)
Sign	Sign

* Delete if not applicable
Annexure "A" – Signed Implementation Completion Certificate
Annexure "B" – M&V Performance Assessment Certificate

Eskom *M&V Measurement Acceptance Date (MAD) Certificate* *Page 1 of 1*