

CHAPTER 4



14

Ability is what you are capable of doing. Motivation determines what you do. Attitude determines how well you do it.” – Raymond Chandler

¹⁴ Photo taken by Johan Bredenkamp at a South African gold mine.

4 IMPLEMENTING RECONFIGURATION STRATEGIES ON SOUTH AFRICAN MINING COMPRESSED AIR NETWORKS

4.1 Introduction

Using the information gathered in Chapter 2, a design strategy was developed in Chapter 3. The new strategy was implemented to reconfigure the compressed air networks of two South African gold mines. The first case study was a reconfiguration that entailed the relocation of a compressor from an abandoned shaft to the main production shaft. The second case study focused on interconnecting two shafts with a pipeline to export compressed air from one section to another section. The following sections discuss the inner details of the reconfiguration strategy implementation.

4.2 Energy efficiency by repositioning a compressor

4.2.1 System background

According to the nameplates of the compressors, at the time of the study Mine C was approximately forty years old. Mine C comprised three shafts and one gold plant. The shafts will further be referred to as three shaft (3#), four shaft (4#) and five shaft (5#). The gold plant will further be referred to as GP.

The only operational shaft was 5#, mining the Basal and B Reefs [48]. The expansion on mining levels was part of near future plans for 5# [48]. Mine C used 4# for ventilation, pumping and as a second outlet for mined ore from 5# [48]. The expected remaining lifespans of 5# and 4# were approximately fifteen years at the beginning of 2012. Mine C's 3# had been decommissioned and only hosted a baseload compressor for mining activities at the other two shafts.

An ESCO implemented an EE strategy on 5#'s underground compressed air network during 2011/2012. Control valves were installed on all the mining levels. The control valves were used to reduce the compressed air demand on underground levels during mining off-peak periods. In turn, a reduction in the power consumption of the compressors was achieved.

The compressor at 3# was initially designed for baseload operation with no capacity control. This caused the compressor to continuously blow off compressed air and caused it to trip when the system pressure increased beyond a certain point (surge protection). Vandalism of infrastructure, cable theft and illegal mining activities have also plagued Mine C's 3#. Mine C had continuously maintained the compressor at 3#. The maintenance costs and fatality risks had become a major concern for the mine.

Mine C presented the opportunity to reconfigure the compressed air network to reduce compressed air wastage and maintenance costs. The surface pressure delivery at 5# also had to be improved for future expansion of mining levels. The decrease in compressed air wastage would result in a decrease in compressor power consumption. Eliminating fatality risks caused by illegal mining activities would reduce the chances of the compressor at 3# tripping during peak demand periods. During the study period the compressor tripped during peak demand periods, thus influencing the production of Mine C.

4.2.2 Network analysis and constraints

Layout

Figure 41 is a simplified schematic layout of Mine C's surface compressed air network. Figure 41 indicates the three shafts and GP interconnected via an interconnecting pipeline.

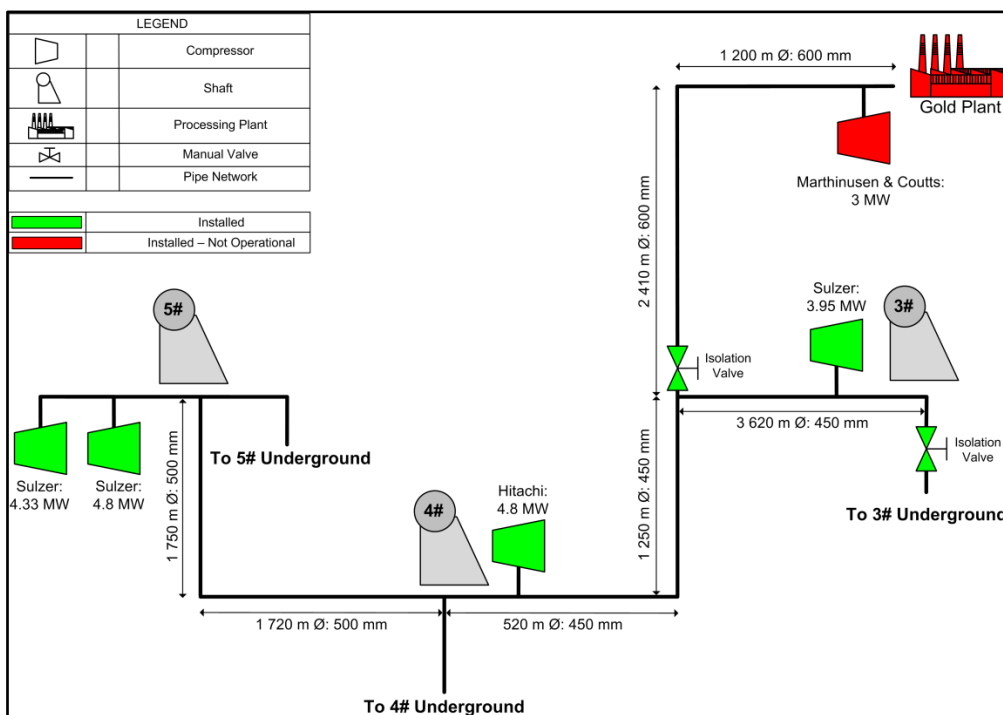


Figure 41: Schematic layout of Mine C's surface compressed air network

The GP had recently been decommissioned and this part of the network had been closed off via an isolation valve. Underground operations at 3# had also been closed off from the rest of the system via an isolation valve. These isolation valves are visible on Figure 41.

Supply side

Mine C used five compressors to satisfy the compressed air demand. The compressors at 5# were the mine's main compressors. The compressor at 4# was used as a standby machine. The compressor at 3# was used as a baseload machine. The GP compressor had been decommissioned and shipped to the mine's salvage yard. Table 13 gives a brief summary of the compressors used at Mine C.

Mine C Compressor Summary			
Shaft	Compressor	Installed Capacity	
		Power (kW)	Airflow (CFM)
5#	Sulzer	4 800	30 000
	Sulzer	4 330	25 000
4#	Hitachi	4 800	30 000
3#	Sulzer	3 950	25 000
GP	Marthinusen & Coutts	3 000	20 000
Total	5	20 880	130 000

Table 13: Mine C compressor summary

The compressors at 5# were fully automated and controlled from the centralised control room located at 5#. The standby compressor at 4# was partially automated with full functionality of the capacity controllers (IGVs). The compressor at 3# was not automated, as the compressor had originally been designed as a baseload compressor.

The compressor at 3# was constantly tripping during low demand periods. Mine personnel did not want to manually stop the compressor during these times. Due to its age, the compressor was started and stopped with great difficulty. According to mine personnel, the compressor at 3# was also constantly running to prevent the compressor from being vandalised by illegal miners. The compressor was located at an abandoned shaft with no security.

Demand side

The main compressed air consumer at Mine C was 5#. Compressed air was required for peak-drilling periods, loading of ore, sweeping and for supplying air pressure at the refuge

bays. At 4#, compressed air was required for loading of ore and for supplying air at the refuge bays. Two small workshops, located at 5# and 4# respectively, were used for maintenance of mining equipment. Table 14 represents the mining schedules and surface air requirements of the three shafts at the time of the study. The schedule was obtained from mine personnel.

Mine C Compressed Air Requirement Schedule			
Shaft	Activity	Time Period	Required Surface Pressure (kPa)
5#	Peak drilling	07:00 – 13:00	470
	Loading	09:00 – 16:00 & 22:00 – 02:00	440
	Sweeping	09:00 – 16:00 & 22:00 – 02:00	440
	Refuge bays	00:00 – 24:00	150
4#	Loading	09:00 – 13:00 & 22:00 – 02:00	440
	Refuge bays	00:00 – 24:00	150
3#	No requirements	00:00 – 24:00	0

Table 14: Mine C surface compressed air requirement schedule

The surface pressure requirements compensated for the benefit of auto compression down the shafts. The three shafts at Mine C had approximately the same depths and therefore experienced the same effect of auto compression down the shafts. Figure 42 illustrates the effect of auto compression at Mine C. According to the figure, the air pressure at 5# increased with approximately 57 kPa from surface to the first mining level.

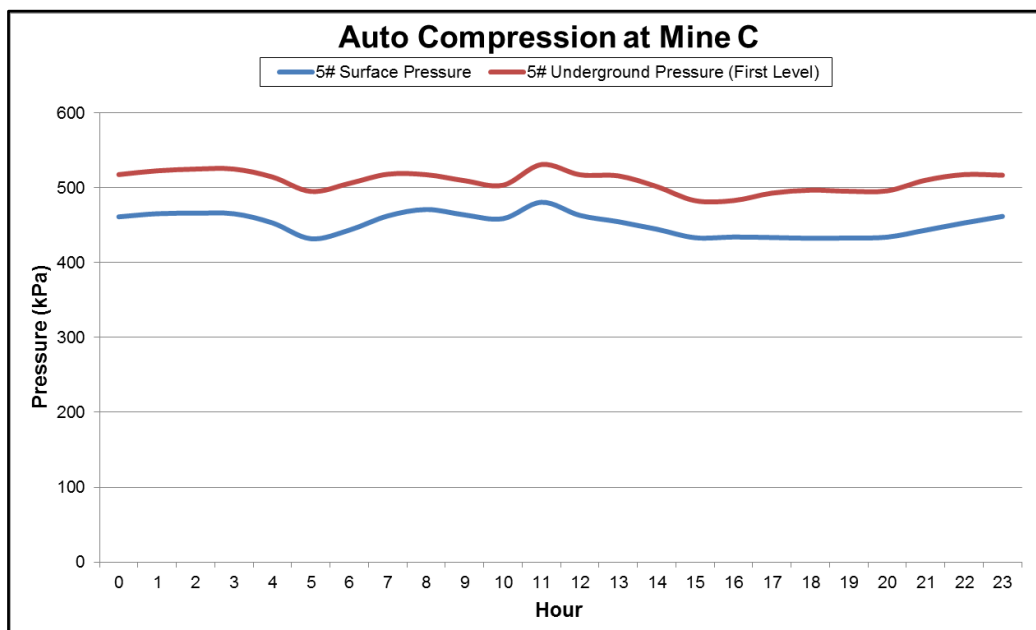


Figure 42: Effect of auto compression on the compressed air pressure at Mine C

Air reticulation network

Mine C's surface reticulation network comprised approximately 12 500 m of commercial steel piping. The reticulation network varied from 450 to 600 mm in diameter as indicated on Figure 41. For the purposes of this study only the surface reticulation network was analysed and evaluated.

The surface pipeline between 5# and 4# was approximately twenty-five years old at the time of the study and in a very good condition. The pipeline between 4# and 3# was approximately thirty-four years old and in a worse condition than the surface pipeline between 5# and 4#. Several compressed air leaks were detected along the pipeline due to corrosion and burst flange gaskets. The pipeline leading to the GP was no longer used. Figure 43 verifies the state of the pipeline connecting 3# and 4#. The average pressure loss from 3# to 4# was 77 kPa throughout a normal working weekday.

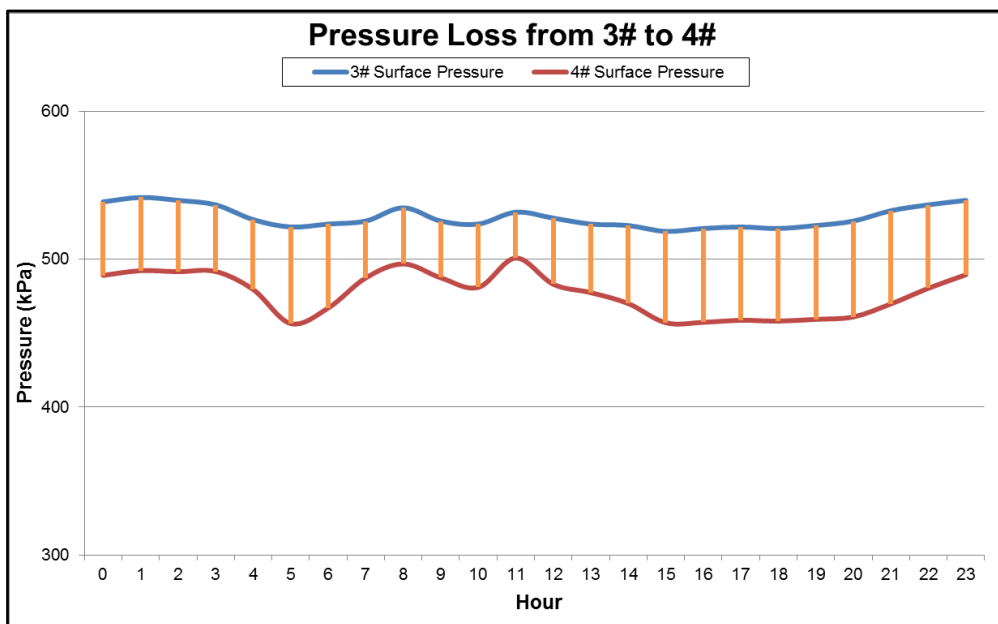


Figure 43: Pressure loss from 3# to 4# over a normal working weekday

Network constraints

According to Table 14 the maximum and minimum pressure requirements between the shafts were 470 kPa and 150 kPa respectively. Mine C's 3# did not require compressed air and the remaining two shafts had approximately the same requirement schedules. Figure 44 presents Mine C's network pressure requirements against the maximum and minimum system parameters averaged between the shafts. The reconfiguration strategy had to comply with these parameters.

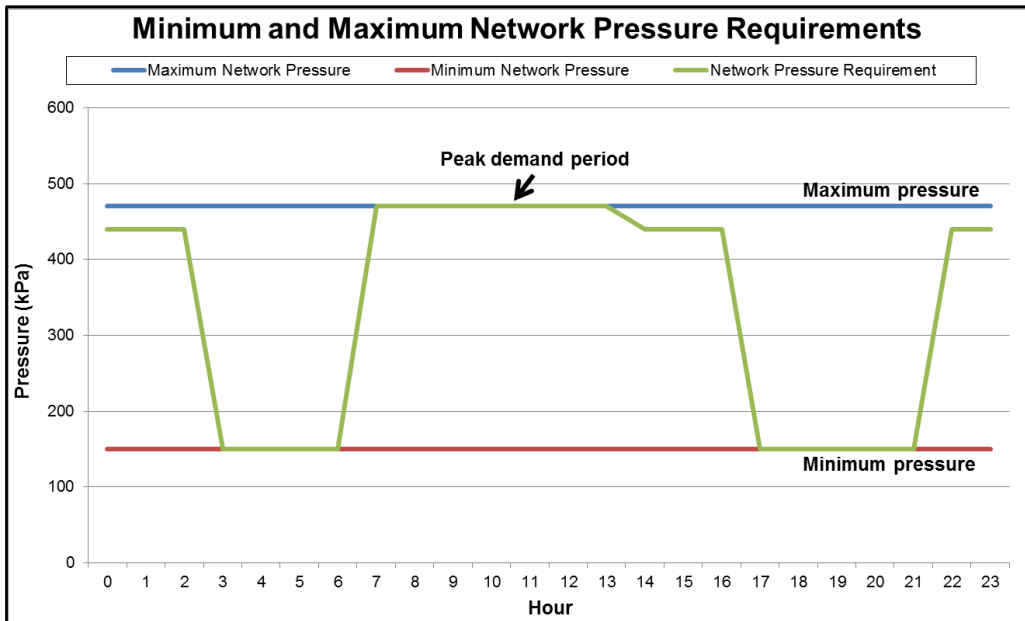


Figure 44: Mine C's minimum and maximum network pressure requirements

Mine C's future development plans were to expand the mining levels at 5#. The expansion would require an increase in surface delivery pressure as the compressed air consumption would increase. According to mine personnel, an approximate surface pressure of 500 kPa would be required at 5# to compensate for the expansion. The increase of 30 kPa had to be built into the reconfiguration design. Figure 45 presents the minimum and maximum network pressure requirements when the expansion was taken into consideration.

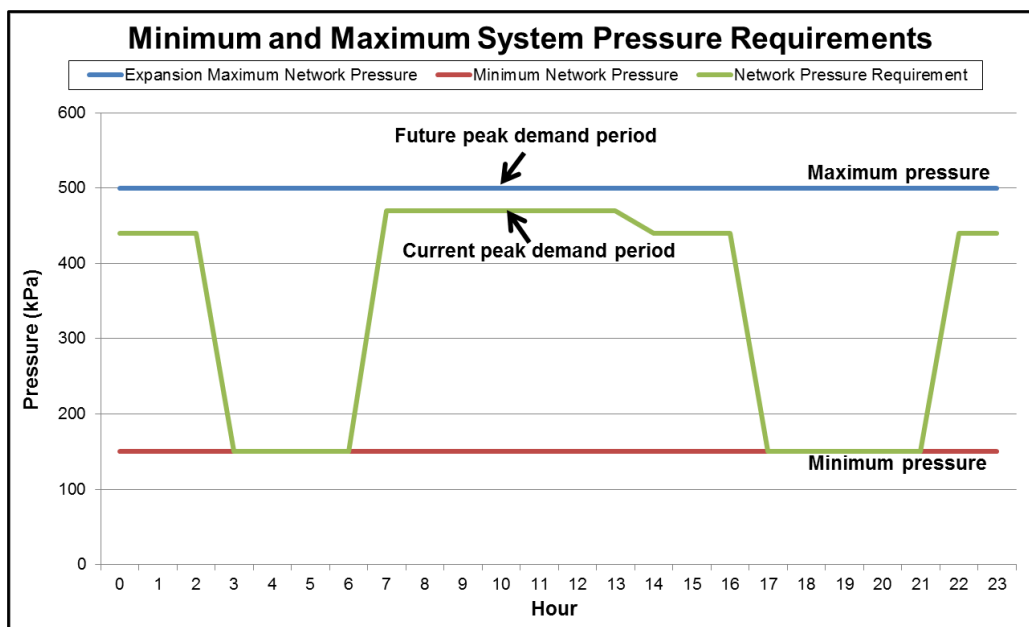


Figure 45: Mine C's minimum and maximum parameters for future developments

No specific flow requirements were available during the time of the study, as Mine C did not have any record of the number of end-users requiring compressed air. Therefore, only the pressure requirements would be used during the reconfiguration of Mine C's compressed air network.

4.2.3 Data processing and network operation

Identifying data-measuring points

Figure 46 illustrates all the data-measuring points that were identified. According to Figure 46 the compressors at 5#, 4# and 3# had PP. All the pressures and flows at 5# and 4# were also measured (FPP). No pressures and flows were measured at 3# (NP).

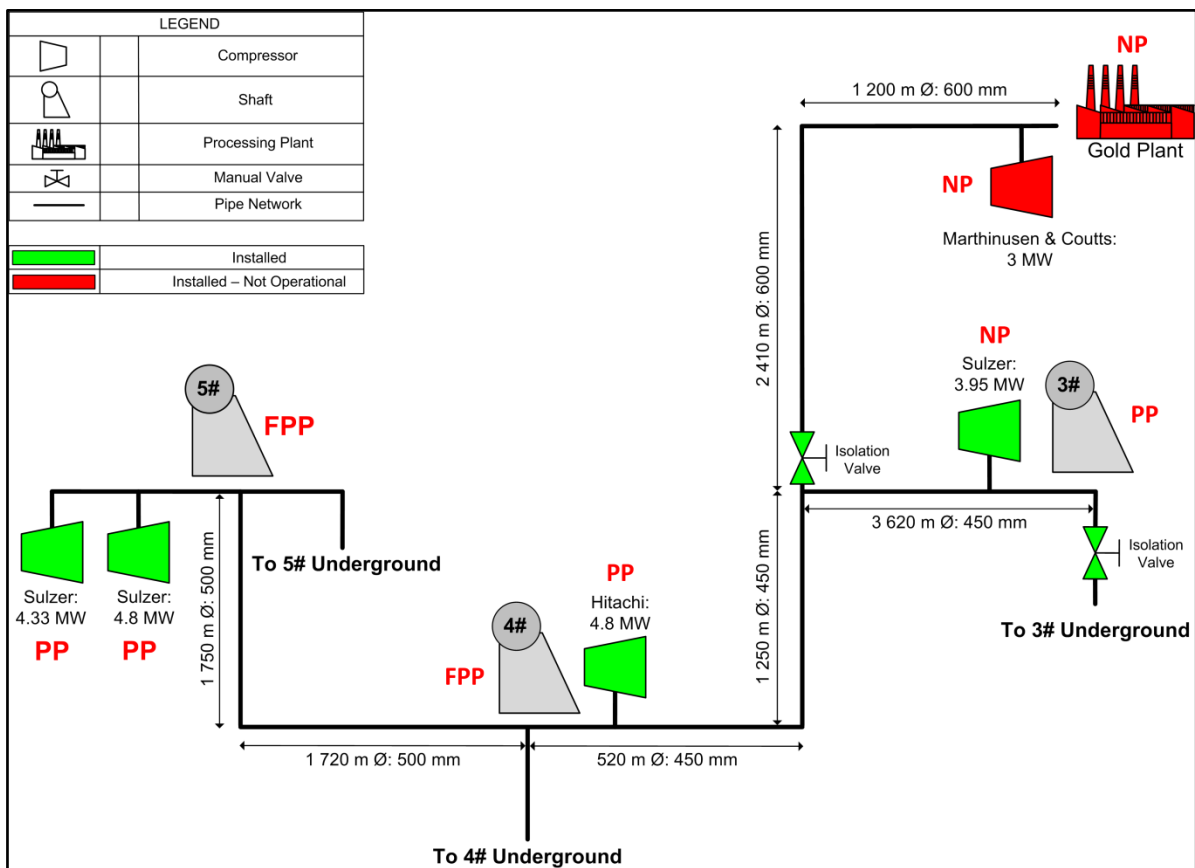


Figure 46: Simplified illustration of Mine C's data-measuring points

Data collection

All the data measured from the measuring points were logged on the local SCADA system. Relevant mine personnel were consulted to obtain a copy of the logged data.

The pressure data for 3# was not available on the mine's SCADA system. A lack of automated instrumentation prevented the data from being measured and logged. The airflow and pressure at 3# were measured using calibrated portable measuring equipment (as discussed in Chapter 3). The portable measuring equipment was installed for an extended period.

Data evaluation

The data obtained from the mine was evaluated for accuracy and consistency. The compressor power and pressure data was verified by installing calibrated portable measuring equipment. The data measured with the calibrated equipment proved to be approximately the same as the mine's measured data. The measured flows from the mine's flow meters was verified by a flow balance between the mine's compressors and the total network consumption. Figure 47 displays the flow balance.

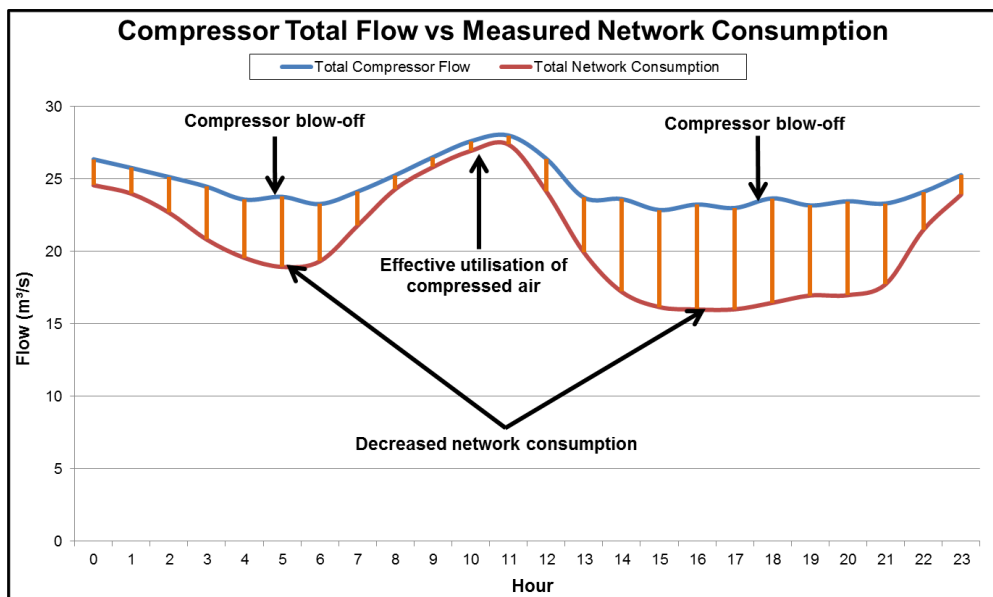


Figure 47: Flow balance between the mine's compressors and total network consumption

Accuracy of the mine's flow meters was determined during peak demand periods when the air was effectively utilised. The compressors blew off excess air during low demand periods, which caused the compressor flow to stabilise while the demand continued to decrease. Considering air losses in the network, Figure 47 displays relatively accurate flow measurements in the network. The assumption was therefore made that the flow data obtained from the mine was relatively accurate.

The following sections discuss the flow, pressure and power profiles developed using the collected data. The flow and pressure profiles were compared with the compressed air requirements of the end-users. Any compressed air wastages and shortfalls would be identified. The power baseline was developed with the combined compressor power data collected from all the compressors used in the network.

Flow profiles

Figure 48 illustrates each shaft's compressed air consumption. It is evident on the graph that 5# was the main consumer. The second highest consumer was 4# which peaked during the loading periods. No air consumption was measured at 3# and the gold plant since these operations had been closed off from the rest of the network.

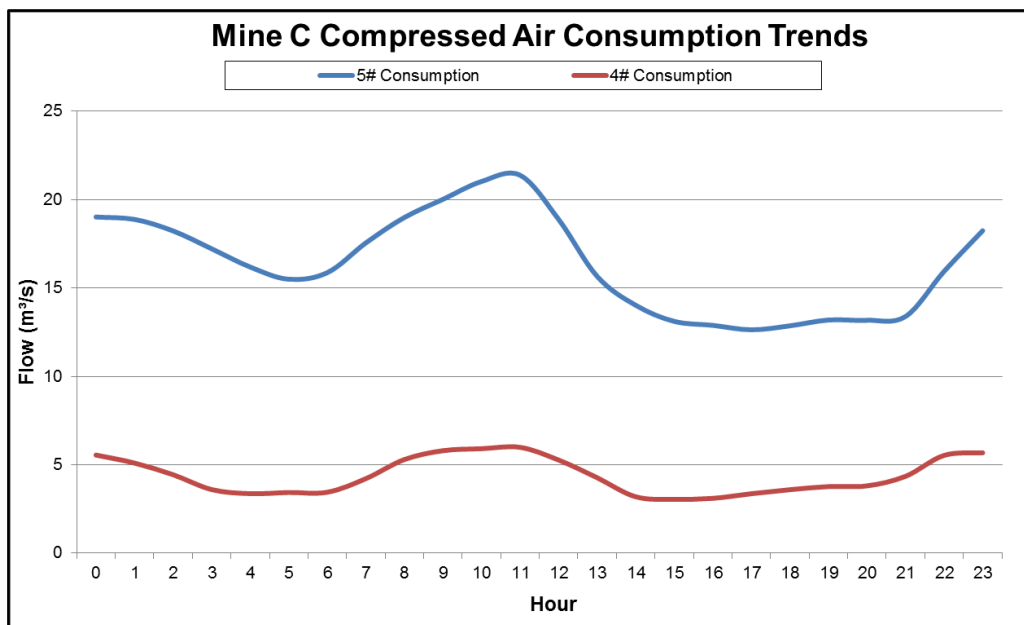


Figure 48: Mine C's compressed air consumption trends

The trend at 5# corresponded with the compressed air requirement schedule discussed in Section 4.2.2. The peak-drilling shift consumed the largest amount of compressed air with increased consumption between 07:00 and 13:00. The increase in air consumption between 22:00 and 02:00 was due to loading and sweeping activities. The consumption during the remainder of the day was due to usage at the surface workshop and underground refuge bays as well as losses due to compressed air leaks.

Compressed air at 4# was required for loading as well as supplying pressurised air to the refuge bays. Loading occurred between 09:00 and 13:00 and again between 22:00 and 02:00. According to Figure 48 it was safe to conclude that the air consumption at 4#

corresponded with the mining schedule. The consumption during the remainder of the day was due to usage at the surface workshop and underground refuge bays as well as losses due to compressed air leaks.

No compressed air was consumed at 3#. This presented an ideal reconfiguration opportunity to move the compressor from 3# to form part of the network where plenty of air was required.

Pressure profiles

Figure 49 illustrates each shaft’s surface pressure profile. The pressure differences between the shafts are visible and were due to pipe friction losses and air consumption differences. The pressure at 3# stayed relatively constant throughout the day. No air consumption occurred at 3# and this might have been the reason for the constant pressure.

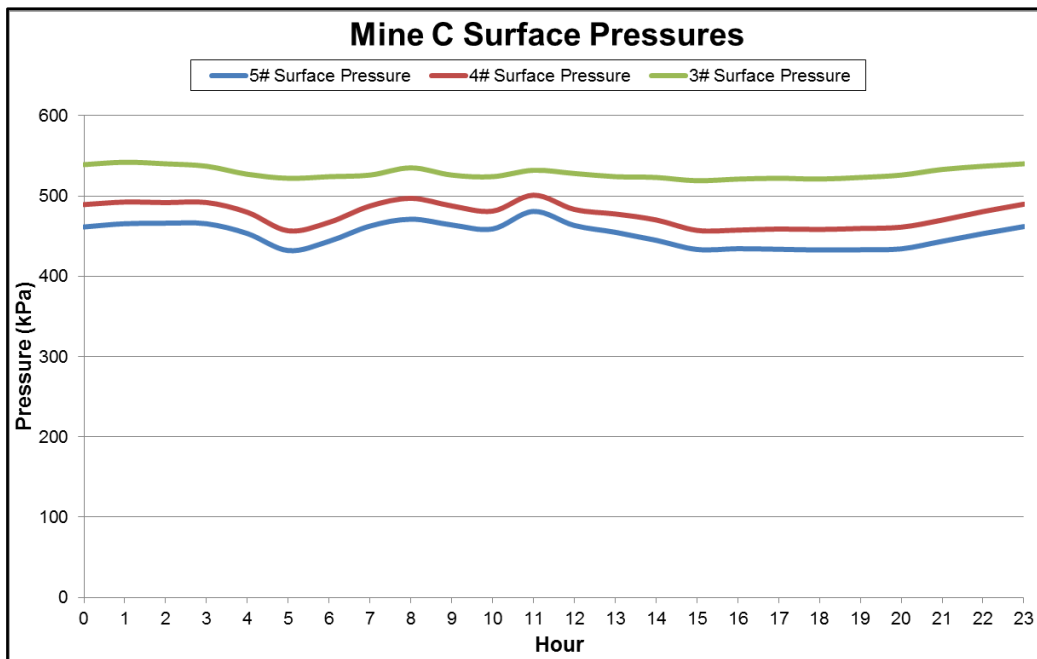


Figure 49: Mine C’s surface compressed air pressure trends

According to Table 14, the drilling shift at 5# required the highest compressed air pressure of 470 kPa. Loading and sweeping required an air pressure of 440 kPa at both 5# and 4#. According to Figure 45 and Figure 49, a future undersupply of compressed air was predicted for 5# during peak demand periods. An oversupply of compressed air was also delivered to 5# and 4# during certain periods of the day. Figure 50 illustrates the predicted shortfall and current wastage in compressed air supply at 5#.

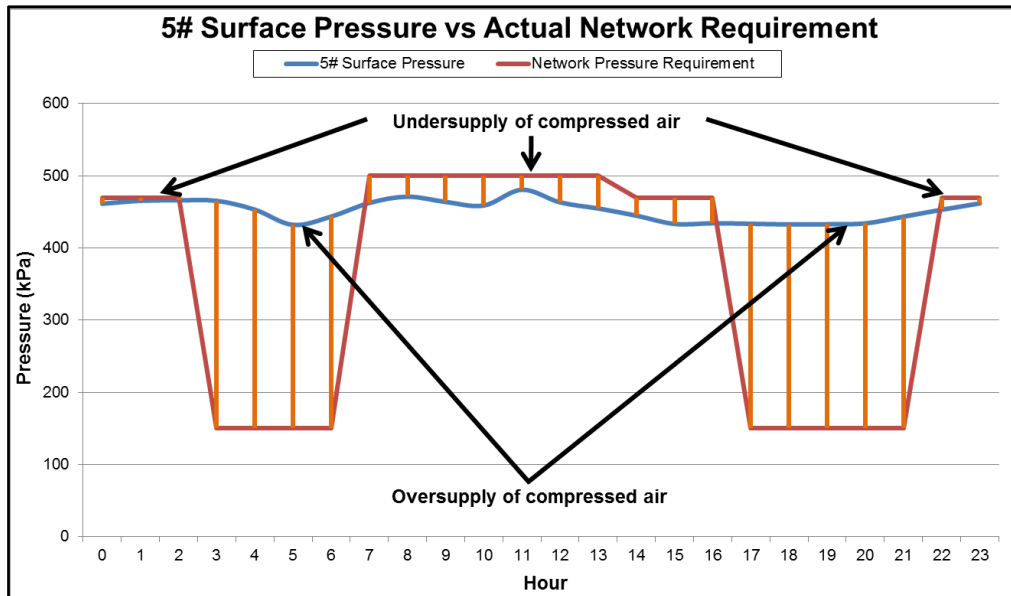


Figure 50: Undersupply and compressed air wastage at 5#

The predicted undersupply of compressed air during peak-drilling and peak-loading periods is indicated on Figure 50. The undersupply was predicted under the same compressor operating conditions (discharge set points) being used at the time of the study. The discharge set points of the compressors could be increased to compensate for the higher pressure demand. However, increasing the set points would result in higher power consumption on the compressors.

It is evident from Figure 50 that compressed air was being wasted between 02:00 and 07:00 and again between 16:00 and 22:00. This was due to the compressor at 3# not being able to reduce its supply capacity during low demand periods. The compressor was constantly running at maximum load conditions. The compressed air wastage problem could be resolved by enabling the compressor to modulate its output, matching supply with demand. The compressor could even be stopped during these periods.

The principle behind the reconfiguration strategy was to generate cost savings for the mine. By increasing the compressor set points, the mine's expenditure on electricity costs would only increase. Mine C also did not want to manually stop and start the compressor at 3#, as it resulted in increased maintenance costs. Therefore, Mine C's compressed air network could be reconfigured to resolve the over- and undersupply dilemma. The reconfiguration strategy had to generate cost savings and improve the surface delivery pressure at 5#.

Power profiles

Individual and total power profiles were developed for Mine C’s compressed air network. The profiles were developed for mining weekdays as Eskom is only interested in power saved during weekdays. The baseline would be used to measure the power savings on the compressors after reconfiguration. Figure 51, Figure 52 and Figure 53 represent the power profiles developed.

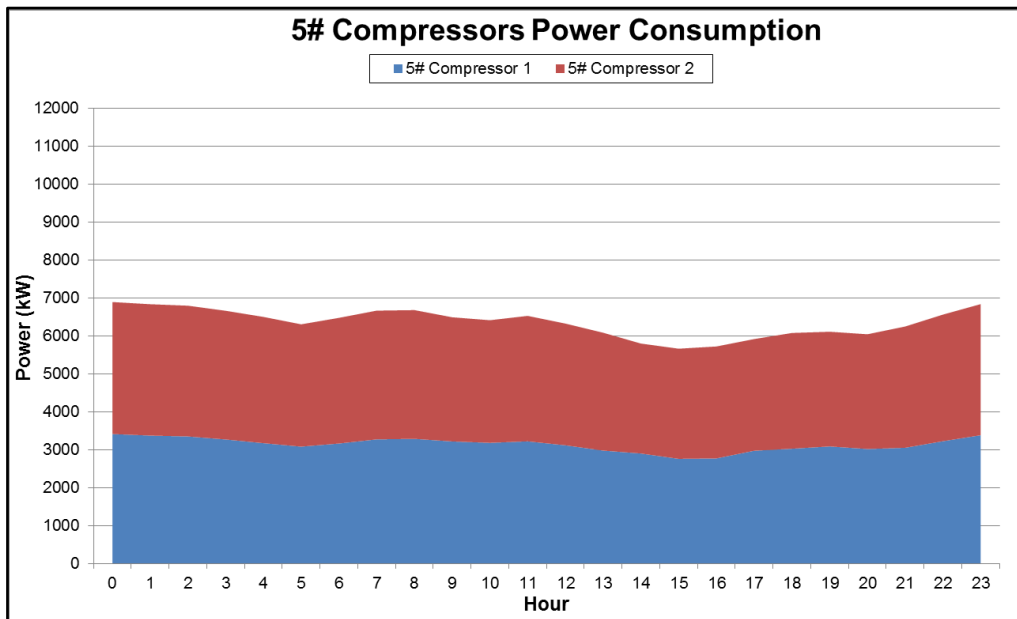


Figure 51: Mine C’s 5# compressors power consumption

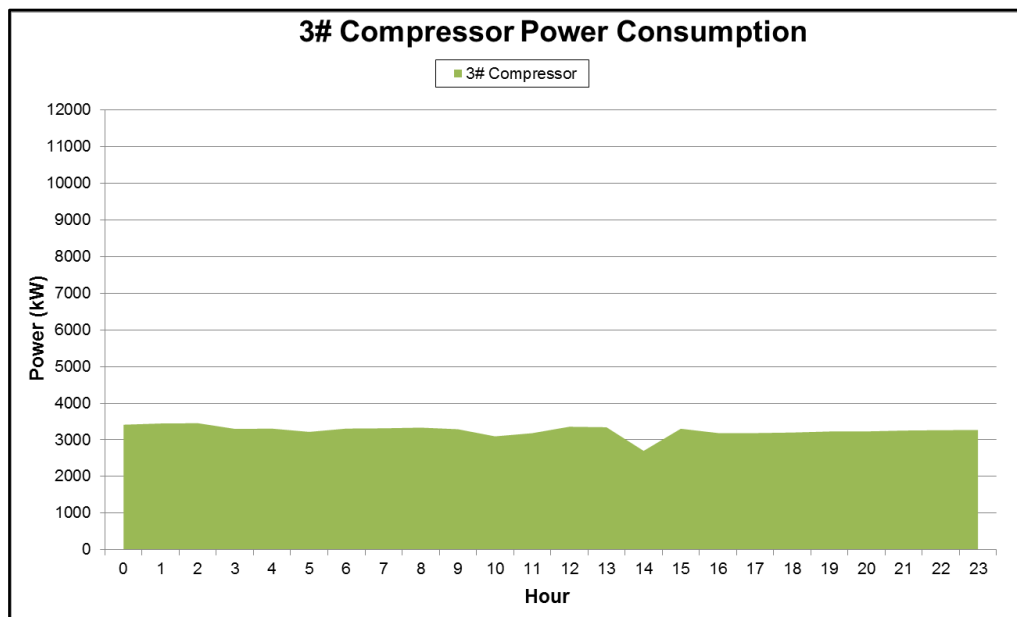


Figure 52: Mine C’s 3# compressor power consumption

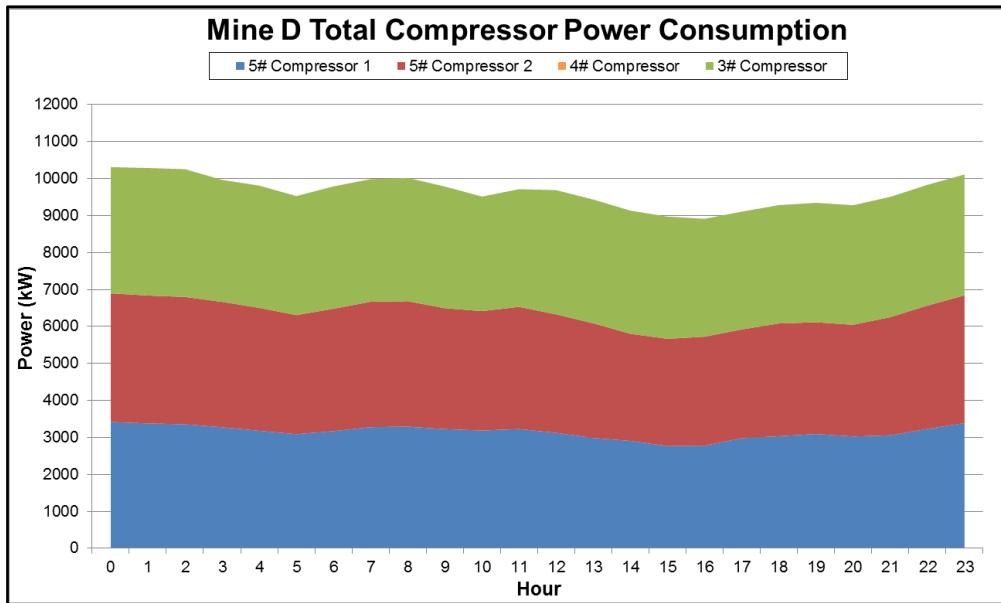


Figure 53: Mine C total compressor power consumption (power baseline)

Figure 51 represents the compressors' power consumption at 5#. The highest power consumption was during the drilling, loading and sweeping periods. The power consumption decreased as the demand for compressed air from the end-users decreased. This was due to the compressors being able to match the supply with the compressed air demand of the end-users.

Figure 52 represents the compressor power consumption at 3#. It is evident from the figure that the compressor was almost constantly operating at maximum load conditions.

Figure 53 represents the total power consumption of all the compressors. The compressor at 4# was not being used during the course of this study. Therefore, the compressor power consumption is not visible on Figure 53.

4.2.4 Reconfiguration strategy development

Preamble

Figure 42 to Figure 53 equip one with adequate information and motivate the initiative to reconfigure the network. The following serves as motives for the solution development:

- excessive maintenance costs due to vandalism on the 3# compressor;
- pressure losses over the 3# to 4# pipeline;

- future compressed air demand increase due to expansion of mining levels at 5#; and
- 3# compressor has no form of capacity control.

Possible solutions

A possible proposed solution for reconfiguring Mine C's compressed air network is illustrated by the letter A on Figure 54.

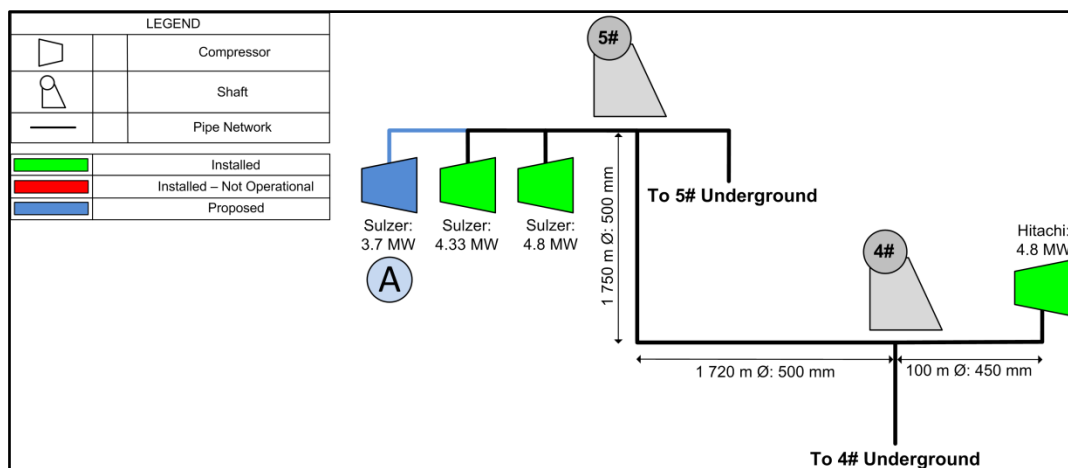


Figure 54: Solution A - simplified layout to reconfigure Mine C's compressed air network

Solution A entailed relocating the compressor from 3# to 5# and eliminating the interconnecting pipeline between 3# and 4#. The relocation procedure also included the automation of the 3# compressor.

Mine C would have an increased surface delivery due to the elimination of the pipe pressure losses occurring between 3# and 4#. An automated relocated compressor would improve the capability of matching the compressed air supply with the demand. The compressor could even be stopped during low demand periods as indicated on Figure 50. Excessive maintenance cost on the 3# compressor would also be eliminated, as the compressor was moved to a well secured area.

Practical constraints

Relocating a compressor from one shaft to another is a major procedure. This operation could have taken up to two years to complete as the mine stated that work would only proceed when finances were available. It was therefore crucial that the solution justified the expected lifespan of the mine.

Costing constraints

A quotation was obtained to relocate the compressor from 3# to 5#. The quotation included full automation of the relocated compressor. It was determined that approximately R15 million was required to implement this solution. However, a refurbished compressor with fully functioning capacity control was available within the mining company. This would reduce the total implementation cost to approximately R6 million, which included full automation of the compressor.

Theoretical analysis and calculations

Simulations and mathematical models of the solution were developed by using appropriate software (KYPipe) and calculations discussed in Chapter 2. Bends and elbows in the pipelines were omitted. The following criteria have been used in the simulation models and calculations:

- compressor discharge set points set at 510 kPa;
- compressor efficiency set at 0.8;
- compressor motor efficiency set at 0.9;
- atmospheric pressure set at 101.33 kPa;
- ambient air temperature set at 30°C;
- density of air set at 1.16 kg/m³;
- absolute viscosity of air set at 0.0000186 N.s/m²;
- specific heat of air set at 1.006 kJ/kg.K;
- specific heat ratio set at 1.4;
- pipe roughness set at 0.045 mm for commercial steel pipes; and
- flow consumption increase of 10% is assumed (prediction made by Mine C's shaft engineer).

The maximum flow for each shaft was used during the development of the simulation. The same compressor discharge set points used at Mine C were incorporated in the simulation. The air consumption of 5# and 4# were taken as 23 m³/s and 7 m³/s respectively (maximum values including 10% increase). Figure 55 represents the simulated results for the proposed relocation of the 3# compressor.

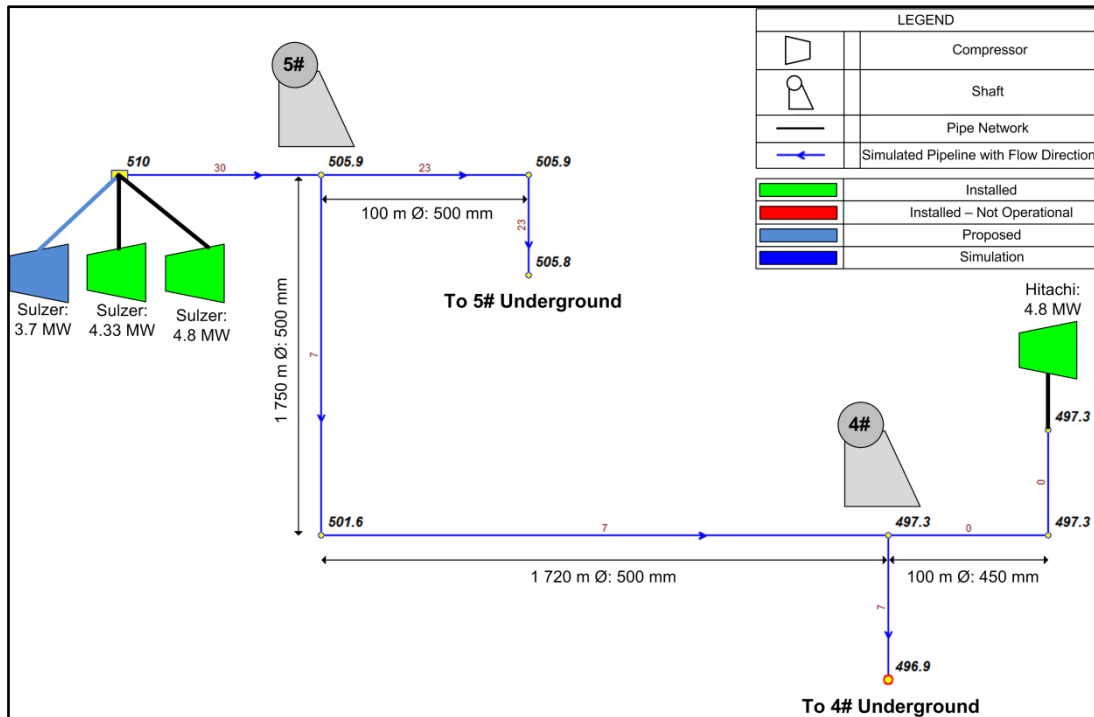


Figure 55: Simulation illustrating the effect of the 3# compressor relocation

According to Figure 55, a pressure of approximately 506 kPa was delivered to 5# at a flow rate of 23 m³/s. A pressure of approximately 497 kPa was delivered to 4# at a flow rate of 7 m³/s. The simulation was repeated for all the other flow conditions shown in Figure 48. Under the same network conditions, the simulations indicated a daily average gain in surface pressure of 40 kPa at 5#. Figure 56 illustrates the gain in surface pressure at 5#.

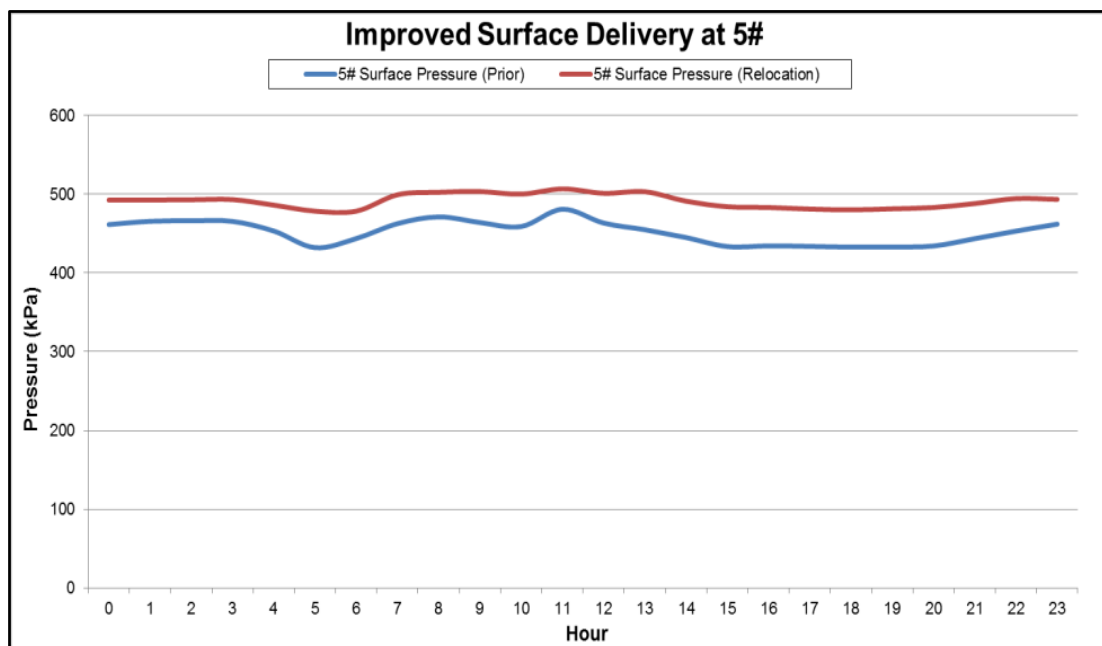


Figure 56: Increased surface delivery pressure at 5# after relocating the 3# compressor

The increased pressure compensated for the predicted 10% increase in compressed air requirements due to the expansion of the mining levels. The increased surface delivery alone was sufficient. No adjustments were made to the compressor set points or other criteria used in the simulations and calculations. The same installed capacity compressor was also used for the relocation simulations. Figure 57 illustrates the simulated surface pressure profile for 5# after the relocation of the compressor. The profile was compared to the actual future pressure requirement profile.

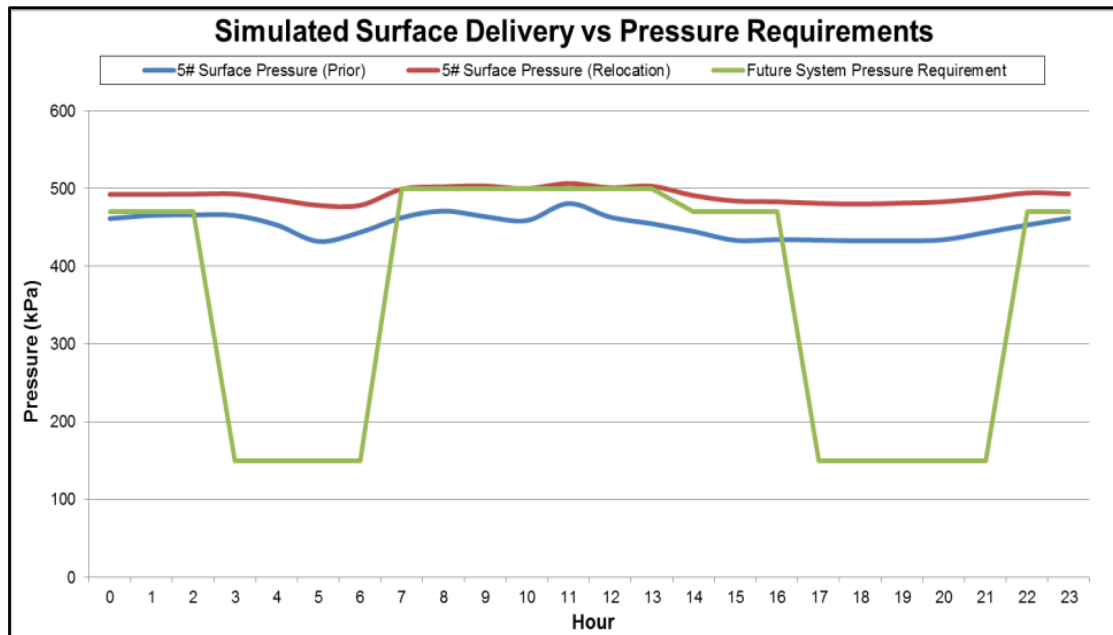


Figure 57: Improved surface delivery against the network pressure requirement schedule

The higher surface delivery signified lower compressor power consumption during certain periods of the day. Figure 58 illustrates the theoretical compressor power required after the relocation of the 3# compressor. The calculations were performed assuming that the relocated compressor was fully automated.

It was evident from Figure 58 that using only the two largest compressors at 5# would be sufficient to satisfy the compressed air demand during low demand periods. The relocated compressor might be switched off during these periods. The automation of the compressor would be helpful in this regard.

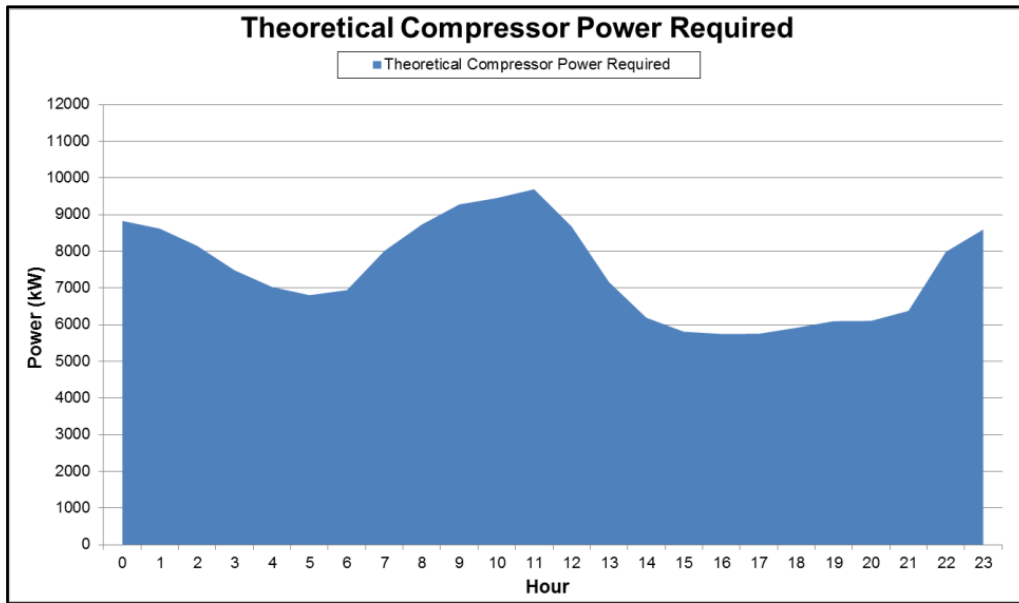


Figure 58: Mine C compressor power required after relocating the 3# compressor

Savings potential

Relocating the compressor from 3# to 5# would ensure a potential surface pressure gain, which in turn would reduce the power consumption of the compressors. Substituting the compressor with a fully automated compressor would increase the power savings potential even more. Mine personnel would be able to stop the compressor from the centralised control room during low demand periods. Figure 59 illustrates the proposed compressor power savings by implementing the reconfiguration strategy on Mine C’s compressed air network.

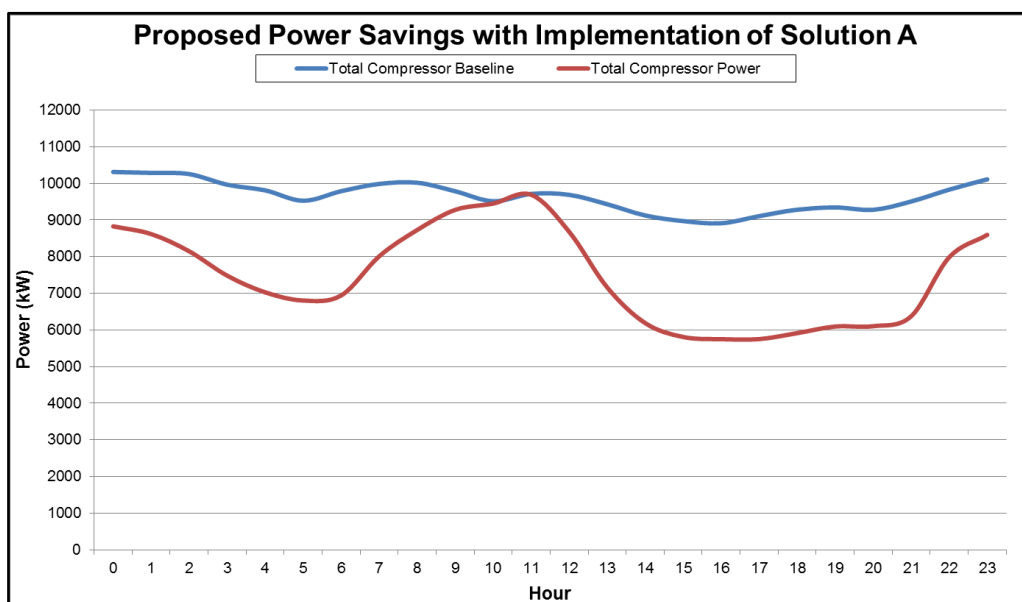


Figure 59: Proposed power profile against the power baseline

The potential average daily power saving by implementing Solution A was approximately 2 100 kW for Mine C's compressors. The implementation cost for this solution was approximately R6 million since Mine C had a refurbished compressor available. The payback period therefore by implementing this solution was approximately six months during the course of this study.

The total amount of money saved on the electricity bill was approximately R170 million over the lifespan of the intervention. The saving was calculated with the help of the Eskom electricity tariff at the time. The amount was calculated over a period of thirteen years (lifespan of intervention) to compensate for implementation periods.

Furthermore, the excessive maintenance cost for the 3# compressor due to illegal mining activities was eliminated. The cost involved in maintaining the 5.4 km pipeline between 3# and 4# was eliminated, since the pipeline could be removed after relocating the compressor. These were all factors that contributed to the potential cost savings involved in reconfiguring Mine C's compressed air network.

The relocation strategy complied with all the system compressed air requirements and constraints. The implementation cost was relatively cheap due to the availability of a refurbished compressor. Implementing this solution on the mine's compressed air network had a very large power savings potential. The savings potential was to such an extent that it would even have been feasible to install a new compressor (R15 million) at 5#.

The solution was presented to relevant mine personnel for approval. Mine C approved the proposed solution and installations commenced in March 2013. The installations are currently still in progress and are expected to be completed by the end of May 2014. The implemented results could therefore not be verified against the simulated and calculated results.

4.3 Energy efficiency by interconnecting two shafts

4.3.1 System background

At the time of the study, compressors at Mine D were approximately fifty years old. As discussed in Chapter 1, this was an indication that Mine D's compressed air network was old. Mine D's network comprised three shafts. The shafts will further be referred to as one shaft (1#), two shaft (2#) and three shaft (3#).

Production at Mine D declined over the years preceding the study. The expected remaining lifespan of 1# was approximately eleven years at the beginning of 2012, while mining at 2# was estimated at twenty-eight months remaining [48]. Both shafts were focusing on mining the shaft pillar and no future developments were planned. Mine D's 3# would be used to hoist ore from mining at the other two shafts and was being recommissioned for this purpose [48].

As part of the DSM programme, an ESCO implemented an EE strategy on 1#'s underground compressed air network during 2011. Control valves were installed on all the mining levels, including the sub-shaft that had been operational at the time. These control valves were used to reduce the compressed air demand on the mining levels, which in turn reduced the power consumption of the compressors on surface. Just prior to the study, the sub-shaft had been closed off due to its ineffective production. This caused a decrease in compressed air demand at 1#.

The change in mining operations at Mine D, especially the decrease in production, caused a reduced compressed air demand between these three shafts. The reduction was so significant that even the smallest compressors at the shafts generated an oversupply of compressed air during certain periods of the day.

The compressor at 2# was originally designed as a baseload compressor with no form of capacity control [38]. The compressor therefore continuously blew off excess air that eventually resulted in additional problems. The blow-off valve was not sufficient to increase the flow through the machine, preventing it to surge. To prevent failure on the compressor, the mine was forced to open underground valves at 2#. Control over the underground valves at 1# was also disabled, resulting in large amounts of compressed air and energy being wasted.

It was therefore essential to reconfigure Mine D's compressed air network at the lowest cost possible. The reconfiguration strategy had to contribute to a decrease in compressed air wastage at Mine D. In turn by reducing the air wastage, a decrease in compressor power consumption could be realised. The aim of the reconfiguration was also to reduce the amount of capital spent on maintenance and other costs.

4.3.2 Network analysis and constraints

Layout

As discussed, Mine D's compressed air network comprised three shafts. Two of these shafts (1# and 3#) were interconnected via a surface pipeline. The third shaft (2#) was a stand-alone shaft and was situated approximately 4 600 m from 1# and 3 000 m from 3# respectively. Figure 60 is a simplified schematic layout of Mine D's surface compressed air network.

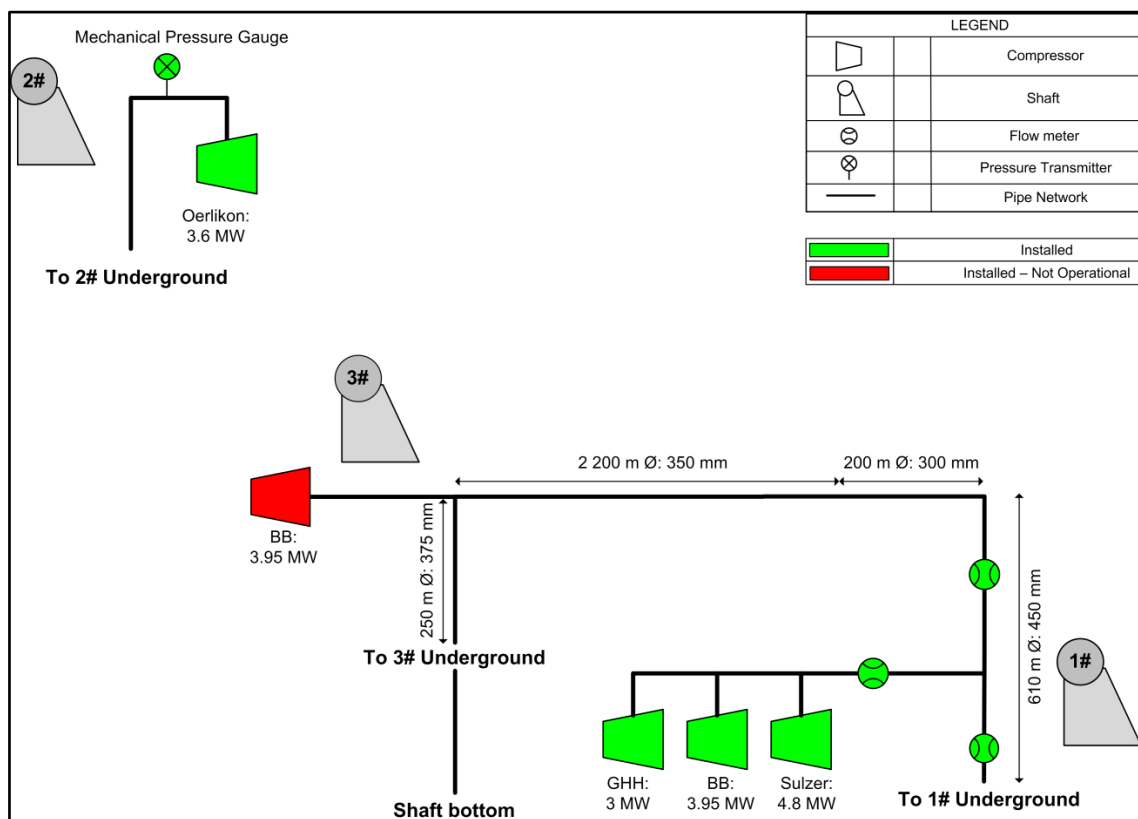


Figure 60: Schematic layout of Mine D's surface compressed air network

Supply side

Figure 60 indicates that Mine D used five compressors to satisfy the compressed air demand. The compressors at 1# were used to satisfy the demand of 1# and 3#. The compressor at 3# was not operational and the compressor at 2# supplied compressed air to the stand-alone 2#. Table 15 gives a brief summary of all the compressors that were used at Mine D and their location in the network.

Mine D Compressor Summary			
Shaft	Compressor	Installed Capacity	
		Power (kW)	Airflow (CFM)
1#	Sulzer	4 800	30 000
	BB	3 950	25 000
	GHH	3 000	20 000
2#	Oerlikon	3 600	25 000
3#	BB	3 950	25 000
Total	5	19 300	125 000

Table 15: Mine D compressor summary

The compressors at 1# were fully automated and could be controlled from the centralised control room located at 1#. The compressor at 2# was not automated and could not be monitored from the centralised control room. However, mine personnel were able to manually control the compressor by frequently visiting the compressor house located at 2#.

According to mine personnel, the compressor at 2# has not been thoroughly maintained over the years. As a result, mine personnel did not want to manually start and stop the compressor as it started with great difficulty and technical complications. The mine was concerned production would be negatively affected if they struggled to bring the compressor online after being stopped.

The compressor at 3# had been decommissioned several years ago and had been moved to the mine's salvage yard. This was due to the decrease in compressed air demand over the past few years. Compressed air was being exported from 1# to 3#.

The flow and pressure output of the compressors at 1# could be regulated (IGV control) according to the compressed air demand of 1# and 3#. The flow and pressure output of the compressor at 2# could not be controlled to match the compressed air supply with 2#'s demand [38]. The compressor was supplying the maximum amount of compressed air during high and low demand periods.

Demand side

The main compressed air consumers at Mine D were 1#, 2# and 3#. These three shafts were also the only shafts in the network that were still operational. At the time of the study, no additional processing plants formed part of the compressed air network.

Compressed air was required at 1# for peak-drilling periods, loading of ore, sweeping and supplying pressurised air to the refuge bays. At 2#, compressed air was required for the same purposes as 1#, except for the times of use that differed. Compressed air at 3# was required for agitation and loading as well as supplying pressurised air to the refuge bays and a small workshop. Table 16 represents the mining schedules of the three shafts and their surface compressed air requirements.

Mine D Compressed Air Requirement Schedule			
Shaft	Activity	Time Period	Required Surface Pressure (kPa)
1#	Peak drilling	08:00 – 14:00	450
	Loading	09:00 – 16:00 & 22:00 – 02:00	400
	Sweeping	09:00 – 16:00 & 22:00 – 02:00	400
	Refuge bays	00:00 – 24:00	150
2#	Peak drilling	06:00 – 15:00	450
	Loading	06:00 – 18:00	400
	Sweeping	06:00 – 18:00	400
	Refuge bays	00:00 – 24:00	150
3#	Agitation	00:00 – 24:00	400
	Loading	17:00 – 07:00	400
	Small workshop	06:00 – 15:00	150
	Refuge bays	00:00 – 24:00	150

Table 16: Mine D surface compressed air requirement schedule

The reason for the relatively low surface pressure requirements was due to the benefit of auto compression down the shafts. The three shafts at Mine D had approximately the same depths. It could therefore be assumed that the auto compression at all three shafts were more or less the same. Figure 61 illustrates the effect auto compression had on the compressed air pressure. According to the figure, the compressed air pressure at 1# increased with approximately 100 kPa from surface to the first mining level.

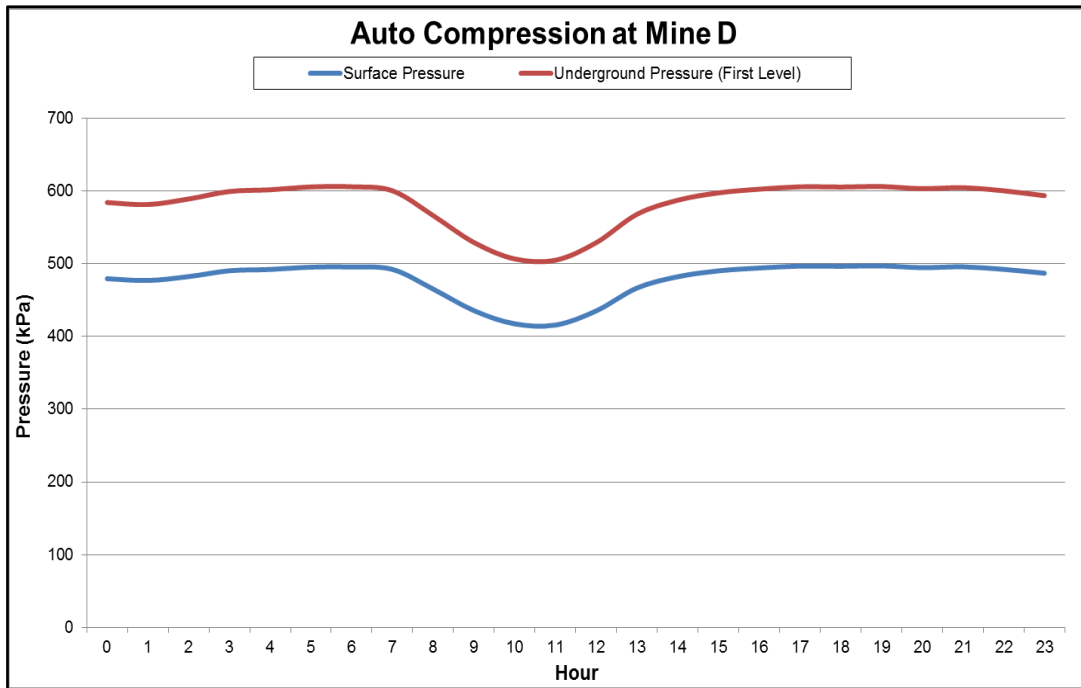


Figure 61: Effect of auto compression on the compressed air pressure at Mine D

The auto compression at Mine D differed slightly from Mine C. This was due to the difference in compressed air consumption and depth of the shafts. Mine D's consumption was lower than Mine C; Mine D was also slightly deeper. This was the reason for the higher gain in pressure at Mine D.

Air reticulation network

Figure 60 depicts the basic layout of Mine D's surface reticulation network. The network comprised approximately 3 300 m of commercial steel piping. The pipe network interconnected 1# and 3# and varied from 300 to 450 mm in diameter. It was difficult to determine the total length of the pipe network, since the majority of the network was underground, dividing into smaller sections on the mining levels. For the purposes of this study, only the surface reticulation network was evaluated.

The surface reticulation network was approximately thirty years old at the time of the study, but in a very good condition. Compressed air leaks due to corrosion on the pipe network were regularly repaired. Figure 62 illustrates the good condition of the surface pipe network. According to this figure, the average pressure loss from 1# to 3# was only 4 kPa throughout a normal working weekday.

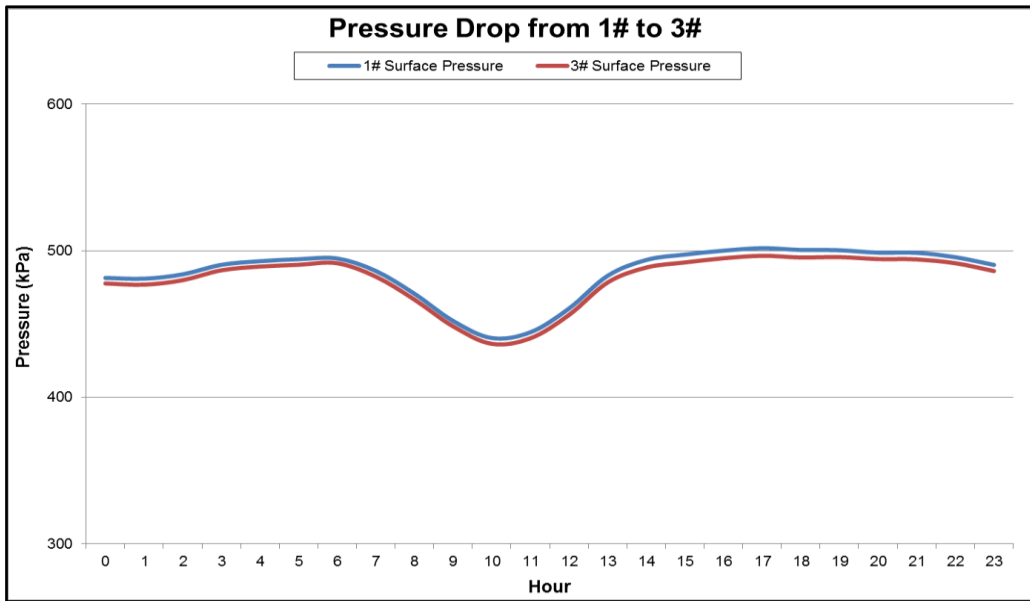


Figure 62: Pressure loss from 1# to 3# over a normal working weekday

Network constraints

According to Table 16 the maximum and minimum pressure requirements for the shafts were 450 kPa and 150 kPa respectively. The requirement periods differed for each shaft. Therefore, the network pressure was determined by the highest pressure requirement of the three shafts during the course of a normal working weekday. The reconfiguration strategy had to comply with these parameters. Figure 63 presents Mine D's average network pressure requirements against the maximum and minimum parameters, averaged between the shafts.

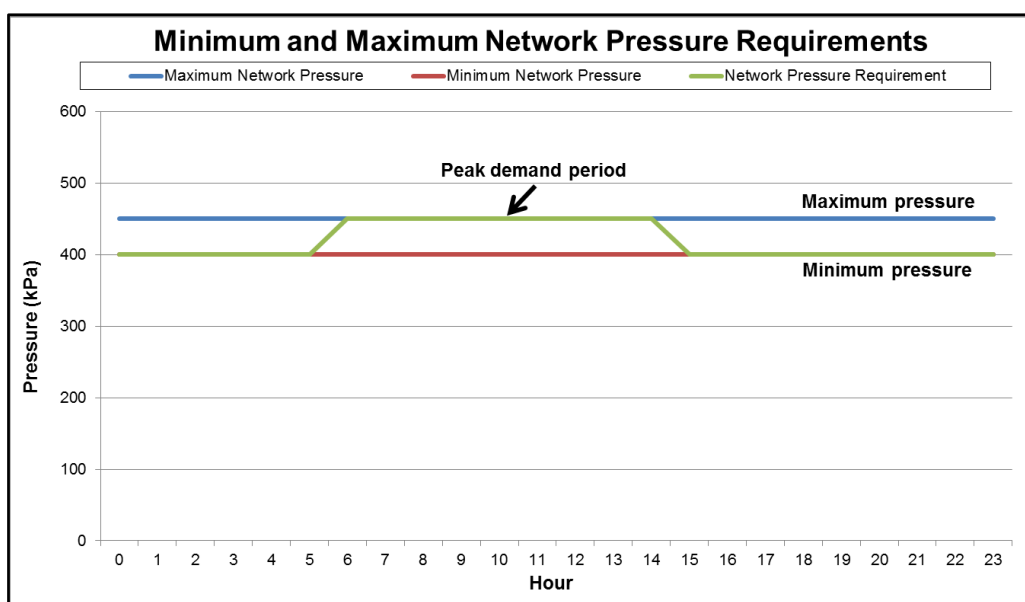


Figure 63: Mine D's minimum and maximum network pressure requirements

As with the previous case study, no specific flow requirements were available during the time of the study. Mine D did not have any record of the number of end-users requiring compressed air. Therefore, only the pressure requirements would be used during the reconfiguration of Mine D's compressed air network.

Relevant mine personnel were consulted to determine Mine D's plans for any future developments and changes in mining operations. Mine personnel confirmed that the only change would be the decommissioning of 2# when the shaft pillar extractions were complete. This had to be considered during the reconfiguration of Mine D's compressed air network.

4.3.3 Data processing and network operation

Identifying data-measuring points

Figure 64 illustrates all the measuring points that were identified. All the compressors at 1# had PPs. All the pressures and flows at 1# were also measured, including the flow from 1# to 3# (FPP). NPs were identified at 2# and 3#.

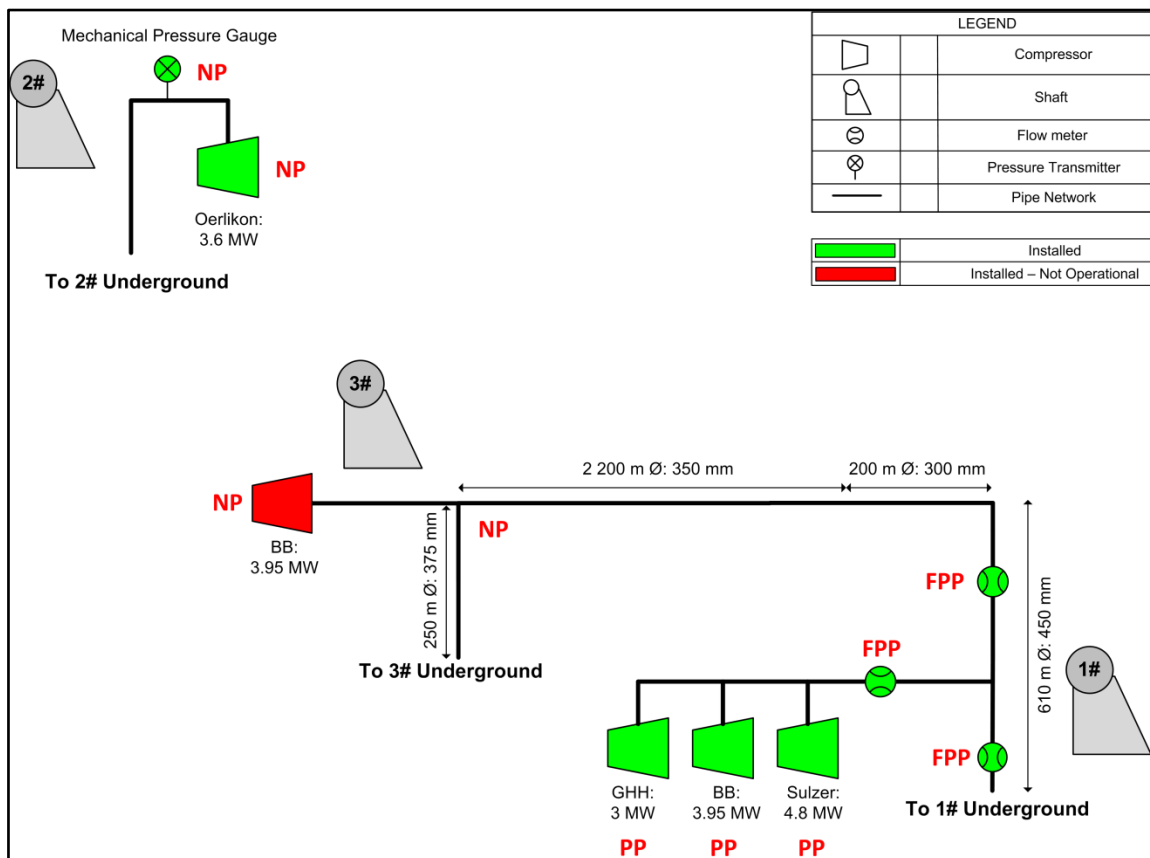


Figure 64: Simplified illustration of Mine D's data-measuring points

Data collection

All the data measured from the measuring points were logged on the local SCADA system. Relevant mine personnel were consulted to obtain a copy of the logged data. The data were used to determine the compressed air- and compressor power consumption trends of Mine D's compressed air network.

The data for 2# and 3# were not available on the mine's SCADA system. Communication failures and a lack of automated instrumentation prevented the data from being logged. Calibrated portable measuring equipment was installed to log the required data at 2# and 3#. The data was measured over an extended period to ensure accuracy and consistency. The flow at 3# was calculated by means of a flow balance.

Data evaluation

As with the previous case study, the mine's data was verified by installing calibrated measuring equipment. Once again, the data measured with the calibrated equipment proved to be approximately the same as the mine's measured data. The measured flows from the mine's flow meters were verified by a flow balancing between the mine's compressors and the total network consumption. Figure 65 displays the flow balance between 1#'s compressors and the measured air consumption at 1# and 3#.

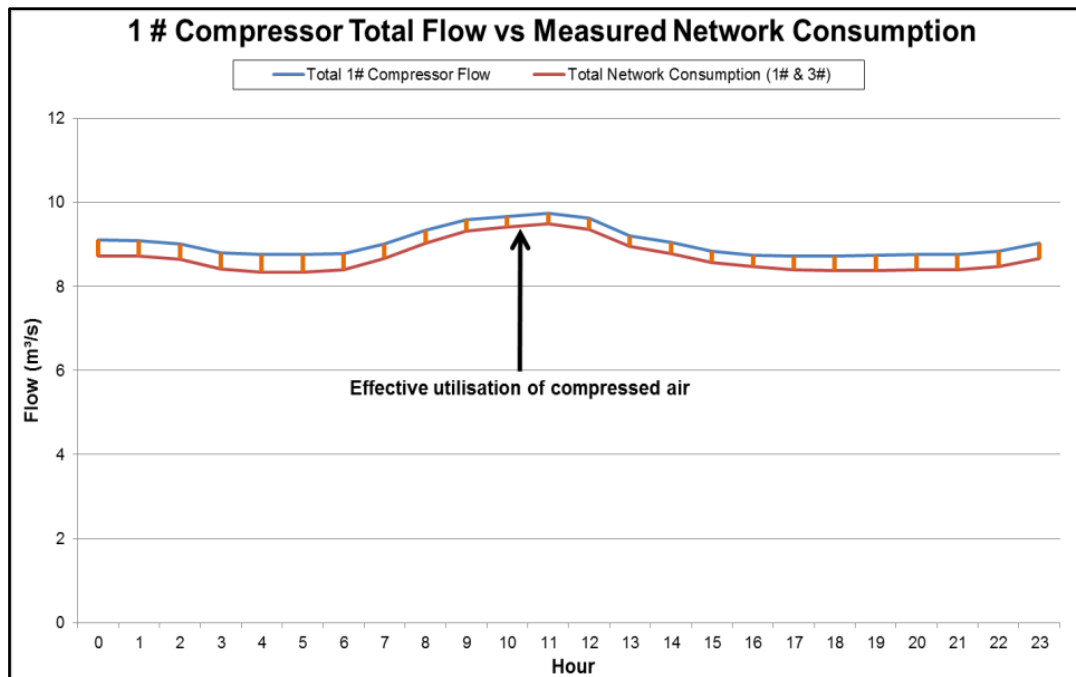


Figure 65: Flow balance between 1#'s compressors and air consumption at 1# and 3#

Considering air losses in the network, Figure 65 displays relatively accurate flow measurements for 1# and 3#. The assumption was therefore made that the flow data obtained from the mine was relatively accurate. The measured pressure data at 2# was compared to readings taken from the mechanical pressure gauge at 2#. The comparison proved to be consistent for the different measuring methods.

The following sections discuss the flow, pressure and power profiles developed with the collected data. The flow and pressure profiles were compared to the compressed air requirements of the end-users. Any compressed air wastages and shortfalls would be identified. The power baseline was developed with the combined compressor power data collected from all the compressors used in the network.

Flow profiles

Figure 66 is a graphical illustration of each shaft's compressed air consumption. It is evident from the graph that 1# was the main consumer in the network. The second highest consumer was 2#. The lowest consumer was 3# and this trend stayed relatively consistent throughout the day.

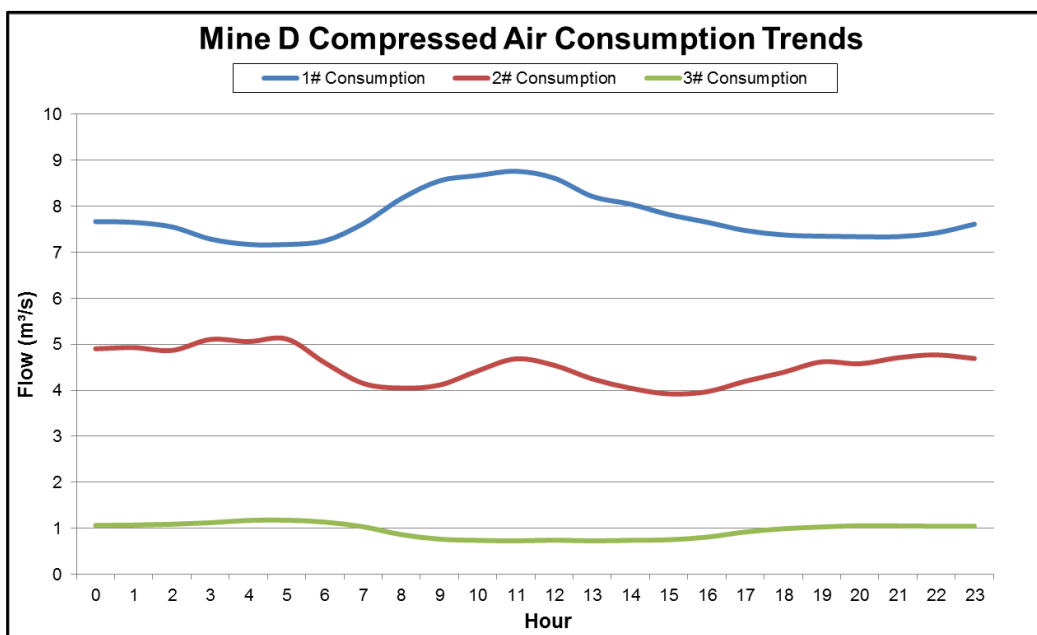


Figure 66: Mine D's compressed air consumption trends

The flow consumption trend of 1# corresponded with the mining operation and compressed air requirement schedule discussed in Section 4.3.2. The peak-drilling shift consumed the most compressed air with increased consumption between 08:00 and 14:00, as indicated on

Figure 66. A slight increase in air consumption was identified between 22:00 and 02:00 and it was due to loading and sweeping activities occurring during that time.

The flow consumption trend of 2# did not correspond with the schedule. According to mine personnel no mining activities were scheduled at 2# between 18:00 and 06:00. However, according to Figure 66 a large amount of compressed air was consumed during this time. After consulting with mine personnel, it was concluded that compressed air must have been consumed by illegal mining activities and major compressed air leaks. This scenario presented major reconfiguration opportunities.

Most of the compressed air at 3# was required for agitation and loading. Loading occurred between 17:00 and 07:00 and compressed air for agitation was required throughout the course of working weekdays. It was therefore safe to conclude that the air consumption trend at 3# corresponded with the mining schedule discussed in Section 4.3.2.

Pressure profiles

Figure 67 is a graphical illustration of each shaft's compressed air pressure profile. The pressure profiles of 1# and 3# approximately followed the same trend. This was because the two shafts were connected to the same compressed air supply. The slight pressure difference was due to pipe pressure losses occurring from 1# to 3#. The trend at 2# differed from the other two as the shaft was connected to its own air supply.

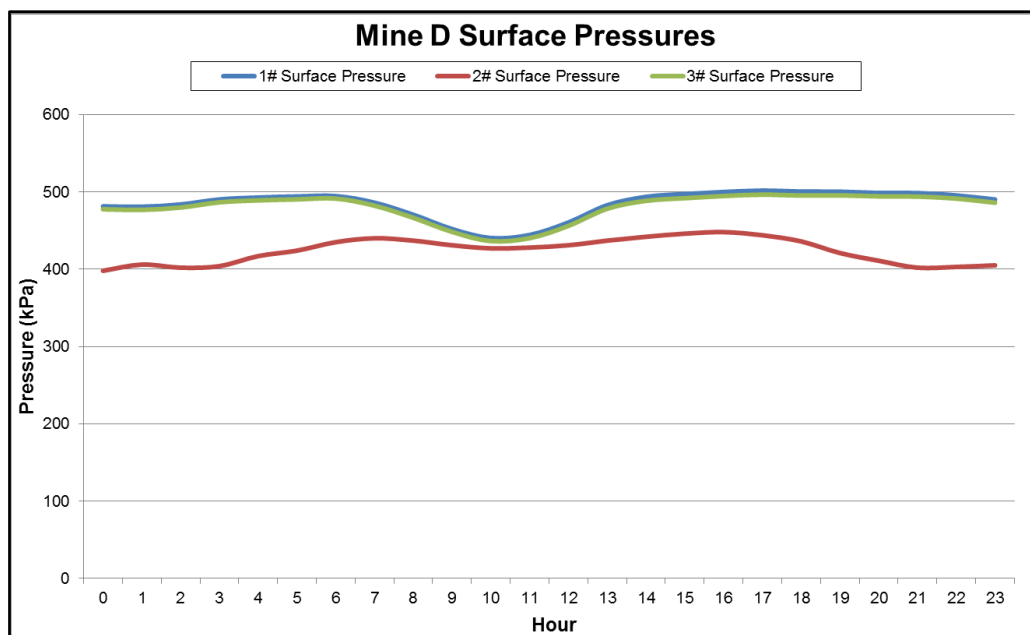


Figure 67: Mine D's surface compressed air pressure trends

According to Table 16 the drilling shifts at 1# and 2# were the periods with the highest pressure requirements at 450 kPa. According to Figure 67 and the pressure requirement trend developed in Figure 63, an under- and oversupply of compressed air occurred at all three shafts. Figure 68 to Figure 70 illustrate the under- and oversupply of compressed air to Mine D's consumers. The orange lines indicate the differences.

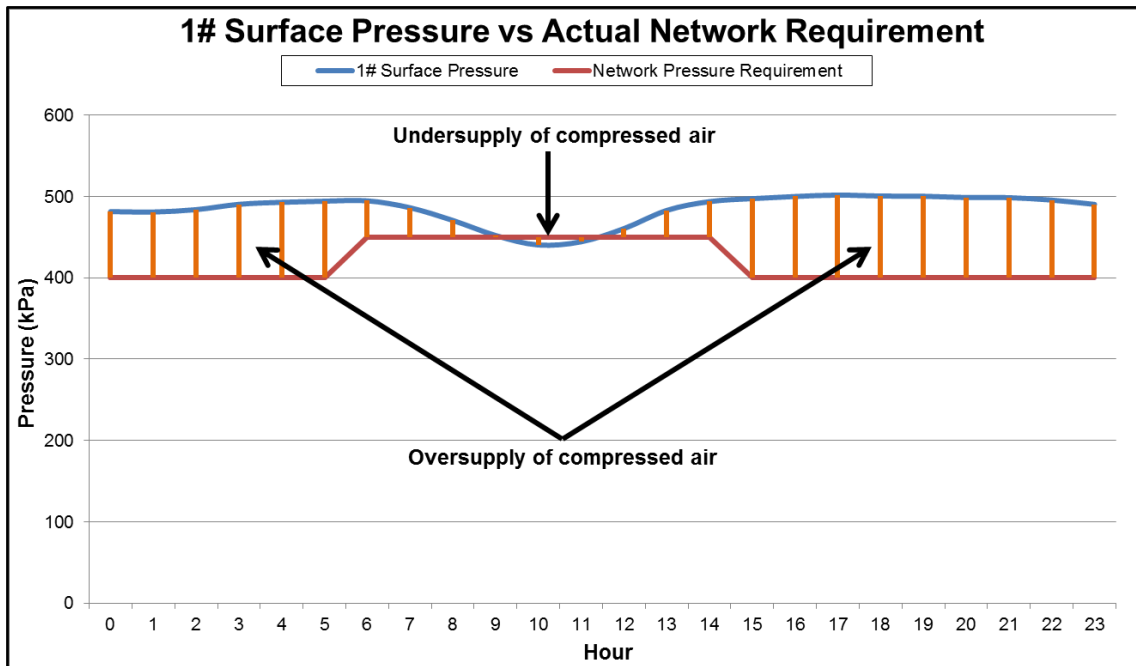


Figure 68: Undersupply and compressed air wastage at 1#

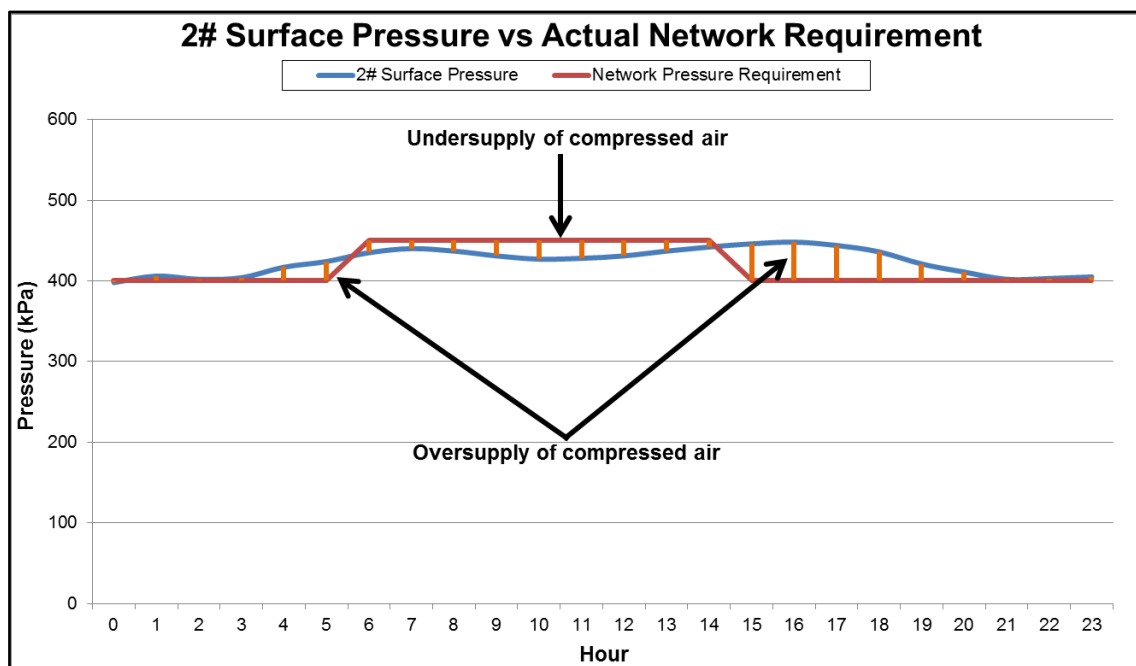


Figure 69: Undersupply and compressed air wastage at 2#

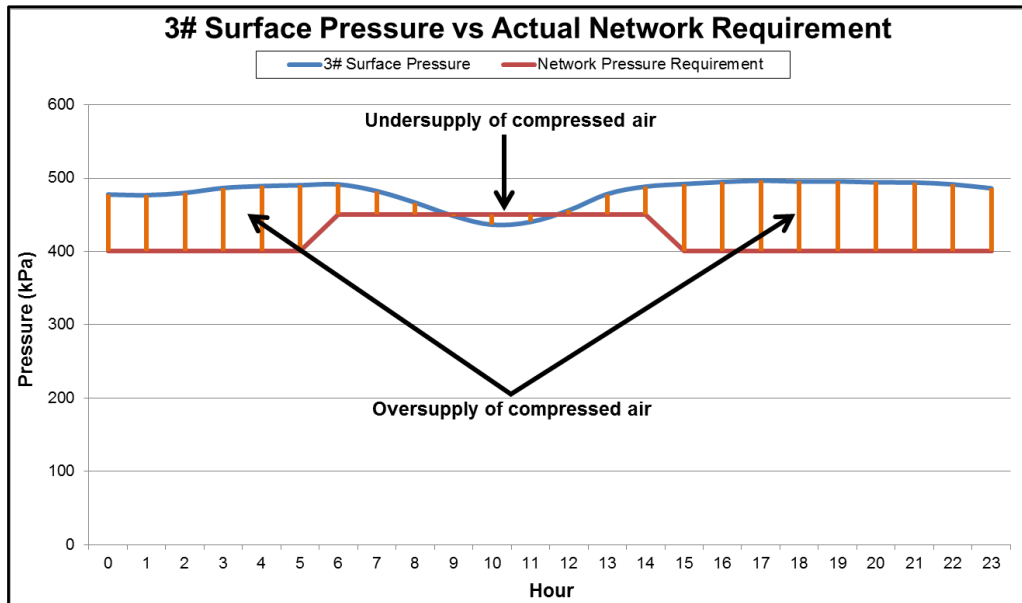


Figure 70: Undersupply and compressed air wastage at 3#

An air pressure of almost 500 kPa was supplied to 1# and 3# during sweeping, loading and no-mining activity periods. It was evident that a large amount of energy and compressed air were being wasted at these shafts. A slight undersupply of compressed air occurred during the drilling shift.

A compressed air pressure of more than 400 kPa was supplied between 18:00 and 06:00 at 2#. No mining activities occurred during this time and compressed air was only required for the refuge bays. This resulted in continuous compressor blow-off of the Oerlikon compressor at 2#. The situation at 2# contributed to the highest amount of energy and compressed air wasted in Mine D's compressed air network. The compressed air wastage is not identified in Figure 69 as the pressure profile has been plotted against the average network requirement profile.

The maximum pressure requirement at 3# was 400 kPa for agitation and loading. Compressed air was being supplied at pressures of 440 kPa and higher between 08:00 and 13:00. Compressed air was being supplied at almost 500 kPa for the remainder of the day. It was evident that an excess amount of compressed air was being supplied to 3#, which again resulted in large energy and compressed air losses due to blow-off of compressors at 1#.

The compressed air and energy wastage at Mine D presented large opportunities to reconfigure the compressed air network. The reconfiguration strategy had to be developed in such a manner that it would compensate for all the air requirements of the shafts, especially

during drilling shifts. The strategy also had to reduce the wastage of compressor power due to excess compressed air generation.

Power profiles

Individual and total power profiles were developed for Mine D's compressed air network. The profiles were developed under the same conditions and for the same purposes as for the previous case study. Figure 71, Figure 72 and Figure 73 represent the power profiles developed for Mine D's compressed air network.

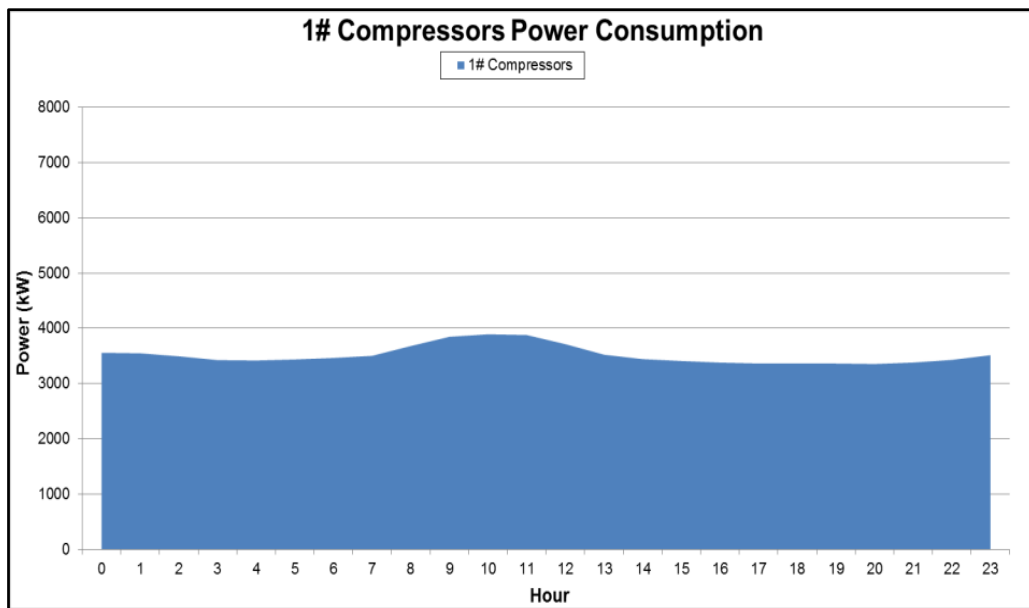


Figure 71: Mine D's 1# compressors power consumption

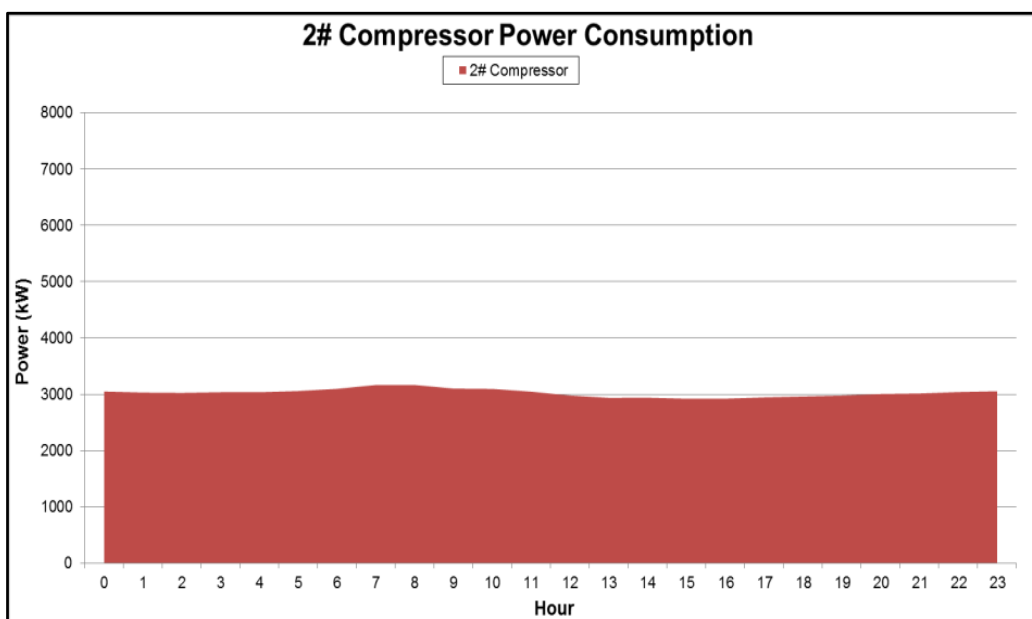


Figure 72: Mine D's 2# compressor power consumption

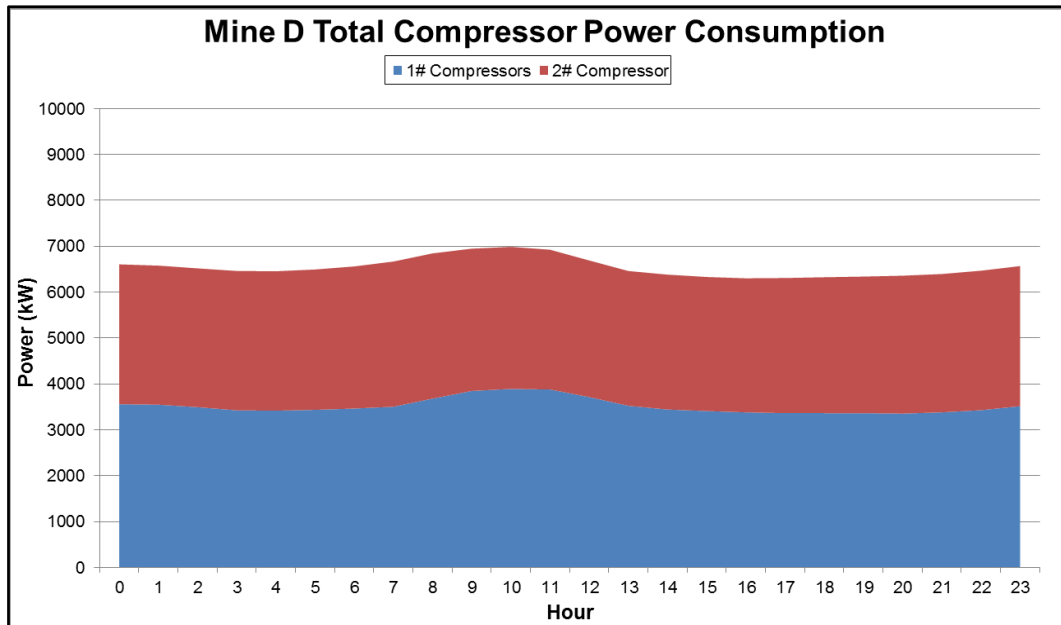


Figure 73: Mine D total compressor power consumption (power baseline)

Figure 71 represents the compressors' power consumption at 1#. The highest power consumption was measured during the drilling shift between 08:00 and 14:00 which remained relatively constant during the remaining period of the day. The compressors' power consumption decreased as the demand for compressed air from the end-users decreased. This was a clear indication of flow through the compressors being reduced during low demand periods.

Figure 72 represents the compressor power consumption at 2# where it is clear that the compressor was permanently functioning at maximum load.

Figure 73 represents the total power consumption of all the compressors used in Mine D's compressed air network. The compressors at 1# and the compressor at 2# are included in the total power profile (baseline).

4.3.4 Reconfiguration strategy development

Preamble

Mine D's network can be reconfigured based on Figure 61 to Figure 73. The following serves as motives for the solution development:

- high compressed air consumption occurs at 2# between 18:00 and 06:00, while no mining activities are scheduled;

- compressed air pressure supplied to the three shafts during certain periods are much higher than required; and
- compressor at 2# has no form of capacity control to match supply with demand.

Possible solutions

Two solutions were identified to reconfigure Mine D's compressed air network, as illustrated in Figure 74. The letters A and B refer to the two possible solutions.

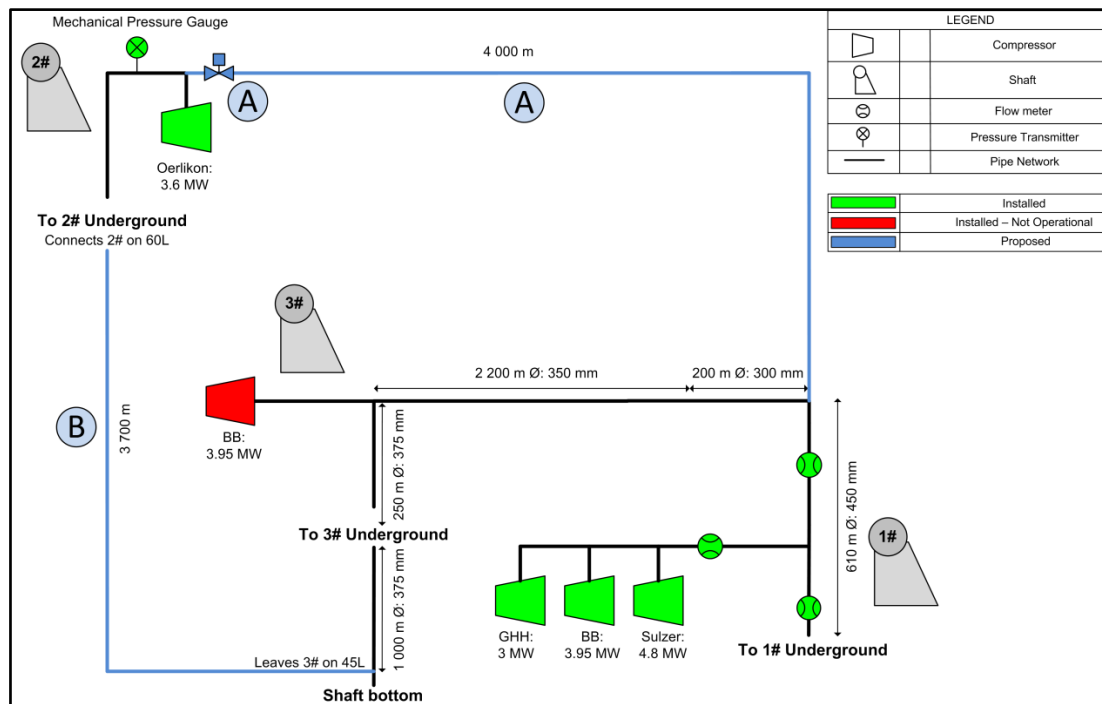


Figure 74: Possible reconfiguration solutions for Mine D's compressed air network

Solution A

Solution A entailed the installation of a 4 000 m surface pipeline, interconnecting 2# with the rest of the network. The compressor at 2# could be stopped as the pipeline could be used to export excess compressed air from 1# to 2#. An additional control valve, indicated on Figure 74, could be installed at 2# to regulate the airflow during the low demand periods. Using the control valve might result in a potential compressor stop at 1#, resulting in further power savings.

The solution was based on the availability of 350 mm (outer diameter) and 450 mm (outer diameter) pipe sections in Mine D's salvage yard. The pipe sections were recovered from a decommissioned pipeline at one of the shafts within the mining company. According to mine personnel, enough piping was available to cover a distance of approximately 4 500 m.

Practical constraints

A pipeline installation requires many man-hours. The installation time can vary from three to twelve months, depending on complications encountered. Considering the lifespan of the mine, installation time could play a crucial role in determining the viability of Solution A.

Costing constraints

Steel piping is very expensive, especially for a distance of 4 000 m. A quotation for 450 mm steel pipes, covering a distance of 4 000 m, was obtained. An amount of R10 million was required for the piping alone. The quotation excluded fasteners, installation and additional equipment. This solution would not have been considered if salvaged pipes were not available. The cost savings over the remaining lifespan of the mine would not have justified the implementation costs.

Solution B

Solution B presented the option to connect 2# and 3# using an underground pipeline. The compressor at 2# could be stopped and compressed air could be exported from 1# to 2# via the interconnecting pipeline at 3#. This solution seemed to be the most viable, because Mine D had already partially installed a 250 mm compressed air pipeline between 2# and 3#. The mine also had salvaged pipes available for further installation. Letter *B* on Figure 74 presents the proposed compressed air pipeline.

Practical constraints

The compressed air pipeline between 2# and 3# had to be refurbished prior to implementing this solution. Missing sections in the pipeline had to be installed and commissioned. It was difficult to transport pipe sections from the shaft's surface to underground operations.

The diameter of the installed pipeline also seemed too small for 2#'s compressed airflow requirements. The compressors at 1# would supply compressed air via 3# through an approximately 8 000 m pipeline. Considering the pipe diameter and length of the pipeline, the pressure losses would be significantly high over this distance. However, the feasibility of Solution B would be revealed during the theoretical analysis.

Costing constraints

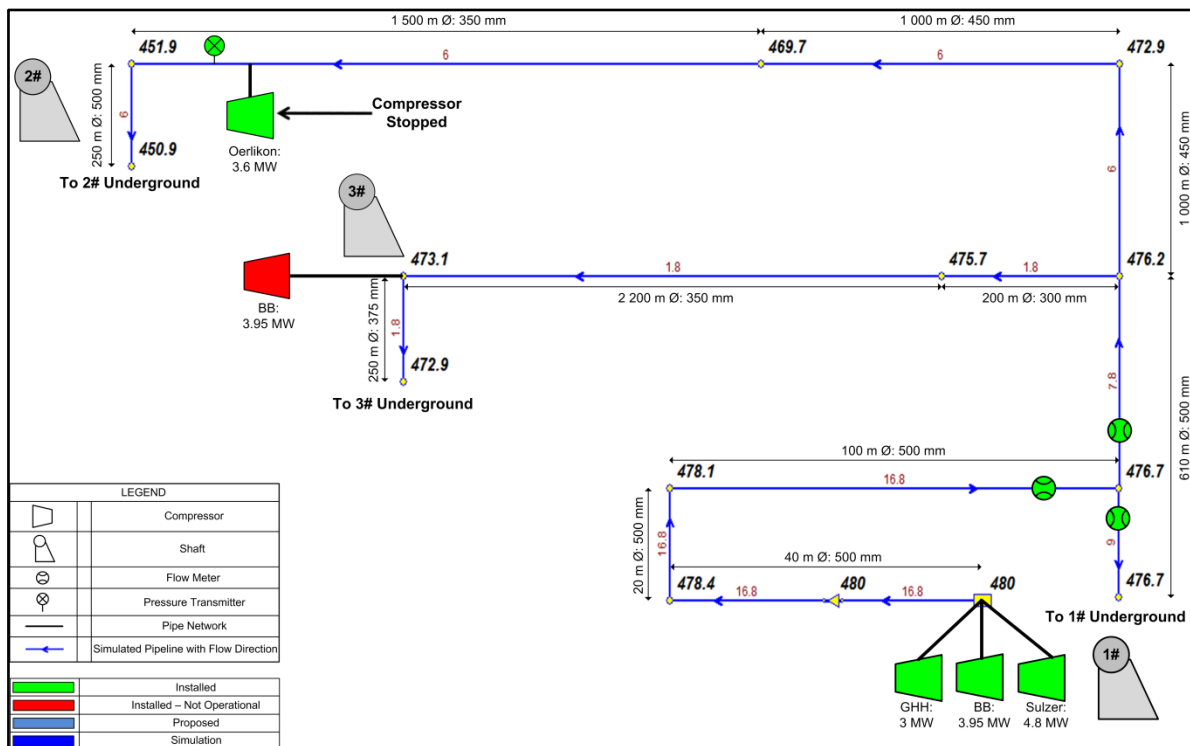
The same costing constraints applied as for Solution A.

Theoretical analysis and calculations

Simulations and mathematical models were developed under the same conditions and assumptions as for the previous case study. The only difference was a compressor discharge set point of 480 kPa was used for this case study. The results of the simulations and calculations were compared to one another. The comparison would identify each solution's capability to satisfy Mine D's compressed air requirements.

Solution A analysis results

Figure 75 represents the simulated results for proposed Solution A. The maximum compressed air consumption of each shaft (referring to Figure 66) was used during the development of the simulation. These values included a safety factor of 5% for minor changes in operations. The air consumption of each shaft is indicated in red on Figure 75. The simulated system pressures are indicated in bold black letters above each node in the simulation.



The simulation was developed by assuming that the available salvaged pipe sections would be used for the interconnecting pipeline. The interconnected pipe section had to consist of 2 000 m of 450 mm diameter, 1 500 m of 350 mm diameter and 250 m of 500 mm diameter pipe sections. The mine had these pipe sections available.

According to Figure 75, a pressure of approximately 477 kPa was delivered to 1# at a flow rate of 9 m³/s. Pressures of 473 kPa at 1.8 m³/s and 451 kPa at 6 m³/s were delivered to 3# and 2# respectively. These values complied with the surface compressed air requirements of the shafts, previously discussed in this chapter. This was an indication that this solution was viable.

Equation 1 to Equation 5 were used to calculate the compressor power required to satisfy the air requirements of Mine D's reconfigured compressed air network. Figure 76 illustrates the compressor power required to satisfy Mine D's compressed air demand over a weekday profile. The calculations were done with and without the use of the control valve at 2#.

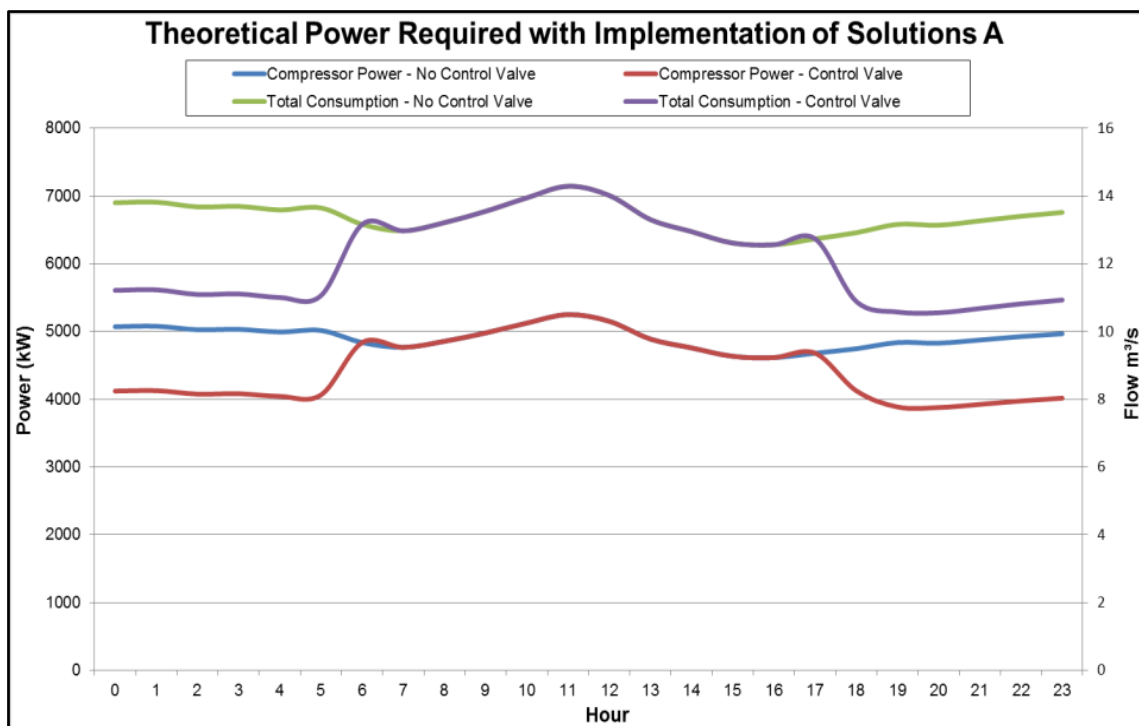


Figure 76: Compressor power required by implementing Solution A

Considering the installed capacities of the compressors at 1#, Figure 76 illustrates that two compressors would be permanently required without the control valve at 2#. If a control valve was used at 2# to regulate the flow and pressure between 18:00 and 06:00, only the largest compressor at 1# would be sufficient. Only two compressors would be required to satisfy the compressed air requirements during peak demand periods. Financially, it was more beneficial to include a control valve in the reconfiguration procedure.

Solution B analysis results

Figure 77 represents the simulated results for proposed Solution B. The simulation model for Solution B was developed under the same conditions as for Solution A, except that the interconnecting pipeline differed. The simulation was compiled using the 250 mm diameter pipeline section of 1 450 m that was already installed at the time. The remaining 2 250 m section was simulated with a 350 mm diameter pipeline.

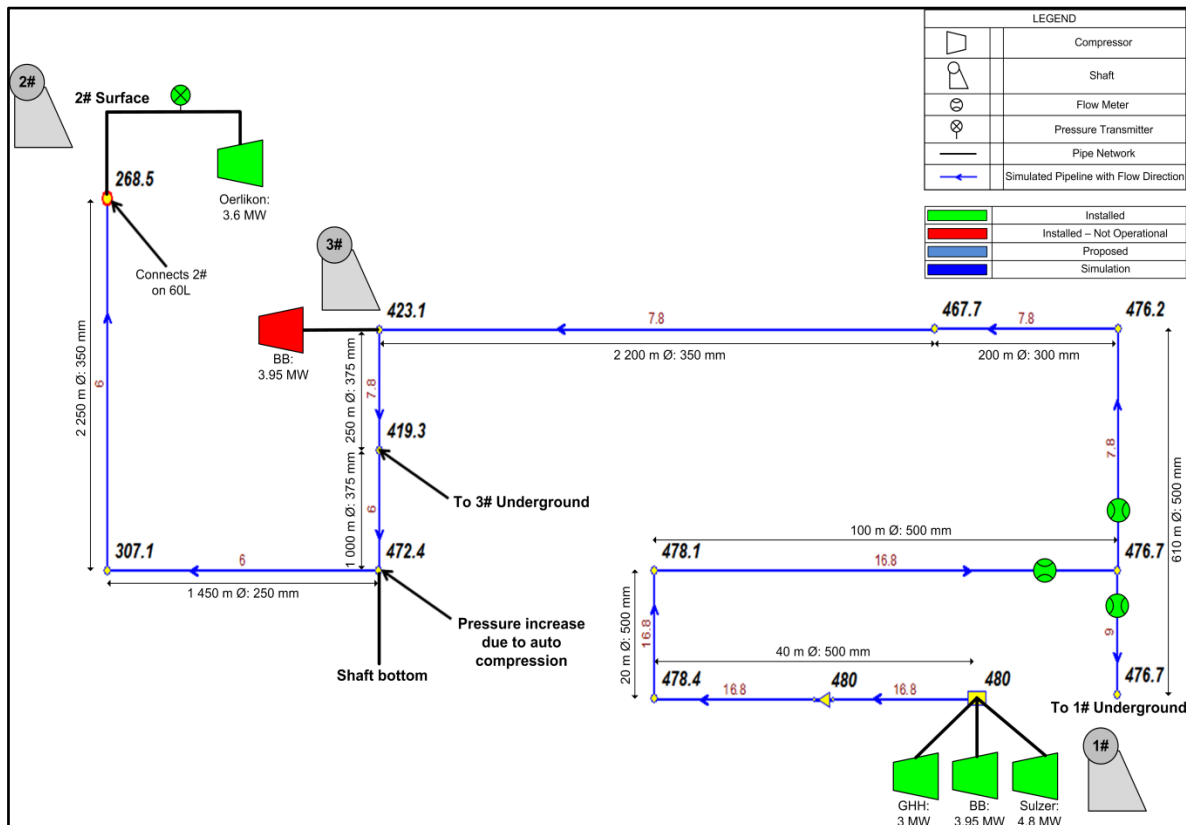


Figure 77: Simulation model for proposed Solution B

According to the simulation model, a pressure of approximately 477 kPa was delivered to 1# at a flow rate of 9 m³/s. Pressures of 423 kPa at 7.8 m³/s and 269 kPa at 6 m³/s were delivered to 3# and 2# respectively. The underground pressure at 3# increased from 419 kPa to 472 kPa. This was due to the effect of auto compression. A pressure drop of approximately 165 kPa occurred from 3# to the end of the 250 mm pipe section. From there the air pressure further dropped to 269 kPa at 2#.

This solution complied with the compressed air requirements of 1# and 3#, but not with the compressed air requirements of 2#. According to the pressure requirement schedule (referring to Table 16), 2# required an air pressure of 450 kPa during peak demand periods.

If this solution was to be implemented, a maximum pressure of 269 kPa would be achieved, regardless of the number of compressors running. This was due to the 250 mm diameter pipe section between 2# and 3#. Higher pressures with this configuration would only be achieved if the discharge pressures of the compressors and pipe diameters were increased.

Figure 78 illustrates a simulation developed with different network conditions. The compressors operated at higher discharge pressures. The pipe diameter after the 250 mm section between 2# and 3# had also been increased to 500 mm. These changes contributed to delivering the required air pressure of 450 kPa at 2# during peak demand periods. The changes are encircled with red in Figure 78.

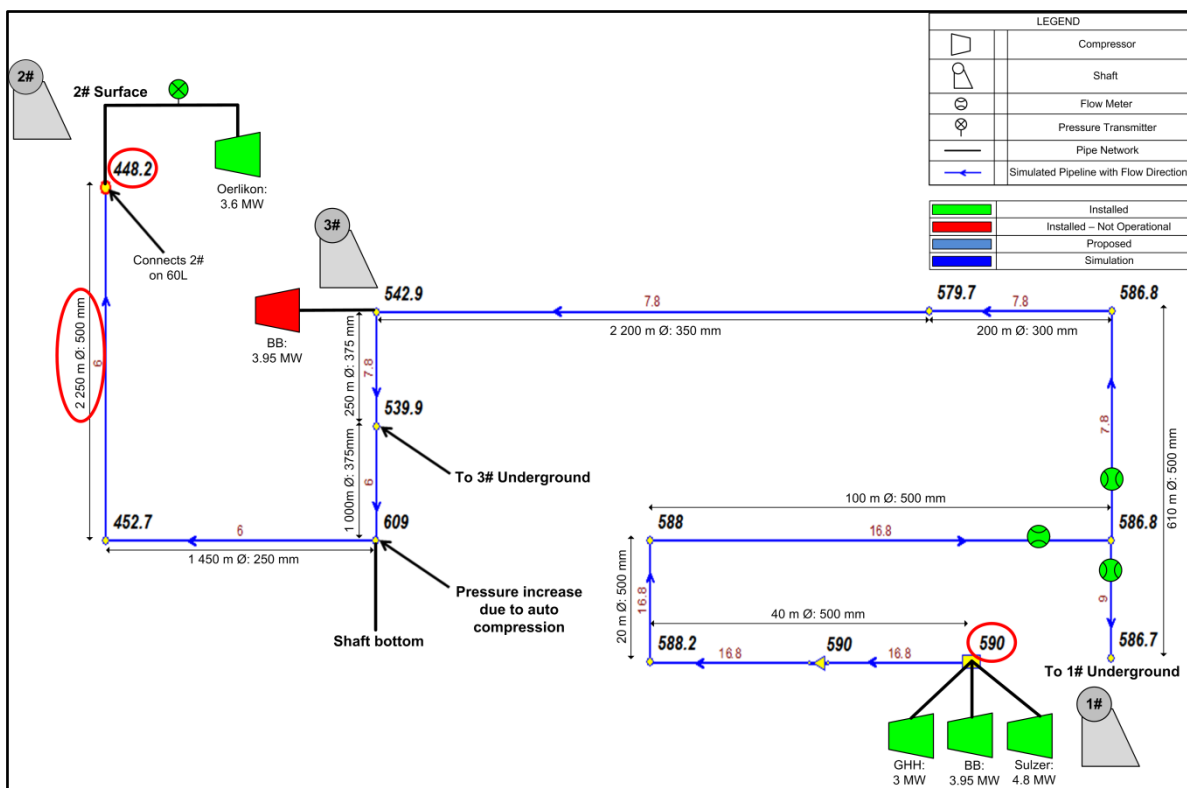


Figure 78: Revised Solution B - increased discharge pressures and pipe diameters

According to Equation 5, higher operating pressures signify higher power consumption on the compressors. Figure 79 illustrates the higher power consumption on the compressors due to the higher operating system pressures. As with Solution A, a control valve could be installed underground at 2# to regulate the compressed air between 18:00 and 06:00. The daily power consumption with the installed control valve is also displayed in Figure 79.

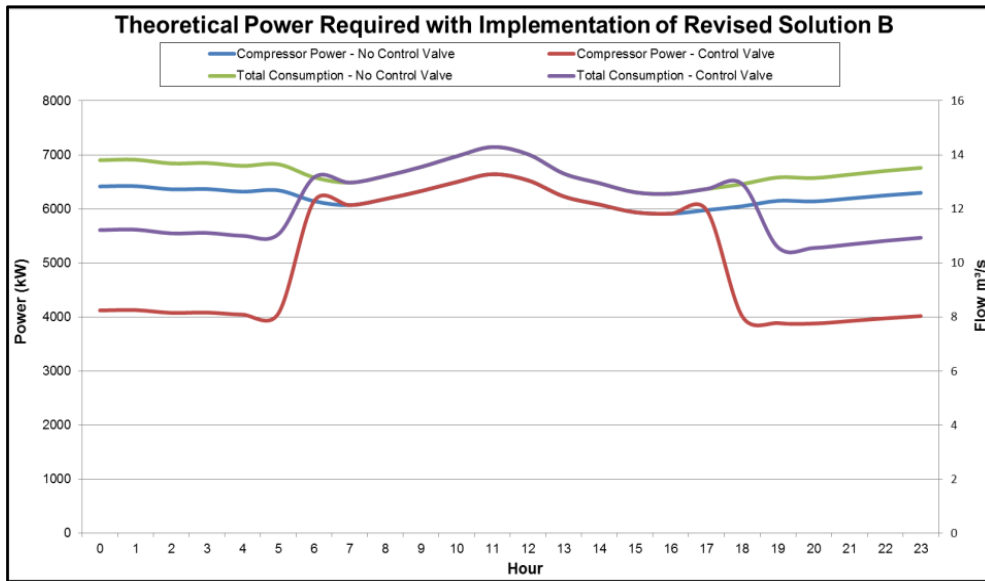


Figure 79: Compressor power required by implementing revised Solution B

Savings potential

Solution A had a potential daily average power saving of approximately 1 900 kW on Mine D’s compressors. Implementing revised Solution B had a potential daily average power saving of approximately 1 400 kW. This saving could only be achieved if the discharge set points on the compressors were reduced to 480 kPa and the control valve was throttled to deliver 150 kPa between 18:00 and 06:00. The potential saving with Solution A was achieved without changing any set points and by just controlling the valve at 2#. Figure 80 illustrates the proposed power savings for Mine D’s compressors by implementing Solution A and revised Solution B.

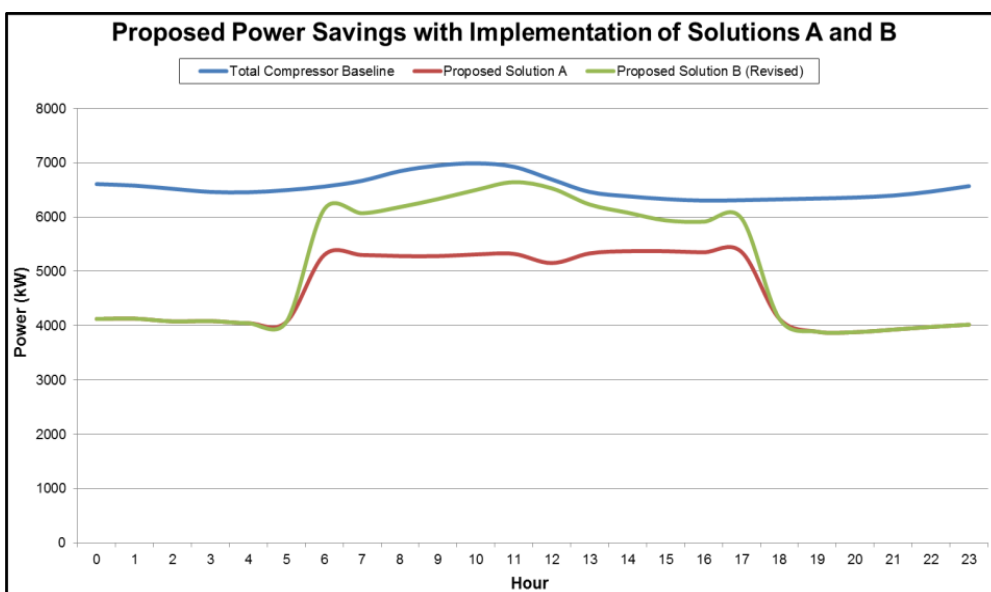


Figure 80: Proposed power savings for the solutions measured against the baseline

The implementation costs for both solutions were approximately R500 000, since Mine D had most of the equipment available in its salvage yard. Payback periods by implementing Solution A and revised Solution B were approximately three and four weeks respectively.

The total saving on the electricity bill was calculated over a period of one year to compensate for the installation time to implement the solutions. The annual proposed amount of money saved on the electricity bills was approximately R8.6 million for Solution A and R6.2 million for revised Solution B. The financial savings were calculated with the 2012/2013 Eskom tariff.

Solution selection

Considering the lifespan of Mine D's 2#, Solution A was the most appropriate solution to reconfigure the network. Solution A complied with all the system compressed air requirements and offered the option with the highest overall cost saving. Solution A offered a cost saving of approximately R8.1 million (financial savings minus implementation cost), while revised Solution B offered a cost saving of R5.7 million (financial savings minus implementation cost). This was a difference of nearly R2.5 million over the expected lifespan (one year after implementation) of the mine.

Solution A was presented to relevant mine personnel for approval. Mine D approved the proposed solution and commenced with the installation of the interconnecting pipeline. The aim was to complete the installations by the end of 2012 to start realising the proposed savings by March 2013. This gave the mine a cost saving lifespan of exactly one year.

The detailed implementation and practical results is discussed in the following section.

4.4 Implementation and results

4.4.1 Installations

Installation of the proposed infrastructure to reconfigure Mine D's compressed air network commenced at the start of 2012. The installation of the interconnecting pipeline was completed by the end of October 2012. The control valve at 2# was installed by the end of February 2013. Final commissioning of the proposed flow meters was only completed by the end of September 2013. Figure 81 illustrates the proposed infrastructure and interconnecting pipeline installed between 1# and 2#.

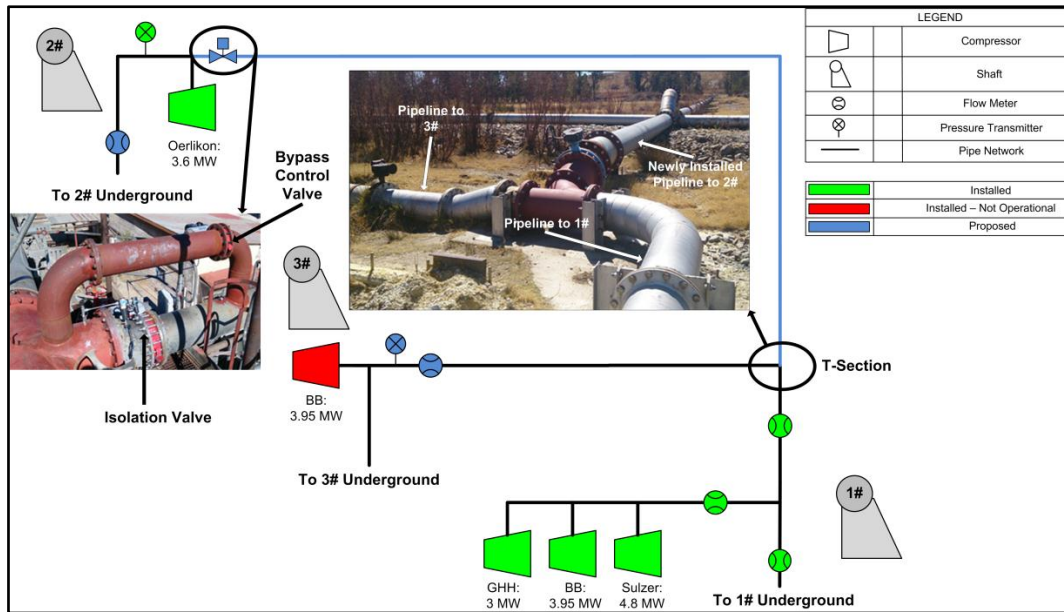


Figure 81: Proposed infrastructure to reconfigure Mine D's compressed air network¹⁵

The pipeline varied between 350 and 500 mm in diameter from 1# to 2#. This was due to the availability of 350 to 450 mm diameter pipes in the mine's salvage yard. The 500 mm section was from 1# to the T-section shown in Figure 81. Figure 82 indicates sections of the installed interconnecting pipeline from the T-section to 2#.



Figure 82: Interconnecting pipeline installed to export compressed air from 1# to 2#¹⁶

¹⁵ Photos taken by Johan Bredenkamp at a South African gold mine.

¹⁶ Photos taken by Johan Bredenkamp at a South African gold mine.

The control valve to optimise the reconfigured network at Mine D was installed at 2# and is illustrated in Figure 81. The control valve was installed in a bypass configuration. A 450 mm isolation valve was installed on the main line with a 250 mm control valve over the isolation valve. The reason for the smaller bypass valve was to improve the control over the air flowing to 2#. Additional flow and pressure monitoring equipment were also installed. This would enable mine personnel to constantly monitor the conditions throughout the network.

4.4.2 Control and optimisation

A Real-Time Energy Management System (REMS) was used to automatically control the valve at 2#. The control system would determine the set point for the bypass valve configuration. The software package was also used to monitor and log the network conditions (flows and pressures) of the reconfigured system. Figure 83 and Figure 84 are screenshots of the REMS software used at Mine D.

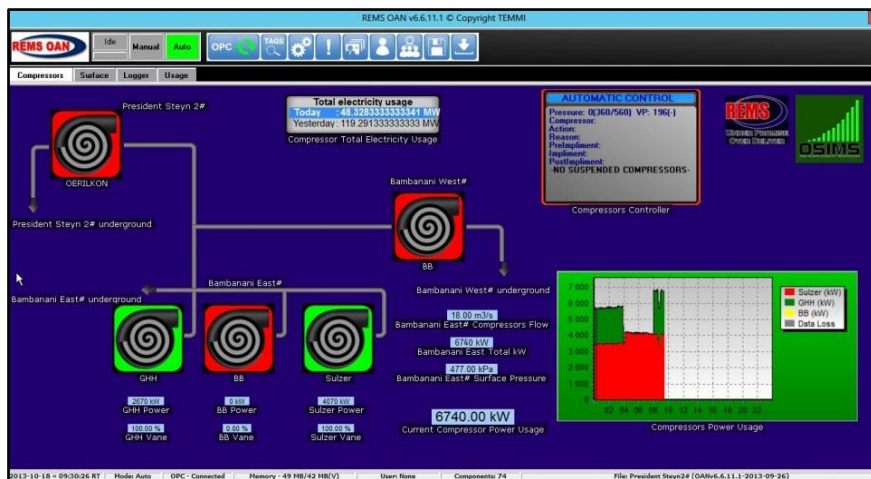


Figure 83: REMS screenshot of the compressor monitoring page

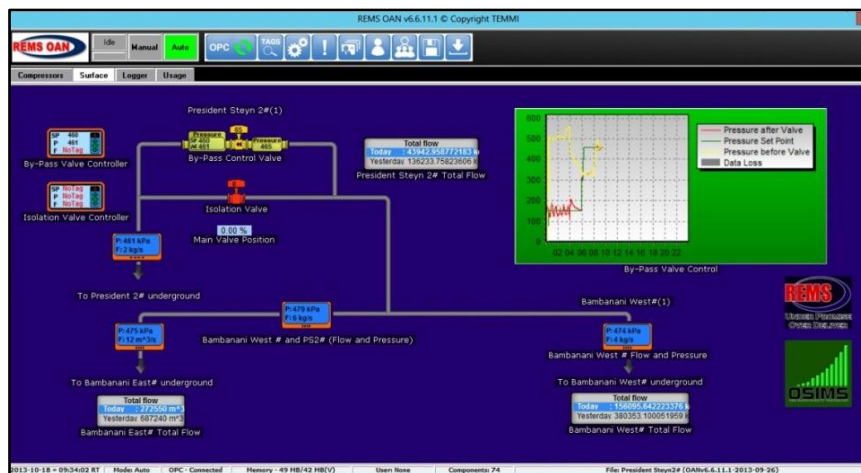


Figure 84: REMS screenshot of the valve control and network monitoring page

The valve operation would generally entail a reduction in 2#'s pressure during non-production and other low demand periods (18:00 to 06:00). This would ensure an increase in the network's pressure, which in turn would provide the opportunity for one of 1#'s compressors to be turned off. The compressor would be started in the mornings when the valve at 2# opens and the network pressure would decrease. An example of typical operation during a normal working weekday is illustrated in Figure 85.

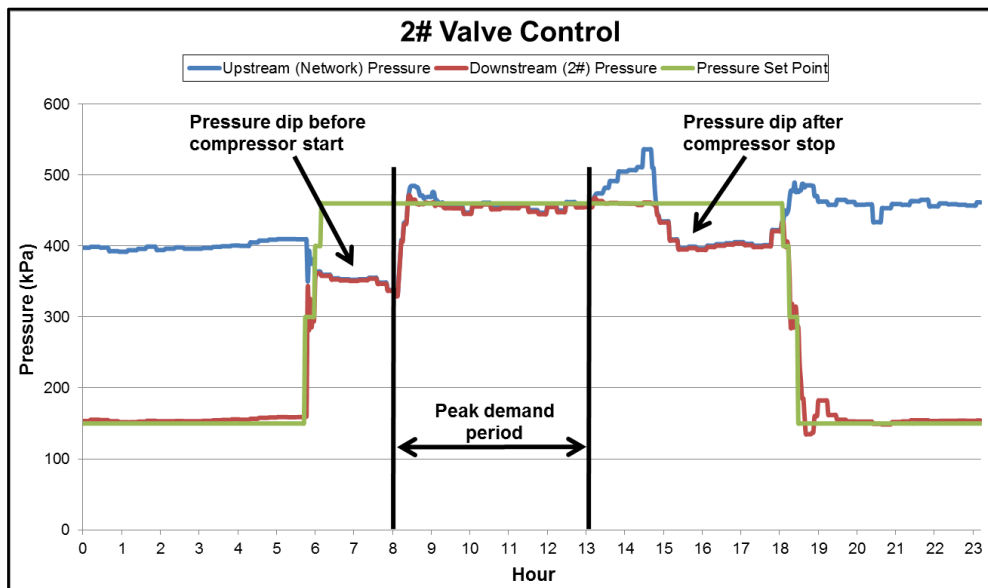


Figure 85: Bypass valve control at 2# during normal mining weekdays

According to Figure 85, the second compressor was normally started at 08:00 to supply sufficient air pressure (450 kPa) for the drilling shift. The compressor was turned off again at 15:00 when the system pressure increased rapidly. From 15:00, a constant network pressure of 400 kPa was maintained until the valve at 2# was closed, maintaining a downstream pressure of 150 kPa at 2#. The valve contributed to maintaining a sufficient network pressure for mining operations (1# and 3#) from 18:00 to 06:00. The 150 kPa supplied to 2# was sufficient for the refuge bays.

4.4.3 Savings results

Performance assessment (PA) for the project commenced on 1 March 2013 and continued for a consecutive three-month period. The results proved an average power saving of 1 700 kW over a daily profile. Figure 86 represents the average compressor power profile constructed over the PA period, compared to the baseline constructed prior to implementation.

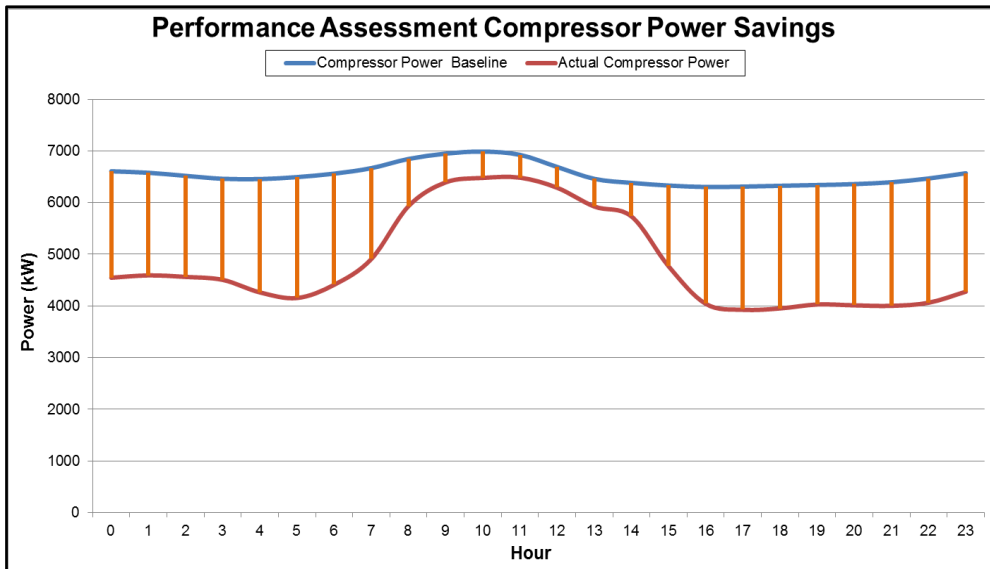


Figure 86: Compressor power savings achieved during PA

The impact of the reconfiguration strategy is evident on Figure 86. It was possible to switch off a compressor during certain periods of the day, whereas prior to implementation it was not possible. A further improvement on the savings was realised when a major compressed air leak was fixed on the underground reticulation network. The average power saving on the compressors over a weekday profile was improved by approximately 300 kW. Figure 87 illustrates the increased compressor power savings as a result of fixed air leaks.

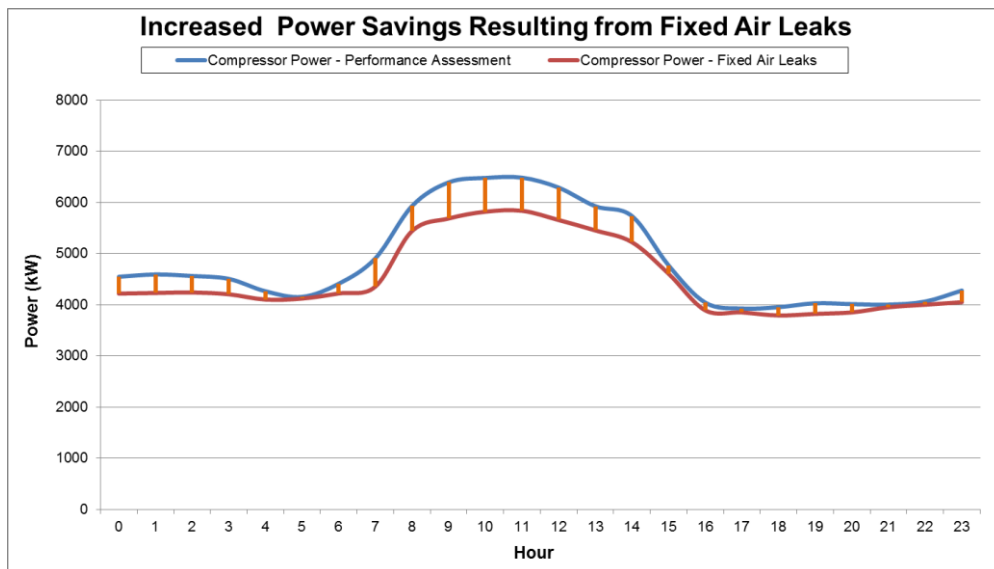


Figure 87: Improved compressor power savings after fixing the air leaks at 1#

A further financial saving was achieved on reduced maintenance costs on the compressors. The compressor at 2# was constantly switched off and resulted in reduced friction on the

machine. The exact maintenance saving is unknown as Mine D did not have these figures available. The practical results obtained reflected upon relatively accurate predictions made by the author.

The theoretical and practical comparison is discussed in the following section.

4.4.4 Theoretical and practical comparison

The average predicted saving through simulations and calculations reflected an average error margin of approximately 12%, compared to the actual PA data. The margin decreased to approximately 9% after fixing major leaks on Mine D's underground network. Figure 88 is a graphical comparison between the baseline, PA power profile, reduced power profile (fixed air leaks) and the simulated power profile.

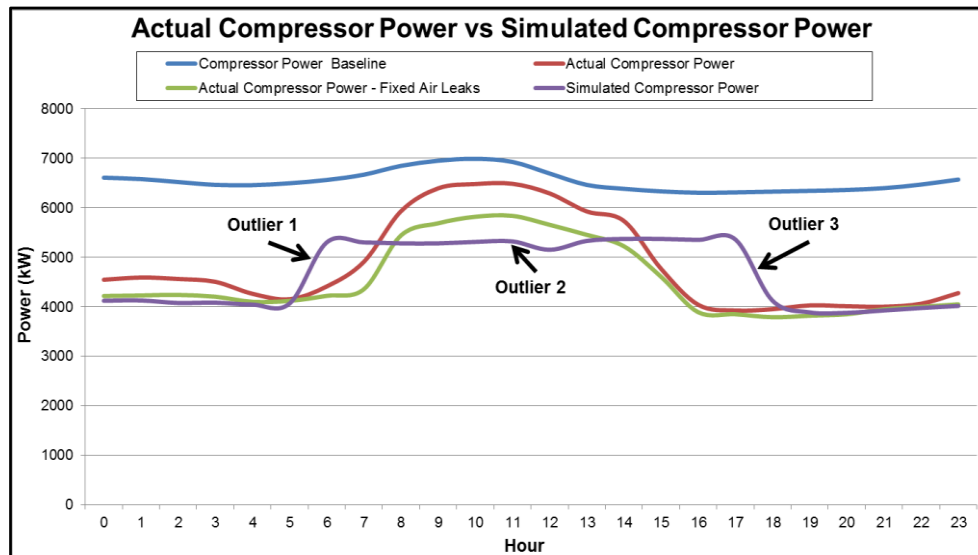


Figure 88: Comparison between the simulated and actual compressor power usage

Simulation software, such as KYPipe, does not compensate for air losses (air leaks) in a network. It is evident from Figure 88 that when the air leaks were fixed the margin between the actual profile and simulated profile decreased. However, Outlier 1, Outlier 2 and Outlier 3 were still identified in the trends.

The simulations were originally developed according to data received from relevant mine personnel. According to the data and the mine's requirements (stated by mine personnel), the second compressor was only meant to be switched off at 18:00 and started at 06:00. After reconfiguration, demand from 06:00 to 08:00 and from 14:00 to 18:00 decreased. The start of the second compressor could be delayed until 08:00 and could be stopped at

15:00. Outlier 1 and Outlier 3 were the results of decreased consumption and changed compressor schedules.

Equation 1 was used to calculate the amount of power required by a centrifugal compressor to deliver a certain flow at a certain air pressure. Through Equation 1 it was determined that approximately 5 300 kW was required to satisfy Mine D’s maximum compressed air demand. Unfortunately, a power reduction to 5 300 kW was not possible when two of Mine D’s compressors were running. The installed capacities of the compressors did not allow for this reduction. Figure 89 and Figure 90 demonstrate the performance of the two compressors that were mainly used at Mine D.

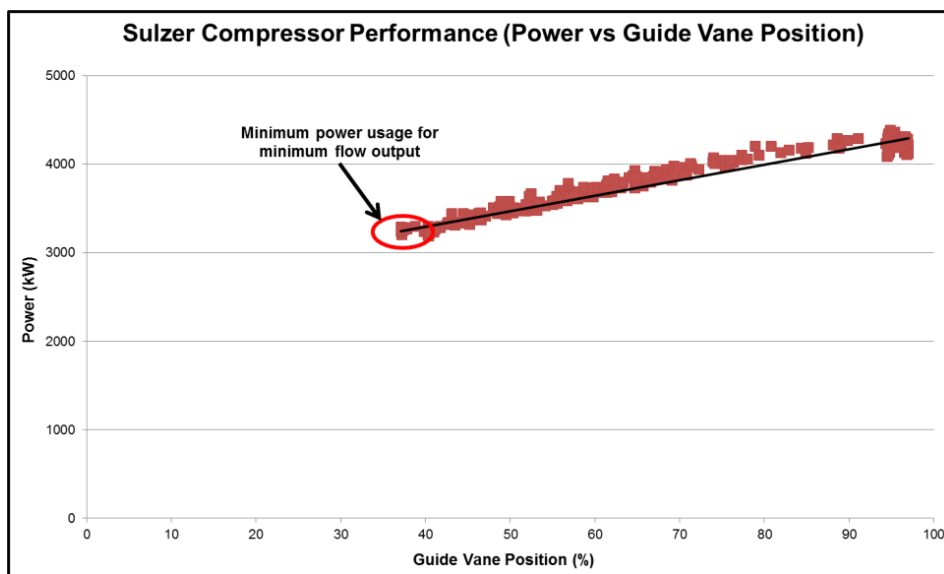


Figure 89: Sulzer compressor performance

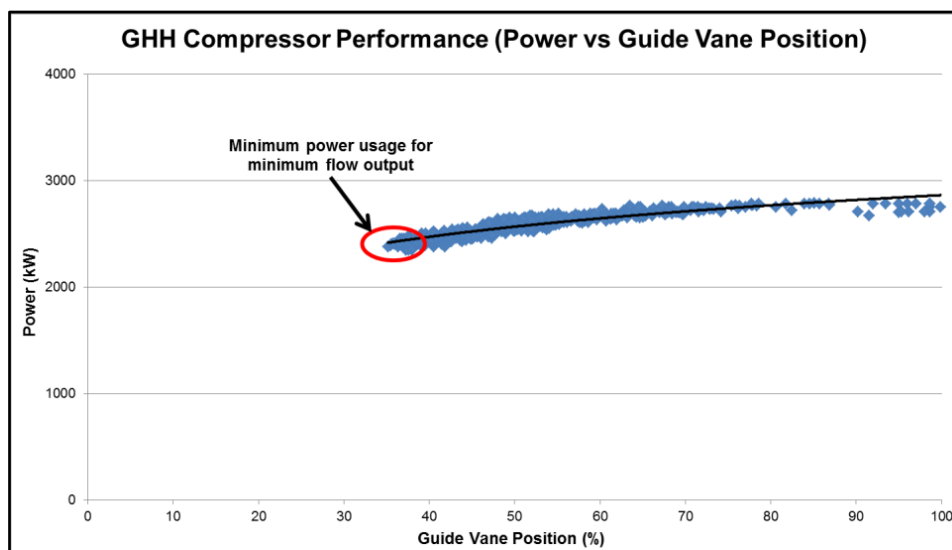


Figure 90: GHH compressor performance

According to Figure 89 and Figure 90, the lowest compressor power used by the Sulzer/GHH combination could only be approximately 5 600 kW. According to mine personnel, the BB compressor was very inefficient and preferably not used. Therefore, Outlier 2 in Figure 88 can be ascribed to the compressors' higher than required installed capacity. The compressed air demand during drilling shifts had also increased since initial investigations. Figure 91 compares the simulated flows with the measured flows after implementation.

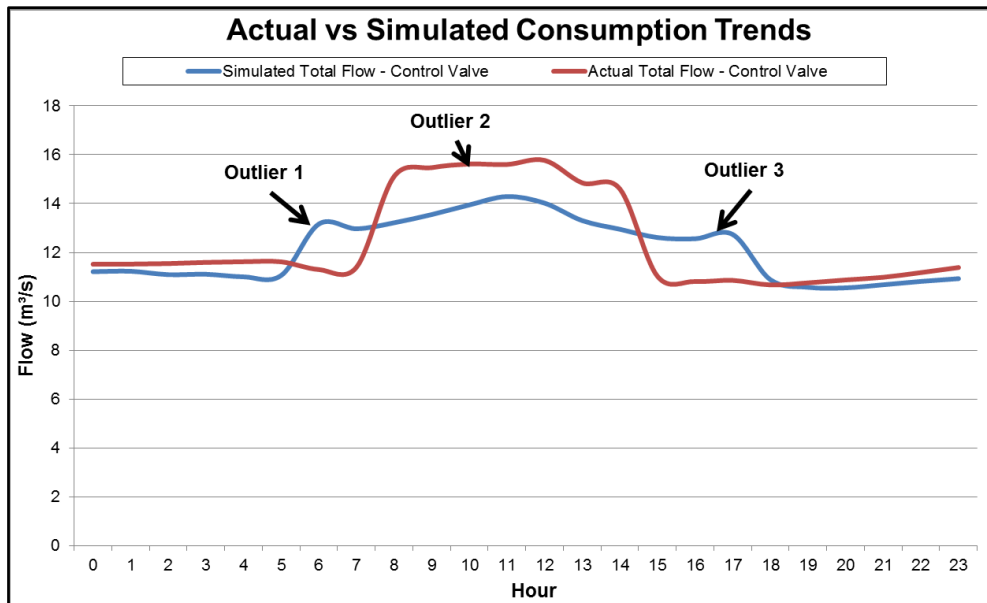


Figure 91: Actual compressed air consumption compared to simulated flows

Outlier 1, Outlier 2 and Outlier 3 are identified in Figure 91. Simulations were only developed for the reduction in flow from 18:00 to 06:00 due to the control valve operation. The simulated values during this time corresponded to the actual data retrieved from the reconfigured network. At the time of the investigation, the flow during the remainder of the day was assumed to stay approximately the same.

Outlier 1 and Outlier 3 were the result of reduced air consumption since initial investigations. The reduction might have been the result of fixing air leaks. Previously two compressors were constantly running during these times, while one compressor is currently running. Outlier 2 was the result of increased air consumption during the drilling shift. According to mine personnel, the increased air consumption was ascribed to a slight production increase at 1#.

The air pressures throughout Mine D's compressed air network were maintained according to the pressure requirement schedule discussed in Section 4.3.2. Figure 92 demonstrates the actual network pressures (complying with the system requirement schedule) against the network's requirements after the implementation of the reconfiguration strategy.

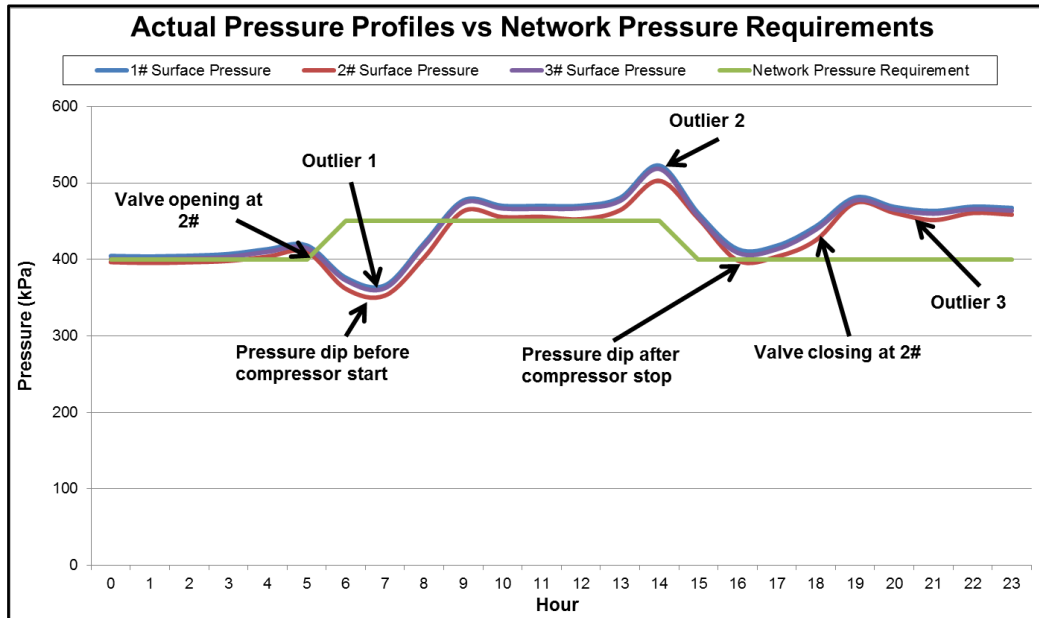


Figure 92: System pressures after application of the reconfiguration strategy

The pressure shortfall during high demand periods at the three shafts were illuminated through reconfiguring the network. This is visible during the drilling shifts displayed on Figure 92. The pressure dip (Outlier 1) between 06:00 and 08:00 was due to the changed compressor operating schedule. The rapid increase (Outlier 2) in air pressure was due to the reduction in air consumption between 14:00 and 18:00. The system pressure increased (Outlier 3) when the valve at 2# was closed. This provided sufficient air pressure for the other two shafts in the network.

4.5 Conclusion

Reconfiguration strategies have been implemented on the compressed air networks of two South African gold mines. Simulated results proved that relocating a compressor (Mine C) could result in an average daily power saving of 2 100 kW. The simulations also indicated an average surface pressure gain of 40 kPa at the main production shaft (5#). This pressure gain was crucial for future expansion on the mining levels at 5#. The practical results for the proposed solution at Mine C could not be verified as the installations are currently in progress.

The simulations developed for interconnecting two shafts in Mine D's compressed air network proved an average daily power saving of 1 900 kW. The saving was obtained with the help of a control valve used to reduce the air consumption of 2# during low demand periods. The proposed solution was implemented on Mine D's network and the practical results proved an average daily power saving of 1 700 kW during PA. Underground compressed air leaks were rectified after PA, which improved the average daily saving with approximately 300 kW.

Reconfiguring mining compressed air networks proved to have a significant impact on reducing the expenditure on electricity bills. The reduction in maintenance costs contributed to further financial savings for the mines. Strategic implementation, such as using salvaged equipment improved the overall cost saving over the lifespan of the mines. It is therefore safe to conclude that significant cost savings is viable by reconfiguring mining compressed air networks.