Sustaining compressed air DSM project savings using an air leakage management system

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Abstract

Title: Sustaining compressed air DSM project savings using an air leakage management system

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Unreliable and unsustainable electricity supply has been experienced in South Africa since 2007. Eskom implemented Demand Side Management (DSM) as a short-term solution to alleviate this problem. Several compressed-air DSM projects were implemented to help reduce the strain on the electrical network.

Compressed air is an integral part of production in deep-level mining, and is extensively utilised. Problems are encountered with the effective management and repairing of leaks, since the majority of mines have little to no procedures in place for leak management. Awareness of the condition of the compressed-air system and leaks needed to be created at management level in order to achieve the best results.

The purpose of this study is to investigate the effect of proper leak management on compressed-air systems in the mining industry. Peak-clipping DSM projects implemented in the mining industry were used for evaluation of results. Contribution to the sustainability of compressed-air DSM projects savings through successful leak documentation was the prime focus of this study. This was achieved through the development of a Compressed Air Leakage Documentation System (CALDS).

This entailed the electronic field-data capture and record keeping of field data, using rugged PDA devices suitable for the extreme environmental conditions encountered in deep-level mining. Report generation on the status of detected leaks created awareness of compressed-air-system performance and leak-repair tracking at management level. Audible detection was sufficient for this study, since the focus was on the larger more-severe leaks. Leaks were expressed in monetary terms to indicate the severity.

It was found that successful management of leaks could contribute to an increase of as much as 85% in project savings. The results also showed that creating awareness through documentation of leaks, and the effect this has on the system, resulted in regular repairing of these leaks. Sustainability of projects was maintained during an evaluation period of ten months, with projects achieving on average 125% of target savings.

The study showed that effective reporting on compressed-air leaks resulted in increased system efficiency and sustainable DSM project savings. It was also seen that leak detection by out-sourced companies did not necessarily result in financial savings. When the mine took responsibility for its own leak detection and repairs, significant savings were realised.

Keywords: Compressed air, DSM, Leakage detection, Sustainability, Project savings, Reporting, Energy efficiency.

Samevatting

Titel: Die volhoubaarheid van kompressor-druklug DSM-projekbesparings deur die gebruik van ‘n lug bestuursstelsel

Outeur: Adriaan Jacobus Marthinus van Tonder

Studieleier: Dr J.F. van Rensburg

Graad: Meestersgraad in Ingenieurswese (Elektries)

Onbetroubare en onvolhoubare elektrisiteitsvoorsiening is ervaar in Suid-Afrika sedert 2007. Eskom het “Demand Side Management” (DSM) as 'n korttermyn-oplossing geïmplementeer om hierdie probleem te verlig. Verskeie kompressor-druklug DSM projekte is geïmplementeer om te help om die las op die elektriese netwerk te verminder.

Kompressor-druklug is 'n integrale deel van die produksie in die mynbou omgewing, en is omvattend geïmplimenteer. Probleme is ondervind met die effektiewe bestuur en herstel van lekkasies, aangesien die meerderheid van die myne min of geen stelsels in plek het om lekke te bestuur nie. Die toestand van die kompressor-druklug stelsel en die omvat van lekkasies moes onder topbestuur se aandag gebring word ten einde die beste resultate te bereik.

Die doel van hierdie studie is om die effek van behoorlike bestuur van lekke op kompressor-druklug stelsels te ondersoek in die mynbedryf. Energiebesparings-DSM-projekte wat in die mynbedryf geïmplementeer is, is gebruik as gevalle studies en vir die evaluering van resultate. Bydrae tot die volhoubaarheid van kompressor-druklug DSM projekbesparings deur die suksesvolle dokumentering van lekke was die eerste fokus van hierdie studie. Dit is bereik deur die ontwikkeling van ‘n stelsel vir die verslagdoening van lekasies, oftewel “Compressed Air Leakage Documentation System” (CALDS).

Dit behels die elektroniese opskryf en dokumentering van lek-data wat versamel is in die veld. Geharde “Personnel Digital Assistent” (PDA) toestelle, wat geskik is vir die ekstreme omgewingstoestande wat teëgekom word in die mynbou omgewing, is gebruik. Verslae wat die status van die lekkasies wat gevind is rapporteer, is gegenereer om personneel op bestuursvlak op hoogte te hou van die toestand van die kompressor-druklug-stelsel. Die opsporing van hoorbare lekke was voldoende vir hierdie studie, aangesien die fokus op die groter meer-ernstige lekke was. Lekke is uitgedruk in monetêre terme om die erns daarvan aan te dui.

Daar is bevind dat die suksesvolle bestuur van lekkasies kan bydra tot 'n toename van soveel as 85% in projekbesparings. Die resultate het ook getoon dat die bewusmaking deur die effektiewe dokumentering van lekkasies, en die uitwerking wat dit op die stelsel het, gelei het tot die gereelde herstel van lekkasies. Volhoubaarheid van projekte tydens 'n toets periode van tien maande het getoon dat besparings volhoubaar was, met projekte wat gemiddeld 125% van hulle kontraktuele besparingsteikens bereik het.

Die studie het getoon dat doeltreffende dokumentering van kompressor-druklug lekke tot 'n groter stelsel doeltreffendheid en volhoubaarheid van DSM-projekbesparings gelei het. Daar was ook bevind dat lekopsporing wat deur eksterne maatskappye gedoen word, nie noodwendig lei tot finansiële besparings nie. Wanneer die myn egter verantwoordelikheid gevat het vir hul eie lekopsporing en die herstel daarvan, was aansienlike besparings verkry.

Sleutelwoorde: Kompressor-druklug, DSM, Lekkasie opsporing, Volhoubaarheid, Projek besparings, Verslagdoening, Energiebesparing, CALDS.

Contents

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Nomenclature

°C	:	Degrees Celsius
c/kWh	:	Cent per Kilowatt hour
CALDS	:	Compressed Air Leakage Documentation System
CAS	:	Compressed-air System
CRCED	:	Centre for Research and Continued Engineering Development
DSM	:	Demand Side Management
ESCo	:	Energy Service Company
GPS	:	Global Positioning System
GW	:	Gigawatt
GWh	:	Gigawatt hour
HVAC	:	Heating Ventilation and Air-Conditioning
IP	:	Ingress Protection
K	:	Kelvin
kg	:	kilogramme
kHz	:	kilohertz
kPa	:	kilopascal
kW	:	kilowatt
Ltd	:	Limited
M&V	:	Measurement and Verification

MW	:	Megawatt
NERSA	:	National Energy Regulator of South Africa
OS	:	Operating System
OSIMS	:	On-Site Information Management System
Pa	:	Pascal
PC	:	Personal Computer
PCP	:	Power Conservation Programme
PDA	:	Personnel Digital Assistant
RAM	:	Random Access Memory
REMS	:	Real-time Energy Management System
RPM	:	Rustenburg Platinum Mine
SA	:	South Africa
SCADA	:	Supervisory Control and Data Acquisition
UK	:	United Kingdom
ULD	:	Ultrasonic Leak Detector
USA	:	United States of America
USB	:	Universal Serial Bus
ZAR	:	South African Rand

1. Introduction

1.1. Background information on DSM initiatives

Maintaining a reliable and sustainable electricity supply in South Africa has presented problems for Eskom. The construction of new power stations such as Medupi will alleviate this problem in the long term [1]. A short-term solution to the electricity-supply problem is the implementation of Demand Side Management (DSM) initiatives, which will reduce load shedding and power failures. Eskom anticipates that the DSM initiatives will result in a power reduction of 3 000 MW by 2011 [2] .

Variable price structures, known as Time of Use tariffs, were introduced by Eskom in 1992. The most expensive pricing occurs during two peak periods of the day when the electricity-supply reserves are lower than the accepted international standard. Eskom introduced the variable price structure to encourage consumers who use large amounts of electricity to use electrical equipment out of these peak periods in support of the DSM programme [3].

Figure 1 shows the peak periods that occur during a typical 24-hour working week. Two peak periods occur from 7 am to 10 am and from 6 pm to 8 pm. The difference in power consumption between summer and winter times is clearly evident. This load profile makes DSM projects possible, where the aim is to reduce the load on the supply by controlling the demand side.

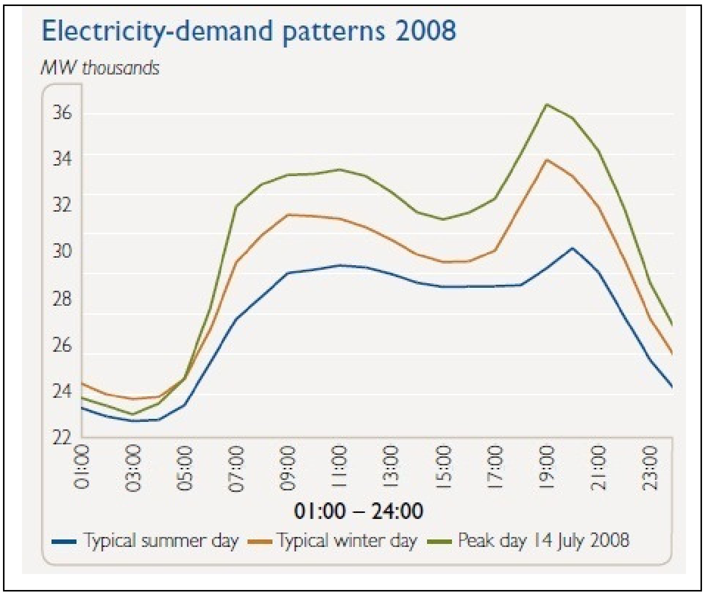


Figure 1 : Typical load pattern indicating peak consumption periods (adapted from[2])

Figure 2 shows the consumer load distribution in South Africa during 2008 and 2009.

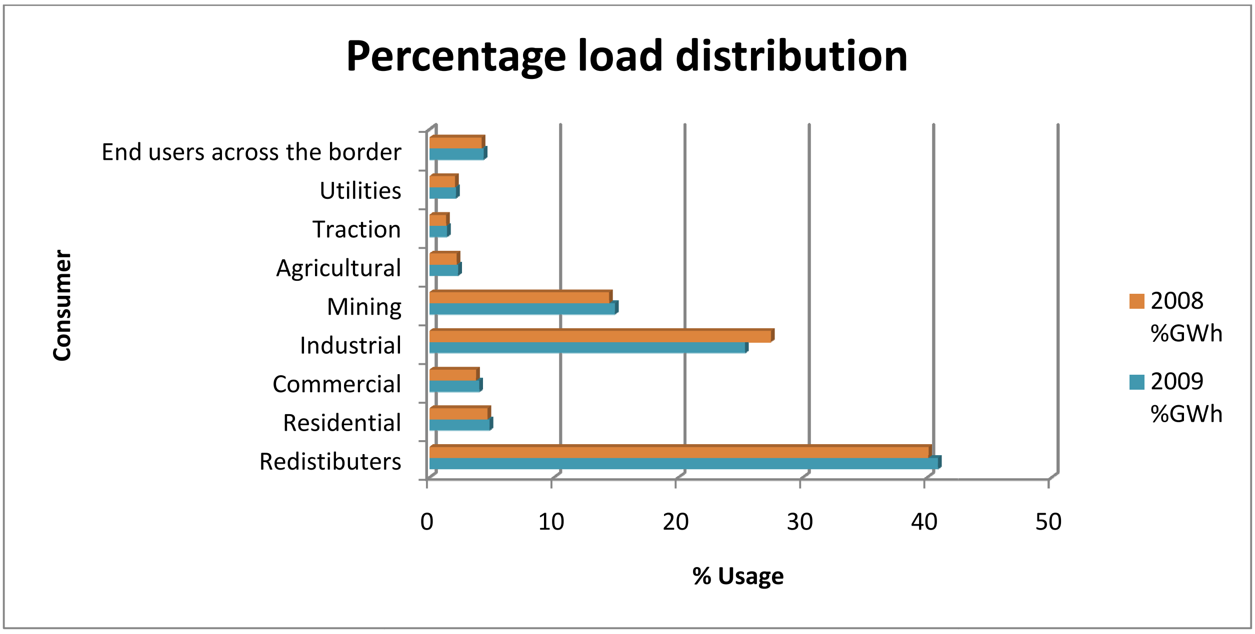


Figure 2 : Percentage load distribution in South Africa [2]

Different DSM initiatives include:

- Energy efficiency, which is the overall reduction in the electricity baseline over a 24-hour period.
- Load-shifting, which requires that the electricity consumption is moved away from the peak residential-demand periods. This still results in the same total daily consumption of energy.
- Peak-clipping, which only reduces the consumption during peak residential times, resulting in lower energy consumption during the 24-hour period.

Figure 3 illustrates the three different DSM methods based on a typical baseline load profile. The peak periods are indicated in grey.

A further benefit of the DSM programme is the funding made available by Eskom to encourage the implementation of DSM projects. Depending on the type of project, all the costs may be covered by the utility. Unfortunately, in some cases, only 50% of total project cost will be paid by Eskom. For example, peak-clipping and load-shifting projects are funded 100% by Eskom, but energy efficiency only 50% [4][5].

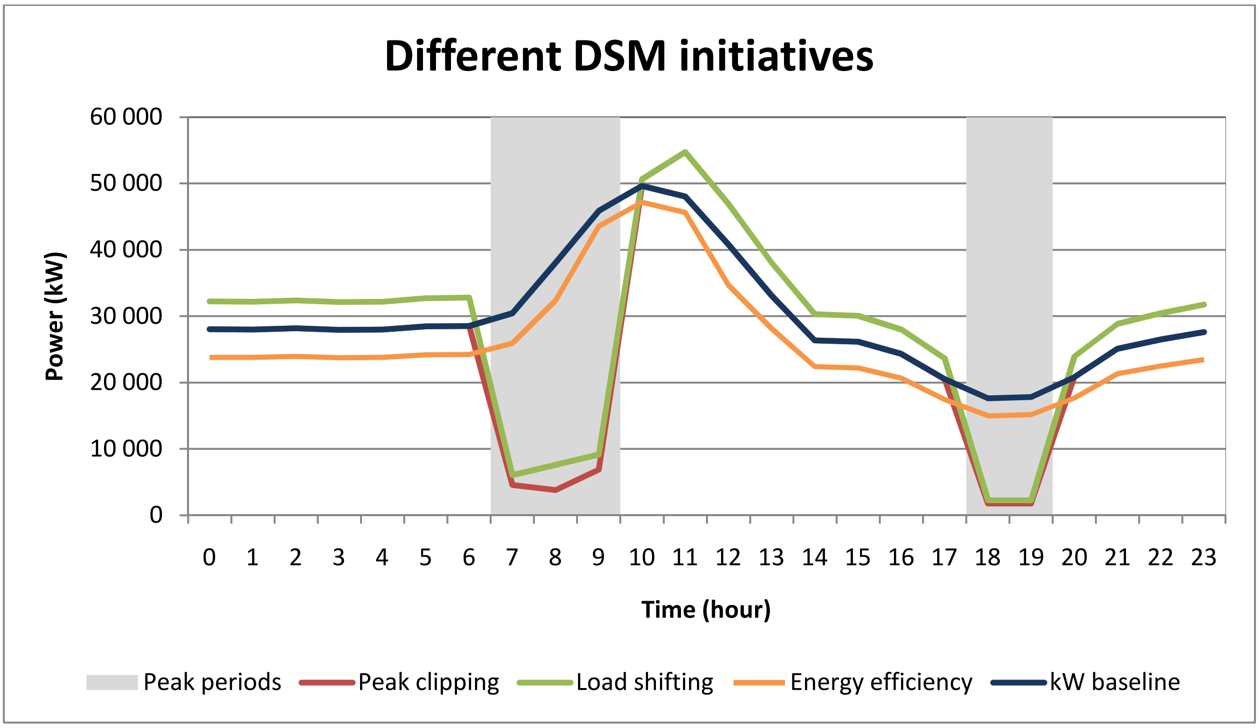


Figure 3 : Different DSM initiatives

Eskom introduced a Power Conservation Programme (PCP) on the first of July 2008. This required the client to reduce power consumption by 10 %. The 250 main power consumers were given the option to participate. Plans to enforce this programme in the industry have already been sent to NERSA for approval [2].

Since the introduction of the Megaflex tariffs in 1992 there has been a significant change in electricity price structures and in particular after 2007 [6][7][8]. Figure 4 shows the tariff increase since 2002 for both high-demand (winter) and low-demand (summer) periods [3][6][7]. With the latest increase granted by NERSA, the tariff structuring changed. NERSA approved an increase of 24.8% on 1 April 2010, 25.8% on 1 April 2011 and 25.9% on 1 April 2012 [9].

These increases are expected to encourage consumers to use electricity more economically. The different price structures shown in Figure 4 encourage consumers who consume large amounts of energy to use large power-consuming equipment during the lower-priced periods. The mining industry is responsible for 14.9% of the total power consumption in South Africa [2]. DSM initiatives have focused on the mining environment owing to its large energy consumption compared with other sectors. Consequently, the mining industry presents a realistic sector to target for implementing DSM initiatives.

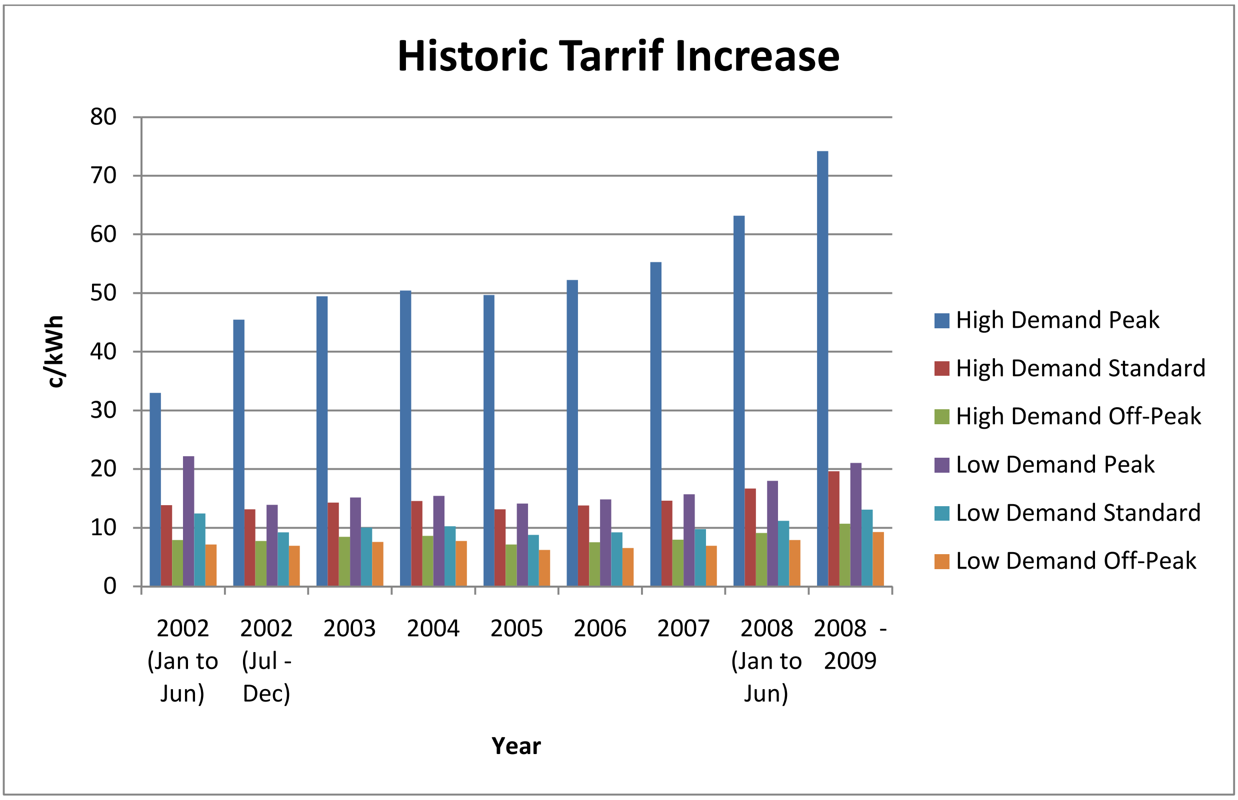


Figure 4: Historic price increase on electricity

AngloGold Ashanti estimates that 18.5% of total costs can be allocated to electricity usage [10]. Assuming that all other costs remain the same, the increased cost of electricity is expected to have an even greater impact on production costs. With these new electricity prices, more than 22% of AngloGold Ashanti's total mining costs will then be attributed to electricity payments.

1.2. Sustainability of electricity savings drives and projects

When a DSM initiative is implemented, the project is subject to a five-year performance agreement. This entails that the contractual megawatt savings must be maintained throughout the five years after project implementation. Contractual power savings are determined during the first three months after implementation, known as the performance-assessment period. The results are then sent to independently selected teams for Measurement and Verification [4].

Experience has shown that the performance of DSM initiatives decreases dramatically over time. A reduction of 64% in the maximum achievable savings, within a six-month period, was experienced with accelerated DSM projects implemented by Eskom in the Western Cape [11].

Figure 5 shows a peak load-clipping project where the performance showed an initial increase, followed by a significant decrease in power savings.

This problem is, however, not unique, but seems to be a trend in DSM initiatives. In many projects, a decrease in savings of 30% to 70% was experienced [12]. This will reduce the expected reserve-energy supply margin dramatically over time, and render DSM redundant.

Various factors can influence the DSM project success. Ownership of the project has a direct effect on the outcome of the project. When accountability is increased, project outcome is affected positively [13]. This has been the case in the mining environment, where projects with a dedicated project manager showed increased performance. For example: when information systems such as leak detection are implemented without proper support from management, failure can be expected [14].

Inadequate and insufficient availability of performance data is a great concern for project performance. An empirical study carried out by a bank showed that when the performance data were presented visually to staff members the profitability of the bank increased [13]. This also led to new developments in information systems within the company. Accurate and sufficient information systems showed a positive impact on performance and success of various projects [15].

During the recession, the workforce in the South African mining sector was cut by 11.1% [16]. This resulted in the mines not always having workers available for maintenance work. For the type of technology required to operate leakage-detection systems, an understaffed workforce can have a detrimental effect on the project implementation.

Another contentious subject in the mining environment is that everything that succeeds is normally performance bonus driven. Production bonuses are a typical example. When bonuses are given for tonnages, the targets are easily achieved. The same must be applied for information technologies. A study showed that when projects are subject to performance-driven resources, success is achieved [17].

When managers and senior personnel get involved in information-system practices, the quality of the reporting is significantly improved [18]. This is due to the fact that faults get detected much sooner and can be resolved rapidly and effectively.

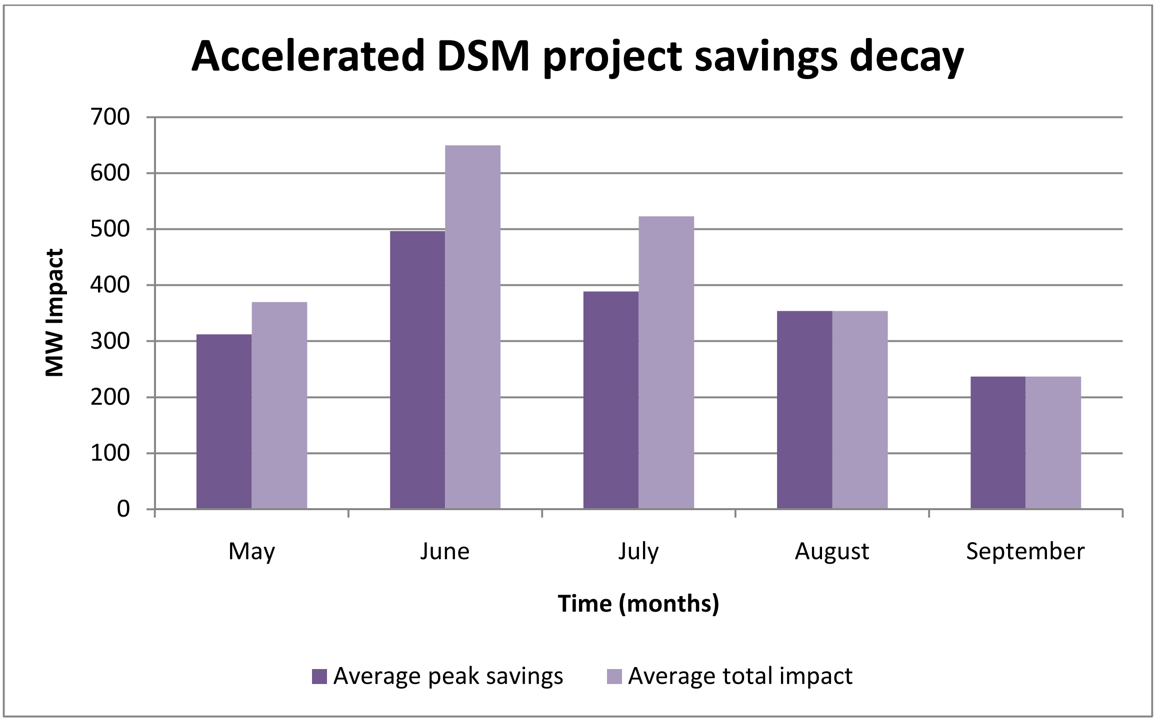


Figure 5 : DSM performance decay [11].

1.3. Energy usage of compressed-air systems

Compressed air is a widely used commodity in the mining industry. Because of the low cost of electricity in earlier years, large compressed-air systems were commonly installed, particularly in the mining industry. Compressed air is always available, on-demand, wherever a compressed-air line is installed. Connection to the system is easily accomplished, unlike electrical equipment which needs qualified personnel for installation. Unfortunately, leaks on compressed-air systems, unlike water or hydraulic systems, are usually unnoticed or ignored.

Compressors up to 15 MW are used by the South African mining sector. These compressors can supply up to approximately 3 500 m^3/min. Pipelines, such as the Rustenburg Platinum Mine (RPM) compressed-air system, can easily extend up to 75 km in length. Owing to the sheer size of these systems, leaks can cause major energy losses and high energy costs.

RPM's compressor ring has a total installed capacity of approximately 60 MW. If the savings through leakage detection is only 20%, a reduction of 12 MW can be realised. This is, however, subject to all the compressors being operated simultaneously. If a more conservative 40 MW power requirement is assumed, the savings could still be 8 MW.

Inco Manitoba, a compressor house with installed capacity of 17 MW, reduced its energy cost by half. This was done by effectively monitoring the 13 km of pipeline, as well as the optimisation of operational procedure of the end users [19]. This meant that the demands of new developments could be easily met without the requirement of additional compressors.

Tolko Industry Ltd's paper and saw mill saved 1.1 GWh per annum by optimising their compressed-air system. Leakages and open air ends accounted for 35% of the systems air usage [20]. Leekseek, a company doing compressed-air network surveys and repairs, reported a leakage rate in excess of 20% for the majority of their clients [21]. Van Leer (UK) Ltd found that 36% of their compressed air was lost through leakages [22].

Compressed-air optimisation projects implemented in the mining sector must be sustainable. To prevent the excessive wastage of expensive compressed air as an energy source, a leakage-detection system must be implemented. This system must be able to effectively monitor and report on the compressed-air reticulation network to improve overall system efficiency. In order to achieve this, the system requires a special monitoring system. A compressed air leakage detection system must be designed and implemented. This in turn will contribute to project sustainability.

1.4. Problem statement

The purpose of this research is to establish a method to improve the performance of DSM initiatives through compressed-air system evaluation and management. Product development is done on a reporting structure to document leakages on a regular basis. Systems presently in place will also be investigated to evaluate short-falls.

Development of this system requires the design of a software system capable of converting all the applicable data for easy interpretation. The system developed will be applied in general to DSM initiatives on compressed-air networks in the mining sector. Development and implementation of these systems will be developed for specific mine layouts.

Performance data of DSM initiatives will be used for verification. An independent measurement and verification team, appointed by Eskom corporate service division, evaluates these data.

The successful implementation of the compressed air information management system will benefit both Eskom and the mining industry. Eskom will benefit by having a reduced load on the electricity-supply grid. The mining industry will benefit through optimised energy consumption resulting in reduced operating costs. A sustainable DSM project may reduce the risk of Eskom Power Conservation Project (PCP) penalties.

1.5. Dissertation overview

The outline of this dissertation is as follows:

Chapter 2: Requirements for sustainable compressed-air savings

This chapter discusses the requirements for the system to be developed. The layout of this section is as follows:

- Compressed-air reticulation systems
- Leakage-detection methods
- Technology presently implemented in practice
- Reporting procedures

Chapter 3: Sustaining compressed air DSM project savings through an air-management system

Implementation and design process of the system are explained in this chapter. Issues addressed here include the following:

- Equipment selection
- Project-specific setup of device
- Data capturing
- Data retrieval and processing

Chapter 4: Results

In this chapter the application of the system is illustrated. Points covered in this chapter include the following:

- Product acceptance in mining environment
- Case studies – Compressed-air reticulation systems

Chapter 5: Conclusion

The document will be concluded in this chapter and suggestions given for future studies.

2. Requirements for performance sustainability

2.1. Preamble

Compressed-air network optimisation can be rewarding when properly implemented. To achieve this, an in-depth study on the problem is required. Research covered throughout this chapter includes calculation of flow rate through a leak of typical size, methods and equipment used for leak detection, as well as reporting on leakages.

2.2. Compressed-air usage in the mining environment

2.2.1. Existing systems

Compressed air is an important production component in the mining sector. This is due to the simplistic connections that can be made to the reticulation network.

Compressed-air applications include the following [23][24]:

- Rock drills
- Diamond drills
- Agitation
- Mechanical loaders
- Loading boxes
- Refuge bays
- Pneumatic pumps
- Actuators
- Ventilation
- Pneumatic hand tools

Unfortunately, compressed air is one of the least efficient sources of energy. Compared with electric, oil electro-hydraulic and hydro-powered drills, compressed-air drills were shown to be the least efficient equipment [25]. Overall efficiency of compressed-air drills was calculated at 2%, compared with the 20% to 31% of the alternative solutions [25]. A study conducted by the United States Department of Energy on inappropriate uses of compressed air suggested moving away from compressed air where possible [26].

2.2.2. Innovative alternatives to compressed air

Alternatives that can be considered for replacing pneumatic equipment are listed below:

- ***Hydraulic powered equipment***

Figure 6 : Hydraulic power pack

Hydraulic power packs use hydraulic fluid flowing through high-pressure lines as an alternative energy source. Typical implementation is replacing pneumatic cylinders with a hydraulic power pack as shown in Figure 6. Because of the higher pressure, smaller cylinders are required to exert the same forces as their pneumatic counterparts. Operational cost is decreased significantly when replacing pneumatic power with hydraulic power [27].

- ***Electrical powered equipment***

Closing of valves from remote locations became part of normal operations in the mining industry. Pneumatic actuators are installed, requiring high pressure for operation. When system pressure is reduced, pneumatic actuators return to the safe fail-to-open position, opening the valve. This prevents system pressure from being controlled at a lower pressure when the high-pressure equipment is no longer utilised. Electric actuators can replace pneumatic actuators so that control valves can still be modulated on lower system pressure. Figure 7 shows an electric actuator mounted to a main-line valve.

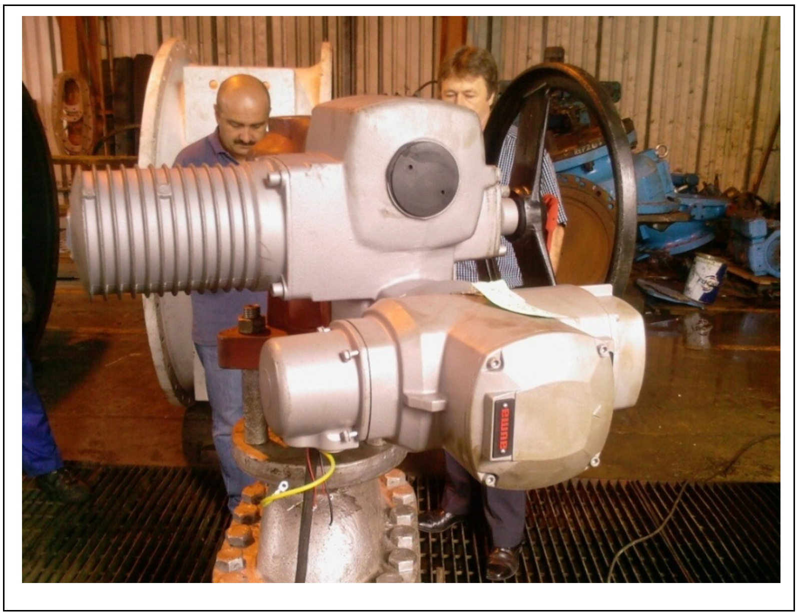


Figure 7 : Electric actuator

Pneumatic rock drills require a high system pressure during the drilling shifts. Replacing pneumatic-powered drills with electric-powered drills would also reduce the requirement of high-pressure compressed air. Electricity consumption of electric drills is less than the compressed-air power requirements of pneumatic drills [28].

- ***Hydro-hydraulic powered equipment***

Hydropowered solutions are another alternative to reduce the requirement for compressed air [25]. This utilises the high pressure in the existing water-reticulation networks to supply hydropowered drills. Hybrid solutions are also available, which combine hydro- and electrical power for optimum results.

Other hydrosolutions include hydropowered cylinders, hydroactuated valves, high-pressure water-jet guns and hydropowered loaders [29].

- ***Mechanical equipment***

Replacing pneumatic agitators with electric-driven mechanical agitators is also an effective way of reducing compressed-air demand. Electric-driven agitators consume only one sixth of the power consumed by pneumatic agitators [30].

- ***Other equipment***

Other means exist to reduce compressed-air consumption. These include fans for ventilation, blowers for refuge bays, line-flow actuators and many more.

2.2.3. Short-term improvements

Unfortunately, most of this alternative equipment is costly to implement and has extended payback periods. Typically, the costs to replace pneumatic-powered loading boxes with hydraulic-powered alternatives will be between R 275 000 and R 680 000. This is based on actual quotations obtained to replace surface loading boxes of a single shaft. Resistance to change to this unconventional equipment also has an impact on the conversion.

Compressed air leakage repair is the single most effective improvement that can be implemented in a compressed-air system (CAS). Financial viability of leakage detection and repairs makes this the first step in improving system efficiency [31].

2.3. Compressed-air reticulation systems

2.3.1. Outline of compressed-air systems

Mine compressor systems comprise several components. Compressor houses, surface piping, valves, shaft pipe columns and level piping are all included in this complex system. All of these components are prone to leaks, which usually occur at bends, flanges, valves, couplers, welded joints, defects in material and other locations where connections are made to the network [32][33]. Figure 8 depicts a simplified CAS in the gold and platinum mining sector. Compressors feed into a compressed-air network from where the compressed air is supplied to different end users.

Compressed air is delivered to shafts by pipelines reaching many kilometres in length. To ensure minimum pressure losses, column diameters ranging from 350 mm to 700 mm are installed. These columns are made up of 9 m sections, bolted together with flanges and sealed off with gaskets.

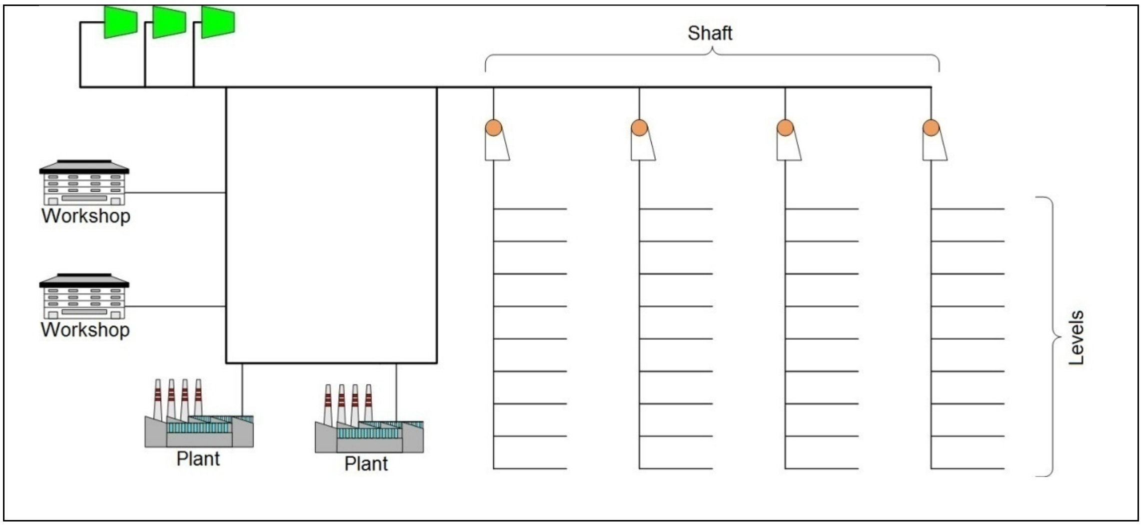


Figure 8 : Typical CAS in the mining environment

Figure 9 shows a compressed-air column with a y-junction, bolted together using flanges. Using these shorter 9 m sections to build the pipelines increases the risk of leakages at flanges, but reduces downtime in case of column failure. Pipe sections can be made up beforehand, reducing repair time or installation time of new equipment such as flow meters and valves.

Very important components in CAS are valves which are used to control or isolate airflow to shafts. Figure 10 shows a valve installed in a network, indicating possible leak locations. Air leaks tend to become a problem over time, with leakages occurring at the stem (indicated in green) and flanges (indicated in red) of the valves.

Figure 9 : Y-junction in compressed-air column

Columns installed in the shaft supply air to the underground levels. Leaks in this section of the network can easily be overlooked if a proper maintenance system is not put in place. Shaft inspections are carried out on a weekly basis, presenting an ideal opportunity to identify leaks.

In order to supply air to the levels where they are needed, a T-piece is installed in the main column connecting to a smaller diameter pipe. A valve is normally inserted just after the T-piece in order to isolate the level if required. All these components contribute to create the intricate air networks that are found in the mining industry. Leaks are therefore very likely to occur, and a system for detecting and repairing the leaks is essential.

Figure 10 : Valve leakages

2.3.2. Intricate piping networks

Because of the size of compressed air networks, complex situations develop. Surface layouts are mostly uncomplicated, with pipelines connecting various parts of the network consisting mainly of straight pipelines. The underground piping is usually where the most savings can be achieved by monitoring and repairing leaks. Leaks in the pipe system are not the only cause of losses. Significant losses have been caused when sections are closed down without closing off the compressed-air supply.

In the underground layout shown in Figure 11, the complexity of such systems is evident. Excessive pressure drops were experienced in the main column going down shaft A. This resulted in a reversal of flow on 76 level during production shifts. A possible cause of this problem may be from unaccounted losses due to compressed-air leakages. This could, however, not be confirmed owing to insufficient leakage-detection systems. Implementation of the system developed during this study could lead to more conclusive results.

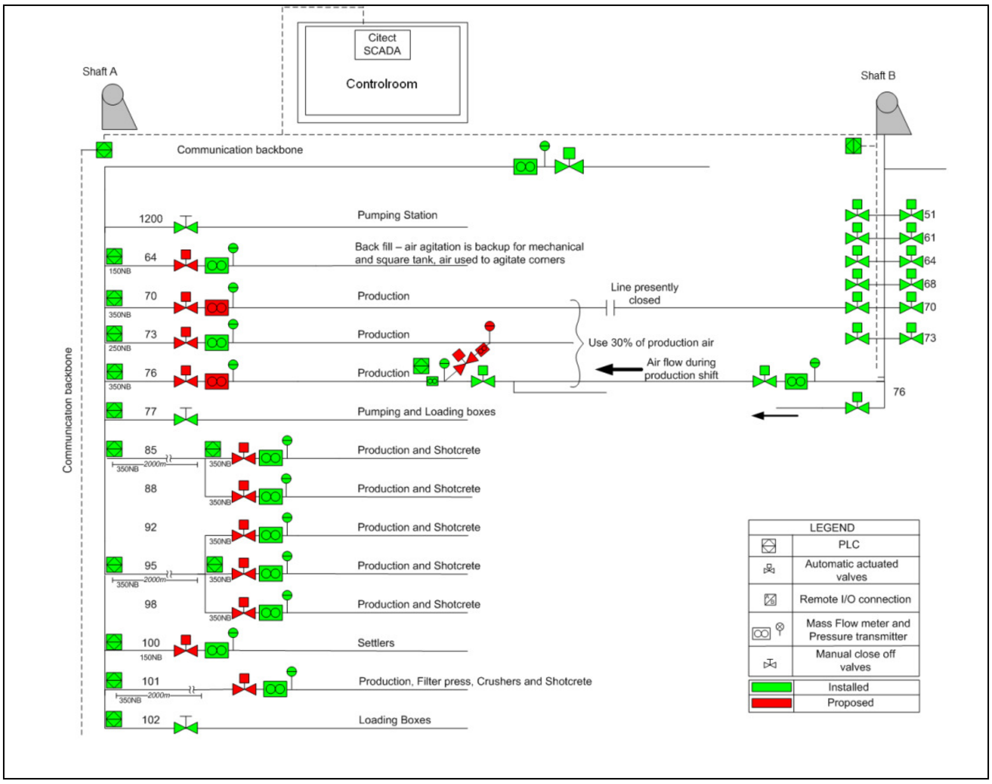


Figure 11 : Complexity of an underground compressed-air reticulation network

South African gold mines reach average depths of approximately 2 750 m [34]. Compressed air is essential for these large networks. The larger the system, the greater is the saving potential for leak-management systems.

2.3.3. System dynamics

Piping networks are subjected to certain characteristics that affect the dynamics of the system. Bends, reducers, valves and other restrictions cause turbulent flow in the system. Turbulent flow causes additional friction [35], which can quickly erode away the inside wall of the pipe, resulting in leaks. Leaks are also the cause of fluctuations in system pressure which affects the performance of pneumatic equipment [36], and can negatively affect production.

The financial impact of leakages is often overlooked. Energy is used to compress air, and a loss in system pressure translates to a loss in energy [33]. Equations [2-1] to [2-5] can be used to express compressed-air losses in monetary terms [33].

$$w_{comp,in} = \frac{w_{reversible\ comp,in}}{\eta_{comp}} = \frac{nRT_1}{\eta_{comp}(n-1)}\left[\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right] \qquad [2\text{-}1]$$

- $w_{comp,in}$ = wasted mechanical energy in kJ per kg;
- $w_{reversible\ comp,in}$ = energy put into compressor to generate compressed air in kJ per kg;
- η_{comp} = compressor efficiency;
- n = polytropic constant taken as 1.4 (isentropic compression);
- R = molar gas constant (0.287 kJ/kg.K);
- T_1 = temperature of air into compressor in Kelvin;
- P_2 = discharge pressure (gauge pressure + atmospheric pressure) in kPa; and
- P_1 = atmospheric pressure in kPa.

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

- $\dot{m}_{air}$ = mass flow rate of air through leak in kg/s;
- $C_{discharge}$ = discharge coefficient of leak, ranging from 0.60 to 0.97;
- T_{line} = temperature in line at position of leak in Kelvin;
- P_{line} = line pressure at leak (gauge pressure + atmospheric pressure) in kPa;
- A = area of leak in m^2; and
- k = specific heat ratio (1.4 for air).

$$P_{wasted} = \dot{m}_{air} w_{comp,in} \quad [2\text{-}3]$$

$$Energy_{saved} = \frac{(P_{wasted})(operating\ hours)}{\eta_{motor}} \quad [2\text{-}4]$$

$$Cost\ savings = (Energy_{saved})(unit\ cost\ of\ energy) \quad [2\text{-}5]$$

To evaluate these equations, actual figures from the mining industry will give more clarity. System characteristics are taken as follows:

- Gauge pressure at 500 kPa;
- Atmospheric pressure at 87 kPa;
- Air temperature at 25 ˚C;
- Line temperature at 28 ˚C;
- Assume a compressor efficiency of 80%;
- Coefficient of leak taken at 0.65, based on assumption in [33];
- Motor efficiency taken at 0.98 (synchronous motors).

Tariff used for the calculations was taken as the average of Eskom's peak and off-peak tariffs for both winter and summer months. These values are given in Table 1.

Table 1 : Eskom tariff used for calculations [8]

Unit cost of energy	c/kWh
Peak winter	141.9
Standard winter	36.9
Off-peak winter	19.7
Peak summer	39.6
Standard summer	24.3
Off-peak summer	17.0
Average	46.6

Results obtained from this method of calculation are tabulated in Table 2. The 150 mm and 200 mm sizes have been inserted to show the importance of correctly isolating open-ended pipes.

From this the significance of leak detection can be seen. Repairing leaks as small as a 3 mm or 6 mm in diameter every month can justify the salary of a person dedicated for leakage detection and repairs. This solution is viable if the size of the CAS is taken into account. A leak of 3 mm can easily go by unnoticed in the mining sector.

Table 2 : Energy and cost savings from leaks

Hole diameter (mm)	Area of leak (m^2)	Mass-flow (kg/s)	Mechanical energy (kJ/kg)	Power wasted (kW)	Energy savings (kWh/yr)	Cost savings (ZAR/yr)
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

2.4. Leakage-detection methods

Unlike fluids, leaks on compressed-air systems are not easily detected by visual inspection. To find leakages on these systems, various technologies and methods have been implemented over the years. These methods include:

2.4.1. Audible leakage detection

When a leak occurs in a pressurised system, the flow of compressed air through the orifice generates a sound which is known as white noise, containing various frequencies [37]. Depending on the size of the leak, detection can be done by walking along the pipeline and listening for the distinct hissing sound.

Effectiveness of this method is directly influenced by the size of the leak, as well as the ambient noise. Larger leaks cause higher flow rates, resulting in louder noises. Detecting smaller leaks, however, renders this method ineffective, especially in noisy environments like the mines. This method can also be time consuming.

2.4.2. Ultrasonic leakage detection

The hissing sound created by the air escaping through the orifice contains a wide spectrum of noise. Frequencies inaudible to the human ear are contained within the spectrum. Ultrasonic leak detectors (ULD) can detect sounds from 20 kHz up to 100 kHz [38].

Heterodyning (the process used by ULDs) converts higher inaudible frequencies to lower audible frequencies. Frequencies ranging from 38 kHz to 42 kHz are usually found in compressed air leaks, and ULDs are designed to be more sensitive in this frequency band [39].

Finding leaks with ULDs is more effective and less time consuming because the majority of surrounding noise does not affect detection [40]. Using the ULD, a leak can be detected from several metres away. A further advantage is that it does not have to be in line of sight, which simplifies detection even further. Figure 12 shows a typical ultrasonic leak-detection kit, including earphones and battery chargers.

Figure 12 : Ultrasonic leak-detection kit [41]

Measurements from ULDs are indicated in various ways. Some have bar indicators; others are fitted with earphones where the sounds are converted to an audible frequency. The SDT170, manufactured by SDT international, returns a dBµV reading [41]. From here, savings can be quantified financially using tables given with the ULD[42]. First, the sound reading is converted to litres per hour, and then to power based on the compressor's efficiency. This is, however, still only a good approximation because of the many factors influencing calculations, as listed in Table 3.

Table 3 : List of factors influencing ultrasonic-measurement calculations (adapted from [42])

Factors influencing quantification of savings
Dimensions and nature of leak.
Ambient noises.
Detection distance.
Angle of instrument with regard to leak.
Type of detector used.
Temperature of air inside piping, as well as ambient temperatures.
Humidity levels of compressed air.
Pressure both inside and outside the pipeline.

2.4.3. Intelligent leakage detection

Modern-day technology plays an important role in the industry. Supervisory control and data acquisitioning (SCADA) systems are being implemented more frequently in the industry. By using a SCADA system and strategically placed instrumentation, leakage detection can automatically be accomplished using these computer-based systems [43].

Detection of leaks is done by detecting acoustic waves emitted by the leak. A set of sensors is placed at different locations throughout the pipeline. From the location of the leak, the acoustic wave is transmitted in both directions down the pipeline. The difference in time that the wave takes to pass the different sensor sets is then used to determine leak location [44]. This is done by the central processing units at these sensors, together with the SCADA system. Flow patterns and pressure variations are monitored to detect leakages. The acoustic sensors determine the position of the leak [45] to within a few metres. Figure 13 depicts the typical requirements of this leak-detection method.

In this figure, P is the pressure transmitter, F is the flow meter, D is a density meter and T is the temperature probe. The sensor indicated with an A is an acoustic sensor, used for detecting the sound waves emitted by the leak. Abbreviations used are SLDS for sonic-leak detection system and RTU for remote terminal unit [44].

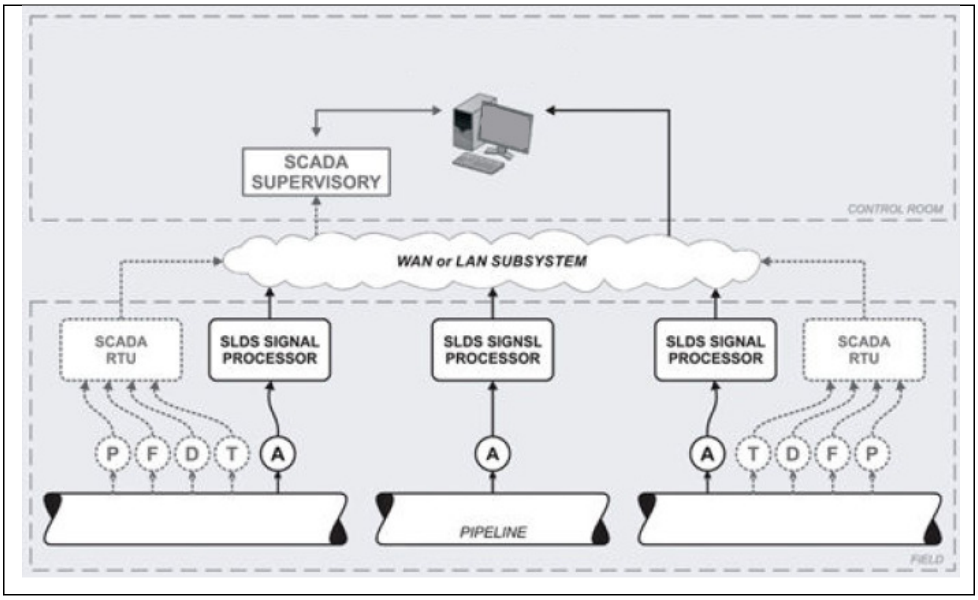


Figure 13 : Intelligent leak-detection system layout (adapted from [45])

The sound wave detected by the acoustic sensors is processed at the sensor. From here it is transmitted to the SCADA system for interpretation. SCADA-based systems can report a leak within seconds after detection [45] to within a few metres.

Initial implementation of this system may be costly because of the numerous sets of sensors that have to be installed. At some mines these sensors may have already been installed. Acoustic sensors, the processors needed at the sensors and density meters, all important in detecting the leak and its location, are not available in the mines. Furthermore, the effectiveness of such a system is very dependent on the quality of instrumentation used [43]. A benefit of this system is that no personnel are required to inspect the pipeline with any form of detection equipment to document leaks.

2.4.4. Other technologies

- **Pigging**

Pigging consists of a plug-type device that is inserted inside the pipe. This device moves downstream, and can perform various functions depending on the type of equipment with which it is fitted with. Leak detection can be done by mounting acoustic equipment on the pig [46]. Figure 14 shows an example of an intelligent pig used in pipeline analysis [47].

The negative side of pigging is the downtime required to do the detection. Piping needs to be disassembled on the one end to insert the pig and disassembled again at the other end to remove the pig. Alternatively, insertion points can be built into the system, where pigs can be inserted without disassembly of piping. These points require a chamber and a valve to isolate the chamber from the ring, increasing the cost involved.

Depending on the length and shape, pigs can get stuck at bends in the pipelines, causing longer downtimes. For compressed-air systems in the mining sector, this is an impractical solution for detecting leaks. Costs involved are too high when the loss in production is considered due to the downtime [43].

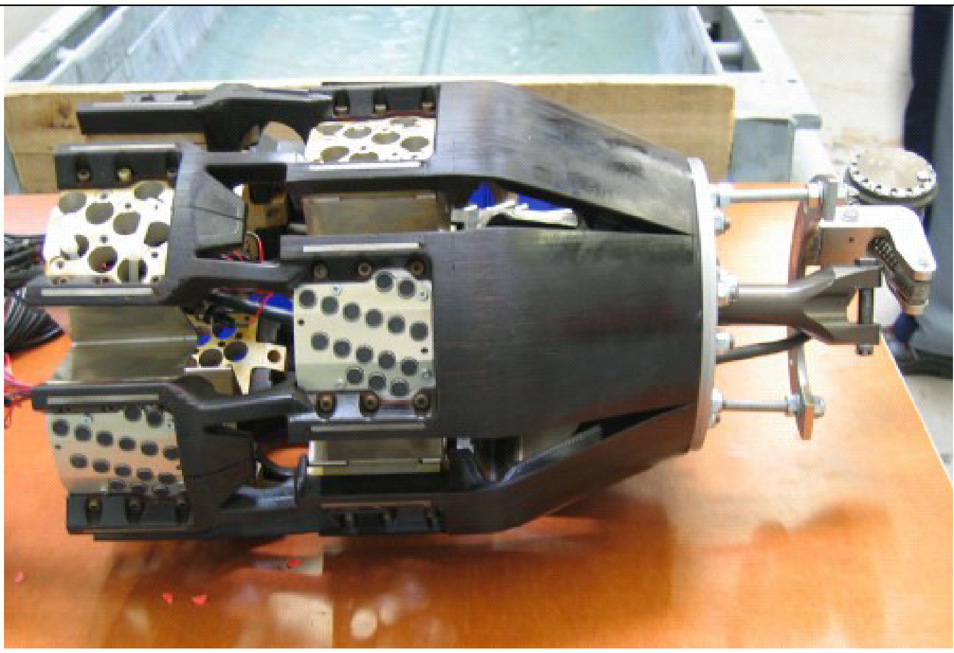


Figure 14 : Intelligent-pig example [47]

- **Soap water**

The old-fashioned soapy water method can also be used on compressed-air piping [32]. Establishing the location of small leaks can be simplified by this low-cost method, but for the majority of the leaks this method is too time consuming. Pipe-network size and layout render this method impractical.

- **Dyes/tracer gases**

Another effective method of detection is by adding a tracer gas or odorant [46] into the compressed-air network. This is, however, impractical since compressed air is used for ventilation in underground refuge bays.

Similar to air-conditioning units, dyes can also be added to the system and used to detect point of leak using ultraviolet detection kits [39].

- **Load/unload test**

The percentage of compressed air lost through leakages in the system can be obtained by load/unload test. With this test, the system is pressurised from an unpressurised system till normal operating pressure is obtained. The time it takes the compressors to achieve working pressure is noted. Then the compressors are taken off-load and the system is left to drain while the time is recorded. In order to obtain more accurate results, the test must be repeated about 3 to 5 times. Execution of tests must preferably occur with all air users removed from the system [48].

To calculate the total leakages, the following equation applies [48]:

$$System\ leaks = \left(\frac{load\ time}{load\ time + unload\ time}\right) * (capacity\ of\ compressors) \qquad [2\text{-}6]$$

For percentage of air generated that is lost through leaks [48]:

$$\%\ Leaks = \left(\frac{System\ leaks}{capacity\ of\ compressors}\right) * 100 \qquad [2\text{-}7]$$

Leak location cannot be determined through this method, although a good approximation of total losses can be made. In the mining environment, this test can only be done in off weekends or during shutdowns, in order to avoid loss in production.

2.5. Data representation and reporting

Finding leaks is just one of the processes needed in order to achieve savings. After detection, the next step needed is transferring the information to the responsible person from where it can be fixed. The following topics need to be addressed.

2.5.1. Data collection

Various methods exist for collection of data on site. The aim of this study focuses on automation of the reporting and documentation of these leaks, and what technology would best suit the mining environment.

- **Traditional pen and paper**

Presently, the most common and cheapest form of reporting is done the old-fashioned way. People documenting leaks walk around with notepads and, when they come across a leak, they record it in writing. From here it is reported to the relevant personnel in order to get it fixed. Sometimes these notes are added to a spreadsheet for conversion to an electronic format, which can be a time-consuming process.

One of the many problems with the pen-and-paper method is loss of data. Notebooks used for documentation might get misplaced, or information lost owing to the booklet being exposed to moisture, especially in deep-level mining.

- **Handheld devices**

With handheld devices, like a personal digital assistant (PDA), the recording process is already done in electronic format. However, PDAs are more expensive than the traditional notepad, especially the robust unit required for the mining environment. Here, devices need special ingress protection (IP) ratings depending on where they are utilised. Figure 15 shows a robust PDA handheld unit with adequate IP rating for the mining environment [49].

PDA is a step in the right direction to convert documentation on leaks to electronic format, which can be distributed by email. In the long run, the initial upfront cost is outweighed by its benefits [50]. Electronic format of the leakage documentation is much easier to store, and requires less space. Tracking on leakage reparation is improved, since prioritising is simplified [51].

Development of a system running on a PDA requires a lot of time on the software side [52]. After the design of the program, field testing is required to evaluate the software and do debugging.

Data input is more time consuming than its pen-and-paper counterpart [53]. Pen and paper has been in use longer and the familiarity results in a reduced input time [53]. With the handheld device, input will initially be slow owing to unfamiliarity with the device and input method.

A smart phone, another option to be utilised, is a phone with built in PDA capabilities. All the functionality of the PDA is incorporated into a cellular telephone. This poses a problem in the mining industry, because phones are not allowed to be taken underground [54].

Figure 15 : PDA handheld unit [49]

Some of these smart phones are equipped with global positioning systems (GPS), and can be a great benefit to surface leak detection in cases where the pipeline reaches several kilometres in length. Positions of leaks can be documented, which will decrease repair times.

- **Laptop computers**

Laptop computers are another option worth considering. Data input can occur faster and with greater accuracy, when compared with handheld devices [55]. Laptops can be used underground for data collection, but are uncomfortable and heavy to carry. A computer is also necessary to store and retrieve data from the handheld unit in order to report on leaks found.

2.5.2. Reporting systems

- **SCADA reporting**

Various SCADA systems exist in the industry today. One of the capabilities, besides controlling and monitoring, is report generation. Some of these systems have report generators which can import external data [56]. Reports can be configured within these types of systems, making this an ideal tool.

However, when a generic system needs to be developed, SCADA systems are a difficult solution because different SCADA systems are used in the industry. Utilising a SCADA system for reporting on leaks is not a financially viable solution.

- **Reporting software**

Programs specifically designed for creating reports decrease the effort involved to generate reports. Some of these programs can even do analysis and interpretation of data, allowing for improved decision making [57]. Reporting structure is also easily customisable for the client's personnel preferences [58]. Distribution of the reports can be executed through the software to all relevant parties [57][58].

HVAC international, an energy services company (ESCo) for Eskom, has various projects running to optimise compressed-air networks. The system developed forms part of one of their products, OSIMS, an acronym for on-site information management system. Reporting solutions have already been developed as part of the OSIMS system.

With the DSM projects that are presently being implemented by HVAC International, customised reports are created as the need arises. These reports are generated by a centralised computer that receives data daily from the sites. Reports are generated through custom coding done in Delphi, based on the data retrieved.

Utilising the same type of system, already developed for other projects, reduces developing time. Alterations need to be made to the existing method to enable the reporting on the leakages documented on the handheld devices. Files retrieved from the PDA will be analysed, and reports generated based on findings. These reports can be distributed to the relevant parties for further analysis.

2.6. Overview of leak detection in South African mines

Leakage detection in South African mines is not a practice that is often pursued. During the research done in this study, some of these leak-detection methods were investigated. This chapter gives a brief description of the structure presently implemented on three mines where leak detection is done. To avoid breaching any confidentiality clauses, the mines will be called Mine A, Mine B and Mine C.

- **Mine A**

Mine A uses the following setup. Detection is done by a company appointed to only finding the leaks. This is done at regular intervals, using ultrasonic leak detectors. The leaks are noted and entered into an electronic spreadsheet. This spreadsheet is given to the mine after the investigation is completed. The size of the leak is estimated in litres per second by using ultrasonic leak detectors.

Table 4 shows an example of the ten most costly leakages as they are noted and archived. The problem with this system at the moment is that the leaks are identified and documented, but reparation is not a priority. A follow-up study will prove the effectiveness of the leak detection, and is scheduled for the near future. The full report can be seen in Appendix C.

Table 4 : Example of leaks detected at Mine A

	Description	Type	Leak rate (ℓ/sec)	Cost of leak (ZAR/ month)	Date
1	85 10 m passed 16 x-cut 20 m passed sets at toilet	Punch hole leak	550	41 536.00	25-Feb-10
2	90 South 12B at box front	Cylinder leak	545	41 158.40	04-Mar-10
3	130 20 m passed MIH ventilation door	Flange leak	482	36 400.64	22-Mar-10
4	90 South 12 at boxfront at stope entrance	Punch hole leak	389	29 377.28	04-Mar-10
5	101 MIH 5 m from dam	Tap leak	359	27 111.68	15-Mar-10
6	90 North 6 x-cut C 20 m into x-cut	Punch hole leak	325	24 544.00	09-Mar-10
7	95 North 4 at N3 B x-cut	Punch hole leak	302	22 807.04	12-Mar-10
8	90 40 m into North 6 x-cut	Punch hole leak	299	22 580.48	05-Mar-10
9	90 West Haulage at travelling way entrance to 85 level	Punch hole leak	298	22 504.96	11-Mar-10
10	106 passed waiting place at switch no. 6	Punch hole leak	298	22 504.96	16-Mar-10

Table 5 shows the summary of the leaks per level. A cost approximation of leaks detected is given to show the severity of the problem.

Table 5 : Summary of estimated cost of leaks detected in Mine A

	Leaks identified		Estimated cost
Level	**ℓ / s**	**m^3/s free air**	**R / month**
79	1 075.3	1.075	81 209.68
85	1 108.5	1.109	83 714.68
90	2 991.5	2.992	225 918.84
95	372.4	0.372	28 122.14
101	386.1	0.386	29 157.52
106	302.6	0.303	22 854.62
108	0.0	0.000	-
112	18.2	0.018	1 372.20
118	372.8	0.373	28 156.88
128	1 240.8	1.241	93 703.71
130	597.5	0.598	45 126.22
133	6.0	0.006	453.12
136	225.9	0.226	17 062.23
Shafts	0.0	0.000	-
Surface	16.2	0.016	1 220.40
Total	**8 713.9**	**8.7139**	**658 072.22**

- **Mine B**

Mine B also uses ultrasonic leak detectors for finding and estimating leak sizes. This is done a bit differently from the previous method. A metre-length stick is used to ensure constant readings. The sensor is placed exactly one metre from the leak, and the decibel reading, as well as the position and type of leak, is recorded.

These readings are then compared with a chart where the decibel reading is converted to an estimated flow rate. Two persons are responsible for the leakage detection on Mine B. After detection is completed, the data are entered into the computer on the surface from where the information is used for further processing.

- **Mine C**

At Mine C the "walk and listen" method is used. Detection is done by listening for the hissing sound, which is then documented in a booklet. From here the information is inserted into an electronic spreadsheet used to track repairs and keep the relevant parties informed of system performance. Leakage detection is done on a weekly basis at Mine C, where both water and air leaks are investigated.

Table 6 shows a sample report for leakages detected at Mine C. At this mine, tracking of the repair process is also documented, as well as the follow-up to verify leakage repairs. Cost analysis of the leaks is not done here. Leaks are repaired based on their size, being small, medium or big leaks. In some cases, flow rate of the leak is detected with flow meters, as the first entry shows (30 ℓ per minute). The complete report is included in Appendix A.

Table 6 : Example report for leak detection on mine C

Date	Level	Location	Drill water	Drinking water	Air leak	Severity	First follow-up	Repaired	Second follow-up	Repaired
12/05/2010	16	East west split		x		30 ℓ/min	**20/05/2010**	**No**	**27/05/2010**	**YES**
13/5/2010	20	West 57		x		Small				
13/5/2010	19	West 63			x	Big	**28/05/2010**	**No**		
13/5/2010	19	West 59			x	Big	**28/05/2010**	**No**		
14/5/2010	29	Station		x		Small				
14/5/2010	29	Tips	x			Small				
17/5/2010	19	West 35	x			Small	**28/05/2010**	**No**		
17/5/2010	19	Rail joint 123	x			Big	**28/05/2010**	**No**		
17/5/2010	25	West 9			x	Big				
19/05/2010	16	Central J134	x			Small	**20/05/2010**	**No**	**27/05/2010**	**YES**
19/05/2010	18	Rail joint 18 (Central)			x	Small				
19/05/2010	18	Rail joint 51 (Central)			x	Small				

2.7. Summary

Leak detection is an important aspect in optimising a compressed-air network. To eliminate all the leaks in the system is impossible, and a 10% leak rate is considered acceptable. The typical leak rate in an unmanaged system can be up to 40%. In order to optimise the compressor network, a detection and management system must be developed and implemented.

This system requires two basic features; a detection method, and a reporting system. Time-consuming methods must be identified and eliminated. Electronic data capturing must be made available for management and reporting purposes. Handheld instruments for collection of this data are required, as well as the development of desktop-based software for processing and generating reports. Various detection methods will be utilised, depending on client preference.

3. Design and implementation of a compressed air leakage documentation system (CALDS)

3.1. Preamble

In Chapter 2 various needs for compressed-air system optimisation were investigated. Leakage detection was identified as the preferred way for effective results with minimal financial-cost implications. This chapter will discuss the development of a documentation system for compressed-air leaks. Different methods were developed and tested in the field. Focus will be on the new system developed, with other attempted systems briefly discussed, together with problems encountered during implementation.

3.2. Design criteria

In order to understand and improve the methods presently being utilised on the mines for leakage detection, research was carried out to identify existing technologies. For this purpose, a questionnaire was developed and used for evaluation. This questionnaire can be found in Appendix E.

From the questionnaire, key points were highlighted on the basic requirements, as well as the deficiencies encountered. Because of the shortage of proper leak-detection practices, the system can be split into two sections: one system for finding bigger leaks, typically in unmaintained systems, and another addressing further optimisation of systems already being monitored and maintained.

The focus of this study is on bigger leaks first and foremost, since maximum savings can be achieved this way. The system will also be rolled out at locations where compressed-air systems are already maintained to evaluate the effectiveness of leak management.

Requirements for an appropriate leak-management system can be categorised into three main sections:

- collecting the data in the field;
- storing the data; and
- reporting on the findings.

Each of these sections will be developed and integrated to form the final product.

Leaks occur throughout the entire stretch of pipeline in a compressed-air system. Information like location, severity and type of leak, must be obtained and recorded. Data must be stored electronically, to allow for further processing and management intervention. As discussed in section 2.5.1, electronic devices are the way forward. For the system developed, a PDA was selected for field-data collection. Detailed description on device selection will follow in section 3.3.

After detection and collection of field data, this information must be stored for record and monitoring purposes. A desktop computer will be used with required software installed. This selection criterion is discussed in section 3.3. Section 3.4 and section 3.5 give the details regarding the setup of the device, and the processing of the field data obtained.

Once the data have been obtained, stored and evaluated, the information retrieved must be made readily available to relevant parties. Reports will be generated from the information obtained and sent out to relevant personnel. These reports will be custom generated to the client's specification. Section 3.6 describes the process followed, and software used for reporting on detected leaks.

The problem with existing leak-detection methods that was identified during the study differed from mine to mine. Some of the mines did not have any form of dedicated leak detection in place. In evaluating methods on mines which had detection programmes running, the main problem areas were identified as:

- Effects of leakages not correctly quantified to show severity;
- Lack of record keeping on previously detected leaks;
- Follow-up on repairs not happening;
- Management level not informed on status of compressed-air system;
- Unused levels not being examined for leakages; and
- Inappropriate uses of air not documented.

To address these problematic areas in existing detection methods, the system developed must encompass these issues. The basic building blocks for the new system entail the following:

- Location, type and severity of leaks;

- The person responsible for recording of the leak;
- The date the leak was recorded;
- List of leaks recorded previously;
- Reporting on the status of recoded leaks;
- Financial or flow-related impact of leaks; and
- Updating of repaired leaks.

3.3. Equipment selection

This section gives details regarding the selection of the various devices, from initial prototypes until the final chosen product. During the development phase, various devices were tried before the final product was selected. Final products utilised include the following: a handheld device for data collection, a desktop computer for data storage, management and report generation, and a printer for creating hard copies of reports when needed.

3.3.1. Palm® handheld devices

- **Palm® Z22**

Figure 16 : Palm® Z22 [59]

Different handheld devices were considered, and the first product that was chosen for field-data collection was the Palm® Z22, shown in Figure 16. The reason for the selection of this device was its light weight, less than 100 g, and relatively low cost. The operating system utilised by the Palm® Z22 is Palm's own Palm OS® Garnet v5.4. Software was developed by HVAC International for interfacing the device with the data collected in the field.

During the implementation phase of the Palm® Z22, some problems were encountered. It was found that the product was not being used owing to the complexity of programming and data input, and the device not being rugged enough.

- **Palm® Tungsten E2**

In order to solve the problem with the ruggedness of the Palm® Z22, a different solution was investigated from the Palm® family. The Palm® Tungsten E2, a more robust device with metal finish, shown in Figure 17, was selected. Since the device is also manufactured by Palm®, the operating system is identical to the Z22. The software developed for the Z22 could be used on the Tungsten E2 without modifications.

Figure 17 : Palm® Tungsten E2 [60]

Changing to a more robust unit did not solve the problems with the device not being utilised. The system was delivered to the client, but not implemented in the field. Further investigation into the problem proved that the device and software was still too complicated to employ. With management not actively involved in the execution of leak detection and reparation strategies, the system was never utilised to its full potential.

With the Palm® Tungsten E2 being a more versatile device, other add-ons were explored. Add-ons for this sort of implementation were barcode scanners and GPS units.

Availability of the Palm® PDAs became a problem later on. Smart cellular phones, or smart phones, started to dominate the PDA market. This rendered the need for a separate device with PDA capability redundant. As discussed in section 2.5.1, the use of cellular phones is prohibited in underground mining. With the manufacturing of the Palm® PDA discontinued, a new type of device was needed for development.

3.3.2. Bar-code scanners

In order to resolve the issue of personnel not doing the detection, a new solution was proposed. Compressed-air reticulation sections are marked with barcodes, and programmed into the system. The person doing the detection scans the pipeline section as he progresses. Locations are preprogrammed, removing the need for manual entries. Progress tracking of detection could now be realised.

The laser barcode scanner interfaces with the Palm® handheld device, as shown in Figure 18. Problems encountered with this system are the complexity added to the CALDS system as a whole. Persons who do the detection are required to program changes in the layout into the system as development takes place.

The added complexity of the system results in greater effort required from the client to operate the system effectively. Systems implementing this technology require dedicated teams for leak detection. Workforce shortages experienced in the mining sector resulted in this system being underutilised. Although the effective implementation of this technology may provide the required results, the complexity made it an impractical choice.

Figure 18 : Palm device fitted with bar-code scanner [61]

3.3.3. GPS-enabled handheld devices

GPS-enabled devices simplify the monitoring of surface-piping networks. Exact location of the leak can be automatically documented on the device, reducing repair time. Two types of GPS solutions were investigated: the add-on to the Palm® devices and the use of a GPS-enabled PDA.

- One disadvantage of the add-on to the Palm® is the power requirements of the device. The GPS add-on required additional power, and could not be driven by the Palm® PDA. Immobility of the device eliminated this as an option for GPS capability.
- A GPS-enabled PDA resolved this problem, but required reprogramming of the CALDS software. This is due to the PDA not running the Palm OS® Garnet v5.4.

GPS devices could not be utilised in underground mining owing to the satellite signal being lost. The surface piping on a typical compressed-air network is a low-maintenance section, and large surface reticulation systems are limited. This system was therefore discarded since it was considered not financially viable.

3.3.4. Archer field pc PDA

Taking all the above information and the client's needs into consideration led to the selection of the ultra-rugged field pc from Archer. With IP67 rating (dust and water proofing) and operating temperatures from -30 ℃ to 50 ℃, this device is ideal for the mining environment [62]. Utilising Microsoft® Windows Mobile® 6 operating system, complete redesign of the handheld software was needed. This was worthwhile since the new industry standard for PDA-operating systems is Microsoft® Windows Mobile®. Future upgrades will also be simplified with the use of this operating system.

Additional equipment can be added to the device according to the different requirements of the client. Figure 19 gives a chart of the available add-ons as supplied by the manufacturer. The on-board serial communication port allows for multiple add-on solutions to be developed. Due to the versatility of the product, it is the ideal solution for this application.

Selection chart
CF & SDIO cards

	COMMUNICATION	UNIVERSAL	OPTICAL	DATA ACQUISITION
Wi-Fi	X	X	X	
Cellular modem	X	X	X	
Bluetooth (class 1 or 2)	X	X	X	
Digital camera		X	X	
GPS receiver		X		
Bar - code scanner			X	
RFID scanner		X	X	
NI CF-6004				X
CF memory card	X	X	X	
SDIO memory card	X	X	X	X

Figure 19 : Add-ons available for Archer field pc [62]

Implementation of the Archer field PC solved the above-mentioned issues as follows:

- Robust device;
- Bigger, easier to read screen;
- Software developed and set-up according to a specific mine layout;

- The input method simplified using predefined selection menus; and
- An additional comment section to enter information that was not stored on the device in advance.

3.3.5. Desktop setup

Processing and record keeping of data obtained from the handheld, as well as the reporting system, are developed on a Microsoft® Windows® 7-based computer system. A desktop computer solution was the preferred choice due to the fact that desktop computers and printers are cheaper than their mobile counterparts, and because mobile units can get misplaced.

The computer setup selected is a basic entry-level computer because of the low processing requirements of the developed software. Computers used during implementation had the following specifications:

- Core2Duo E7500 2.9 GHz processor;
- 2 GB DDR2-800 MHz RAM;
- 250 GB hard drive; and
- DVDRW.

An HP DeskJet printer is supplied with the system, enabling hard copies of the reports to be produced. The software needed is pre-installed onto the system before delivery, and the configuration done according to the client’s specification. The system is delivered as a package, with equipment fully setup.

3.4. Project-specific setup of device

In order to decrease the time of data input, and to simplify the user interface, each project’s devices will be set up as site specific. During the investigation and project-implementation phases, underground layout and pipeline sections of the mine are investigated in detail. From here the air network reticulation is obtained, and all relevant information is available. This information is then programmed into the device.

Figure 20 shows the typical requirement for a mine layout in hierarchical-level format. On some projects, various shafts are included in one project. Information required includes: name of mine

(Mine A), shafts included under the project (Shaft A and Shaft B), levels per shaft (Level 1, Level 2, etc.) and the main areas found per level (cross-cuts, loading boxes, etc.).

Further information required includes pipe sizes used in the mine and whether air logs or water logs are made, as well as where the leak exists on the reticulation. As discussed in section 2.3, leaks occur typically on gaskets, in the pipe itself (punch hole), stems of valves and in rubber hoses. Pipelines and valves not properly closed may also be recorded to show the impact of compressed air wasted through open-ended blowing.

Site-specific programming of the devices is done through a text file and is done by HVAC international project engineers, the company responsible for implementing the system. The text file used for setting up the device is given in Appendix F, and explained systematically with comments.

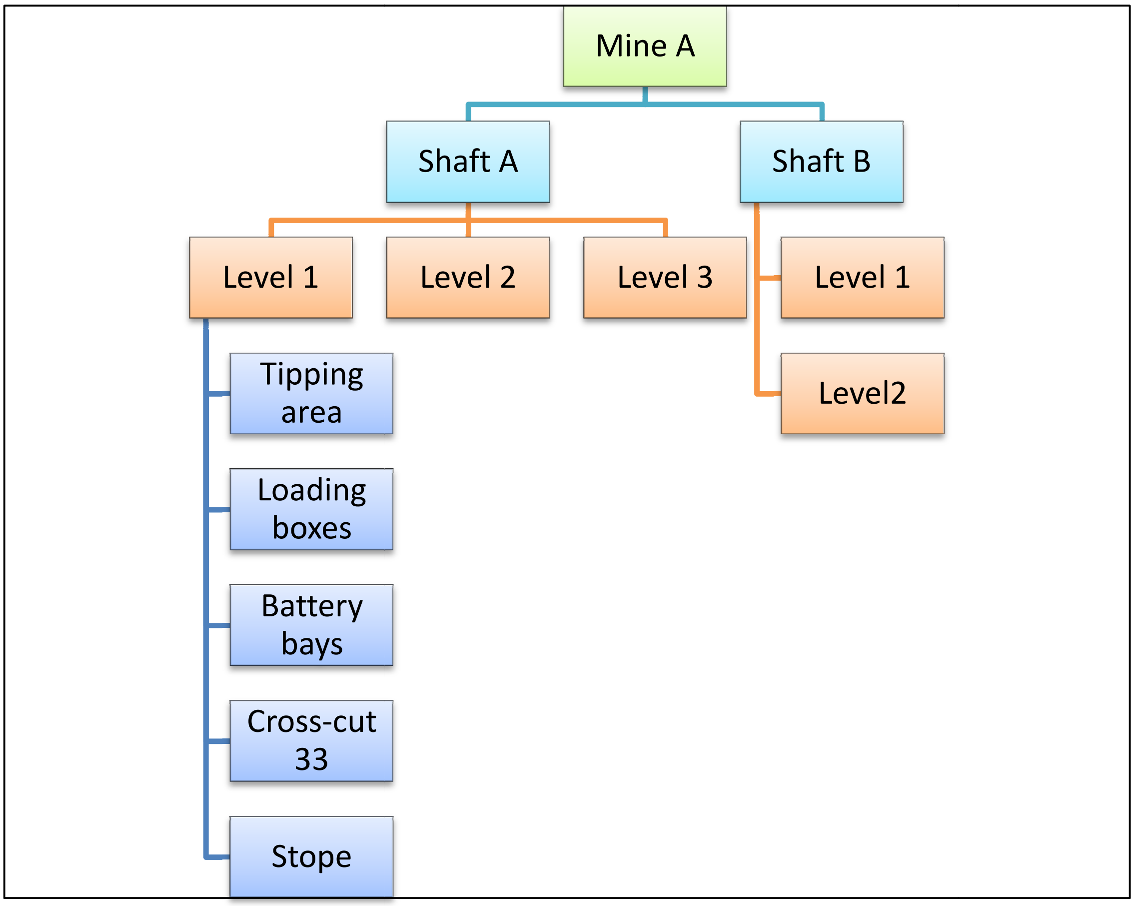


Figure 20 : Hierarchy of mine layout

Programming the device specifically for each mine decreases input time. This is because the selection is programmed into drop-down menus and can be selected by the person doing the leak detection. This simplifies the documentation of leaks, ensuring that the devices will be successfully implemented.

3.5. Data capturing, retrieval and processing

Data capturing gives a step by step breakdown on how the data are collected from the field. The retrieval section describes the synchronising of the Archer field PC with the desktop computer and creating the database of the leaks detected. Processing of the data entails sorting field data into existing and repaired leaks, and expressing the impact of the leaks in monetary terms.

- **Data capturing**

As discussed in the previous section, the Archer field PC is used to capture field data, and needs to be set up to the specific requirements of the project. A typical set-up file, similar to the one included in Appendix F, was loaded on to the handheld device to demonstrate the operation of the device as for a typical mine setup.

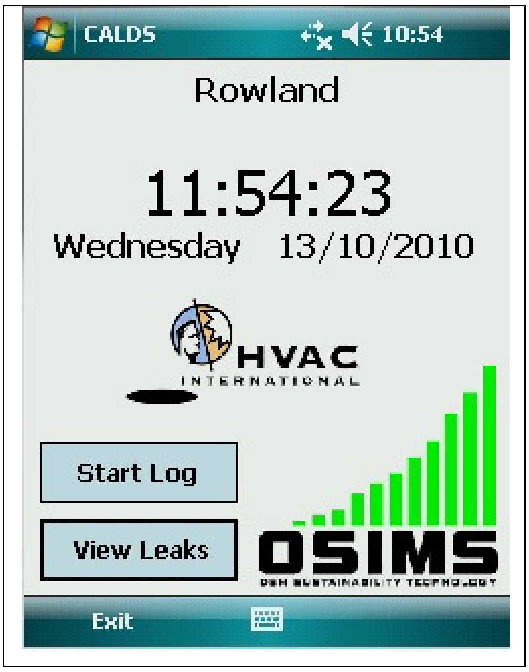
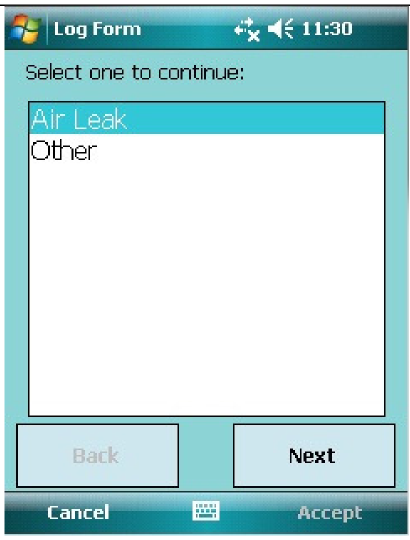
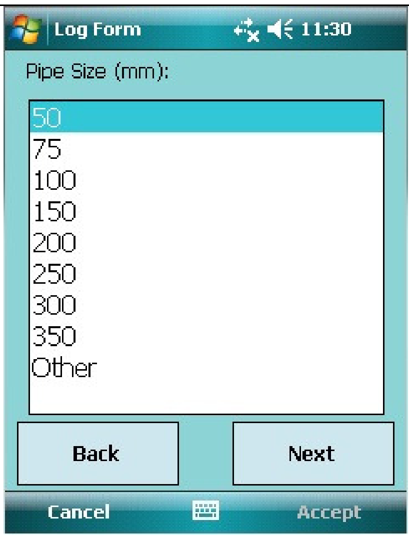


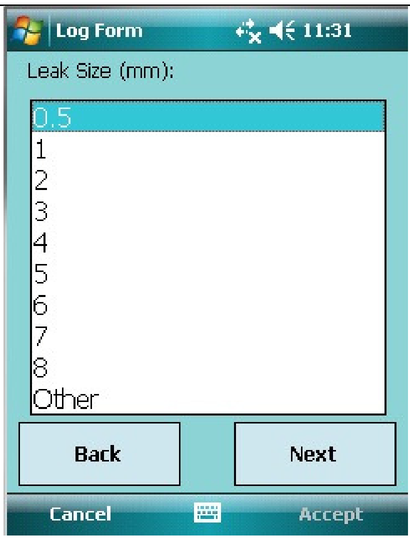
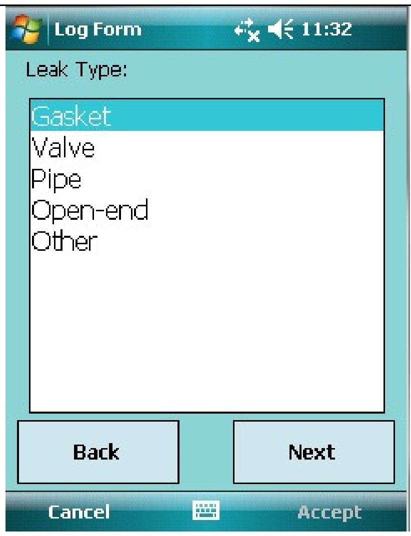
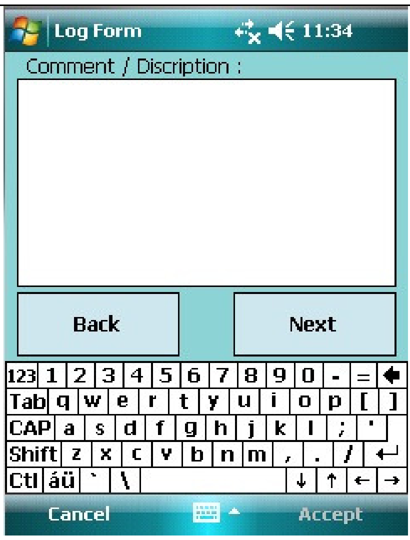
Figure 21 : CALDS home screen

After the unit is powered up the home screen will be displayed. From here, the user navigates, using the stylus, to the start menu in the top left of the screen. By tapping on the screen, a drop-down selection menu will be displayed. CALDS can now be selected from this menu, and the start-up screen will be displayed showing the software logo, and current date and time, as shown in Figure 21.

Table 7 shows the procedure to be followed to enter a new leak.

Table 7: CALDS PDA setup

<table>
<tr>
<td>
</td>
<td>Log type selection input screen. Depending on the setup, either air or water leaks can be selected from the option list. If the “other” option is selected, the screen will display an option to enter other types of logs that are not pre-defined, and the screen will appear as shown in Figure 22.</td>
</tr>
<tr>
<td>
</td>
<td>Pipe-diameter input screen. The pipe diameter on which the leak occurred needs to be selected from the pre-defined list. Values contained in this list are set up for the pipe sizes found on the specific mine.</td>
</tr>
</table>

	In order to calculate the air wasted, the size of the leak is needed. This is entered in the leak-size screen, with the leak size estimated by the person doing the leak detection.
	For leak-repair purposes, recording where on the equipment the leak occurred removes the need for an extra visit by the repair team for position identification. Selection is again done from a list, as specified by the mine.
	The additional-comments section can be used to enter readings from ultrasonic leak detectors, or to enter the details of a photo taken at the location. This is an open-entry field, and is not determined by a selection list. Here the comments have to be entered using an on-screen keyboard.

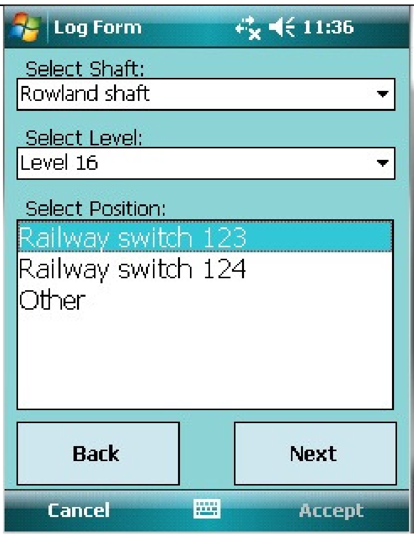
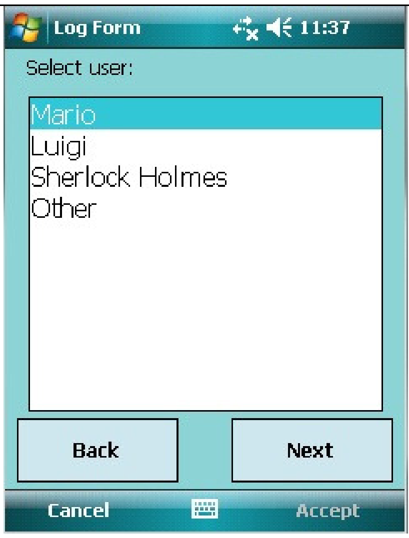
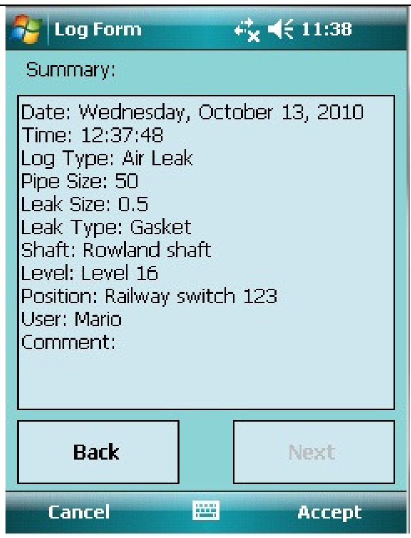
	Location of the leak is entered through locations that are programmed as site specific. This reduces input time and creates consistency in locations included in the reports generated.
	The name of the person doing the detection is preprogrammed and selected from this screen. Additional users can be entered by clicking “other” and inserting the name manually through the on-screen keyboard.
	This screen is displayed to show a summary of the leak entered. Upon accepting the entry, the user will be redirected back to the start screen, as displayed in Figure 21.

Figure 22 shows the interface for entering additional log types.

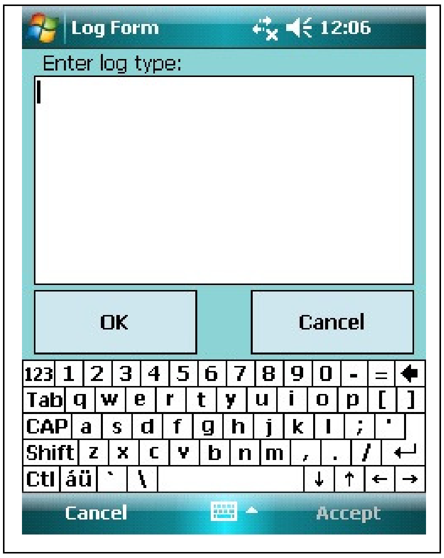


Figure 22 : Entering of 'other' types of logs

Data recorded can also be viewed on the device. This can be obtained from the home screen, as displayed in Figure 21. By selecting the view-leaks option, the entries can be viewed, sorted by date of entry. Figure 23 shows how to view a leak on the device and the screen used to mark the leak as fixed.

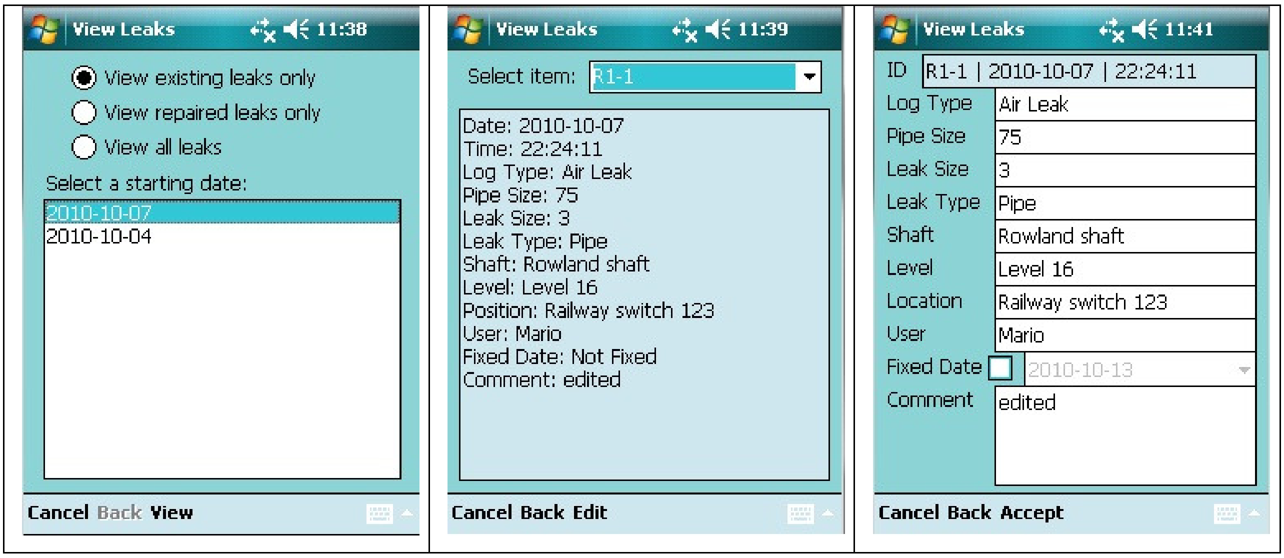


Figure 23 : Viewing data stored on the device

- **Retrieval of data from handheld computer**

The archer field PC comes as a complete package, which includes driver software and cabling. Using the USB cable supplied, the device is connected to the computer. When connecting a Windows® Mobile-operated device to a computer with the Windows operating system installed, Windows Mobile Device Centre is necessary.

Record keeping and management of detected leaks are done on the desktop computer setup. Once the device is connected, data synchronisation will automatically commence. Identical copies of all the data on the device and data in the predetermined device setup folder are then created. The latest versions of files are kept and older versions overwritten. The folder created has the same name as the device name, and is stored in the documents folder of the user.

Logger data collected since the last synchronisation are then added to the logger-data folder, as well as the data file with the last 200 existing logs. After the data have been synchronised, the CALDS application is used to process the data. Figure 24 shows the start-up screen after the application has been opened.

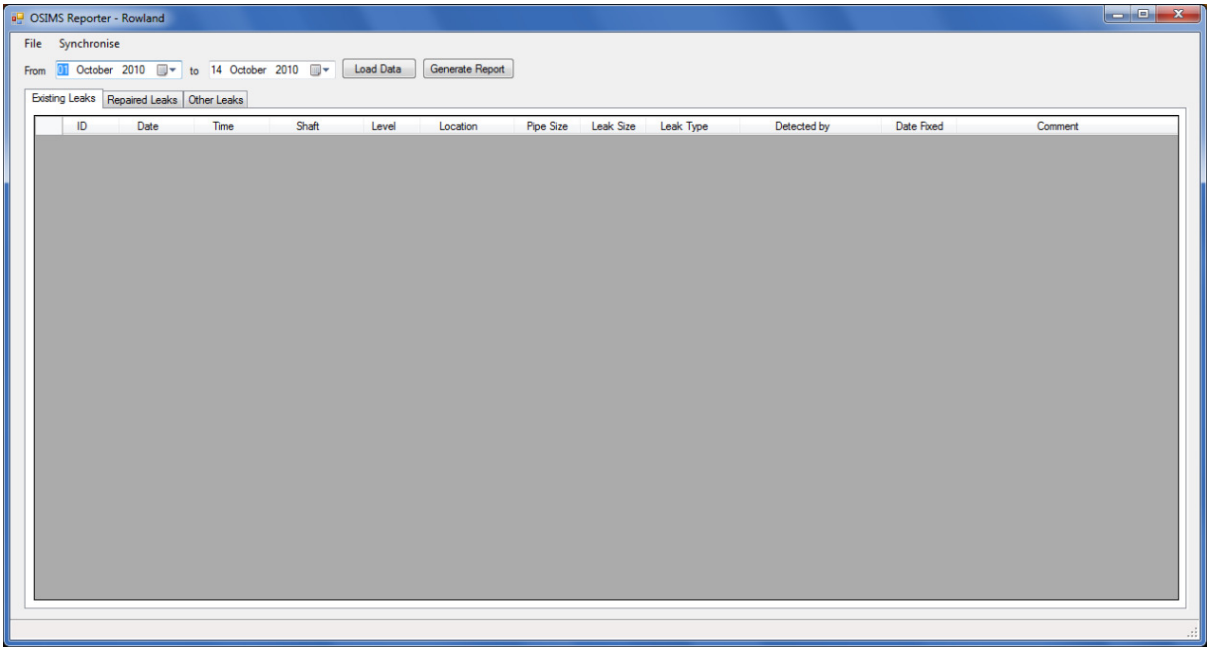


Figure 24 : CALDS application start-up screen

- **Processing of detected and repaired leaks**

In order to start the processing of the data, select the *Set up Mobile Device option* under the Synchronise menu. Here the root directory of the data folder must be specified for the data retrieved from the handheld device. Figure 25 shows the typical directory path, with *Mine Name* and *Device Name* inserted for clarification purposes, and will be customised for individual projects. This function also confirms whether the folder is present at the specified directory path.

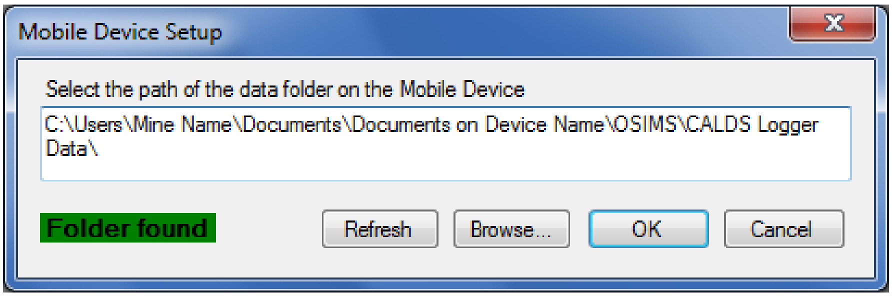


Figure 25 : Mobile device set-up menu

Once the folder is confirmed, the data are combined into a single file, sorted by *Existing leaks*, *Repaired Lea*ks and *Other leaks*. Figure 26 shows the *Existing Leaks* for a typical mine setup, with data recorded as described in section 3.5 under data capturing.

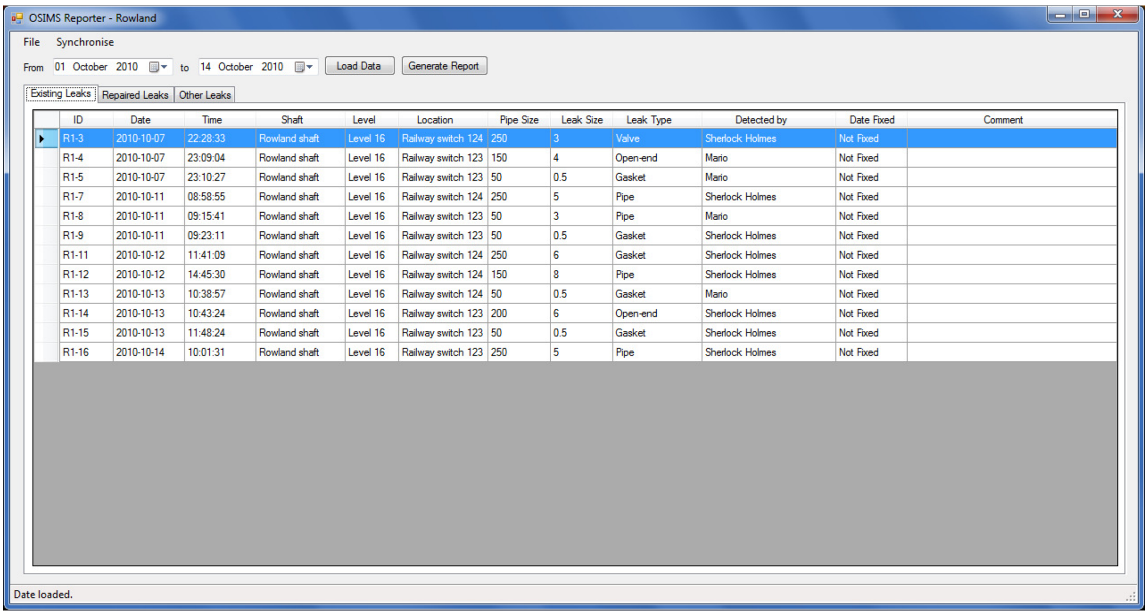


Figure 26 : Table indicating existing leaks

Leaks can either be marked as fixed on the device, or in the CALDS Reporter software. By double clicking on the entry the edit menu will be activated, as shown in Figure 27. A checkbox at the left-hand bottom of the menu can be checked, and the date the leak was repaired entered. The entry will automatically be moved to the *Repaired Leaks* section.

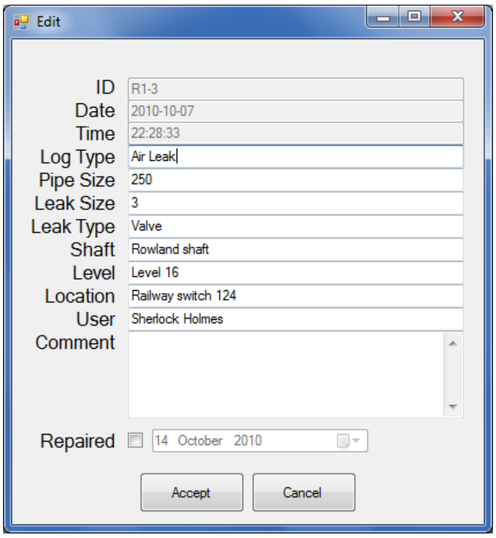


Figure 27 : Menu for editing leak status

3.6. Reporting

Once the data have been processed into existing and repaired leaks, the report can be generated. With the screen display as in Figure 26, the reporting interval can be selected at the top left corner. Typically, *From* date would be the date the last report was generated, and *To* date the present-day date. Custom dates can be entered for specific report generation. After date of reporting has been set, the *Generate Report* button can be clicked to generate the report. The report is then generated and stored under *reports* in the data logger folder.

As described in section 2.5.2, the reporting procedure utilised is similar to the reporting used by HVAC International for project feedback reports. Project-specific details are preprogrammed into a set-up file with the implementation of the system. Leaks documented on the handheld device are inserted from the tables created in the previous section. Reporting is done of both *Existing Leaks,* as well as *Repaired Leaks*. Created reports are in *.xml* format, a format used by Microsoft® Word® 2007. The required software will be supplied with the implementation of the system. The sample template can be seen in Appendix G.

To convert the leaks into monetary terms, equations [2-1] to [2-5], discussed in section 2.3.3, were programmed into the reporting tool. Certain assumptions on some of the parameters, and average pressure of the shafts, were used for the calculations. Assumptions made include the following:

- Atmospheric pressure, 87 kPa (average height above sea level for mines used in study);
- Air temperature, 25 ˚C;
- Line temperature, 28 ˚C;
- Compressor efficiency of 80%;
- Coefficient of leak , 0.65 (based on assumption in [33]); and
- Motor efficiency, 0.98 (synchronous motors).

These values were used because of the fact that the quantification of leaks into monetary terms is only an approximation. Values were compared with similar methods being used by an energy engineer in the mining sector. This comparison is given in Appendix H.

In the case where photos are to be included in the reports, the reporting software monitors the file where photos are stored on the computer. Photos downloaded from the camera are automatically saved in a folder denoted by the date the files are downloaded. Software supplied with the camera copies photos, which have not previously been copied to the directory. Folders with dates in the selected range of the report will automatically be inserted. The name of the photo is used as the caption, and can therefore be linked to the logged entry in the comment column from the detected-leaks tables. Figure 28 shows the camera supplied for this purpose.

Figure 28 : Rugged camera supplied with CALDS

Microsoft® Office Outlook accounts for mail distribution are used upon special request by the mine. This simplifies the distribution of the reports, since e-mail is the primary form of communication on the mine. A group of addresses is created to which the report is sent. E-mailing of the reports is done by the person responsible for creating the reports.

3.7. Summary

Different systems have been implemented and field tested prior to this study. The reasons why the original systems were not accepted in the mining industry were investigated. The deficiencies identified were addressed in the newly developed system with a more robust handheld device and improved software development.

A new system was developed and reprogrammed, using a new handheld device with a different operating system. Processing of the data has been made more user friendly by redesigning the reporting and data-managing software supplied with the CALDS package. Special needs were also catered for in cases where systems were already in place for leak detection, and the developed system did not address the specific requirements.

Desktop software was developed to be more user friendly, and to generate reports that could be viewed by software supplied with the system. Optional to mine specific needs, email accounts could be setup to distribute reports electronically, or by means of hard copies. Printers were included in the package to enable hard copies of reports to be produced, if needed.

4. Results

4.1. Preamble

The CALDS system described in section 3 has been implemented in the gold- and platinum-mining environment for evaluation. In conjunction with HVAC International, a registered ESCo, the compressed air leakage documentation system (CALDS) was implemented as part of compressed-air optimisation projects.

Baseline profiles and actual obtained kilowatt values have been verified by independent measurement and verification teams from South African Universities. Various scenarios have been selected to evaluate the system to obtain a broad understanding of project success.

The following case studies will illustrate the effect of leaks in the mining industry, as well as the successful implementation of CALDS. Case study 1 shows the effect of open-ended pipes and valves on energy efficiency. Case study 2 was selected to illustrate the successful implementation of CALDS.

4.2. Case study 1

To demonstrate the effect that leaks have on a system and the benefits of CALDS, case study 1 was selected as one of the projects implemented by HVAC International on a gold mine. Because of a confidentiality clause, the mine used in this case study will be referred to as Mine 1. Figure 29 shows the compressed-air reticulation network of Mine 1, with the surface connections.

The mine consists of two production shafts, 1# and 3#, as well as a gold plant using air from the compressed-air network. Compressed air is supplied by a compressor house situated at Shaft 3, with a single GHH and three Centac compressors. The compressors have installed capacities as follows:

- GHH with 5 MW,
- Centac with 1.65 MW, and
- Two Centacs with 0.875 MW.

Total installed capacity of the compressors at Mine 1 is 8.4 MW.

Shaft 3 and Shaft 1 are also interconnected on level 121 indicated in Figure 29. Compressed air is supplied to Shaft 1 on surface for loading boxes, and on level 121 for underground usage.

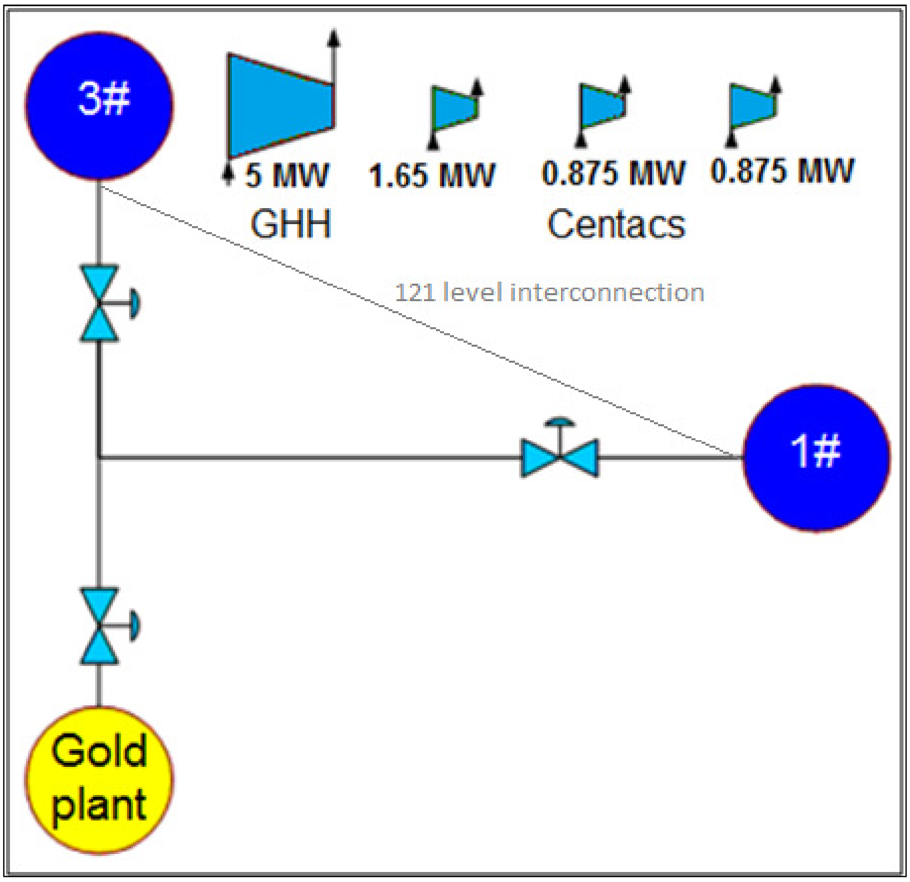


Figure 29 : Mine 1 compressed-air surface network

The DSM project that was implemented on Mine 1 was an evening-peak clipping project with expected impact of 2.5 MW. During the implementation phase of the project, this initial target was not achieved. The reason for the underperformance was suspected to be excessive leakage of compressed air. CALDS was implemented by HVAC International personnel, and an underground leak detection study was conducted.

During the leak investigation, pipes with open-ended blowing were found on one of the development levels. Open-ended blowing results in compressed air escaping through a valve or hose left open. Compressed air was being used for ventilation on these levels. Because ventilation fans were not installed by the mine, this was the only means of ventilating the working area.

The open-ended blowing was detected during January 2010, and it was decided to implement a timer-controlled valve on the development level with the open-ended piping. The peak-clipping project required savings between 6 pm and 8 pm on weekdays. During this period, no compressed air was required on these development levels and the supply could be shut off.

Table 8 shows the average evening-peak savings per month obtained from data for November 2009 until April 2010. These data were obtained from HVAC International's database of implemented projects. Data are verified by an independent measurement and verification (M&V) team, and correlate closely with the values given in Table 8. The report generated by the M&V team is given in Appendix J.

Table 8 : Average monthly power savings on case study 1

	Before CALDS			**After CALDS**		
	09-Nov	09-Dec	10-Jan	10-Feb	10-Mar	10-Apr
Average Eskom peak (MW)	1.46	1.24	1.17	1.76	2.03	2.15
Average savings (MW)	1.29			1.98		
Increase in savings (MW)	0.69					

With the fitment of the timer-controlled valve, the savings achieved during the Eskom peak period increased from 1.46 MW in November 2009 to 2.15 MW in April 2010. Because of the effective management of leaks, a compressor with rated power of 875 kW was no longer required during Eskom peak periods. This compressor was operated solely to supply ventilation in a period where no personnel were underground.

Figure 30 shows the power profile for the period of November 2009 until April 2010. The effect of the installation of the isolation valve can be seen, as the power consumption decreased significantly. The March 2010 and April 2010 profiles show the period in which fewer compressors were required, resulting in an even greater energy-efficiency component.

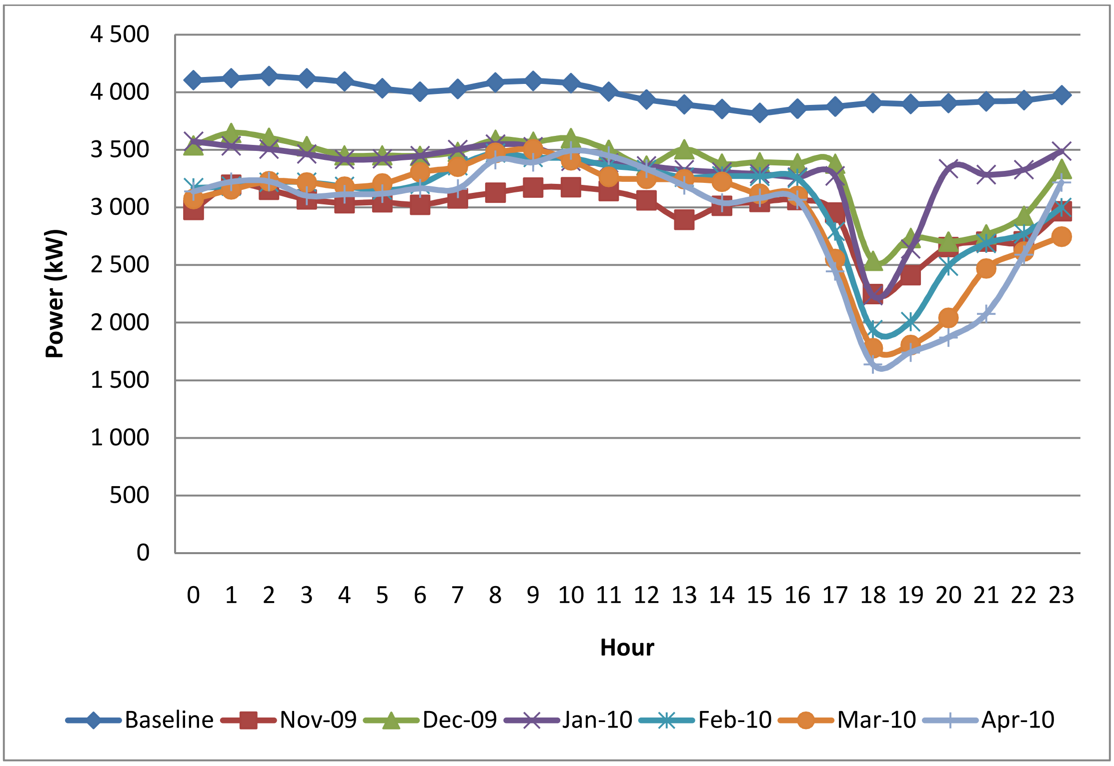


Figure 30 : Mine 1 average monthly power consumption profile of the compressed air system

Figure 31 shows the pressure profile for the same period as the power profile in Figure 30. The pressure did not vary much from baseline values during production times from 6 am until 2 pm. With sufficient working pressure being maintained during this time, production was not affected. The pressure also never dipped below 440 kPa, which is the minimum requirement for loading boxes on surface, as well as the loading level.

This case study shows the importance of fixing leaks and the correct isolation of unused piping in a system. Considerable savings were achieved without negatively affecting the production output of Mine 1.

The control of open-ended blowing that was identified by CALDS resulted in additional savings of 0.69 MW from 6 pm to 8 pm. This was calculated as the average between the first three months before detection and the three months after implementation of the control valve. In monetary terms, the additional saving amounts to R 240 000.00 per annum.

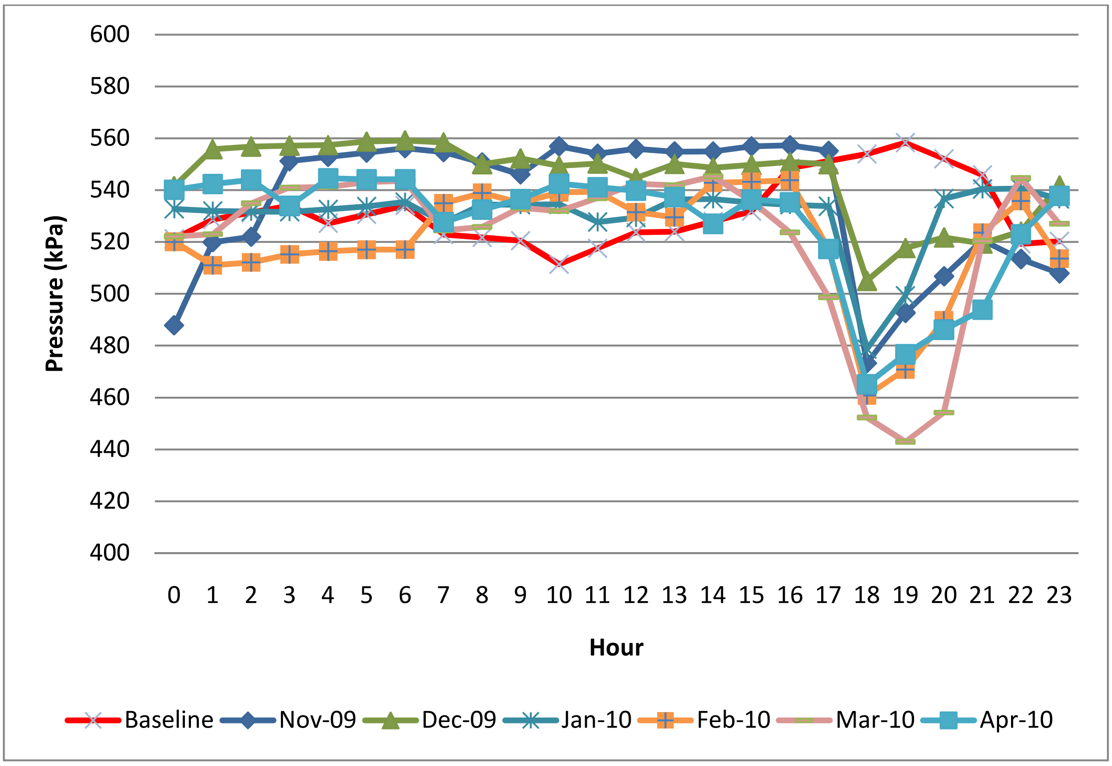


Figure 31 : Mine 1 monthly average pressure profile of compressed-air system

4.3. Case study 2

CALDS was implemented on a gold mine which already had a procedure operational for leak detection. Owing to confidentiality clauses that may be breached, the mine used in this study will be referred to as Mine 2.

Mine 2 consists of three production shafts, with a total installed capacity of 24.65 MW on the compressor network. Compressed air is an integral part of daily operations and the production process. Figure 32 shows the surface reticulation of Mine 2, indicating the three shafts and five installed compressors.

Previous leak-management initiatives

A project was initiated to reduce the compressed-air consumption on the three shafts, and an out-sourced company was contracted to identify the leaks. This company responsible for the leak detection used ultrasonic leak detectors to estimate the flow rate of the identified leaks.

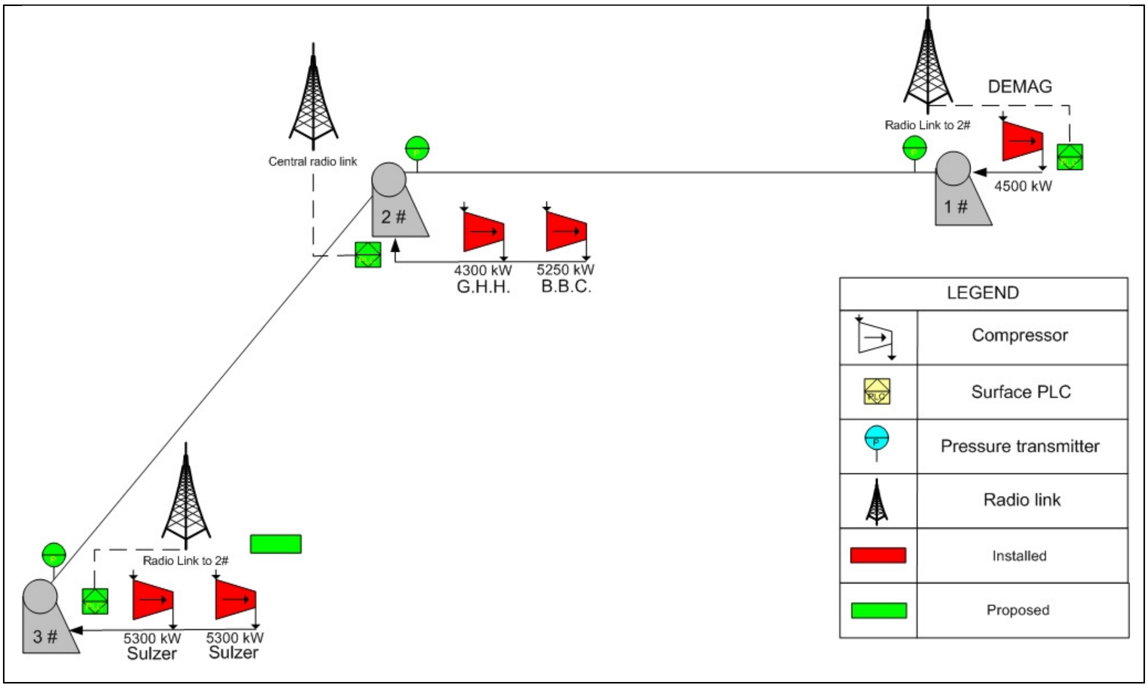


Figure 32 : Mine 2 compressed-air system surface layout

Reports were given to the mine on the leaks found, and prioritised to identify the most severe leaks. Complete reports as generated by the out-sourced company can be found in Appendix B, Appendix C and Appendix D. These reports were summarised, with the most severe leaks identified as follows:

- On Shaft 1, the 22 most severe leaks accounted for 59.1% of total compressed air leaked, with an estimated cost of R 307 132.29 per month;
- On Shaft 2, the 21 most severe leaks accounted for 70.6% of total compressed air leaked, with an estimated cost of R 464 538.62 per month; and
- On Shaft 3, the nine most severe leaks accounted for 79.7% of total compressed air leaked, with an estimated cost of R 294 822.53 per month.

According to these reports, Mine 2 lost an estimated R 1 066 493.44 per month owing to leaks. Electricity running cost of compressors was calculated at R 2 684 000.00, based on an average baseline of 8 MW and average energy cost of 46.6 c/kWh. Based on these values, 39.7% of total energy consumed is lost through leaks.

Costs of leaks were calculated by multiplying the flow rate (litres/second) through the leaks by a constant 75.52 Rand for every litre wasted per second. This factor was utilised by the out-sourced company without giving further explanation on how it was obtained. Leak rates were obtained from ultrasonic detectors detecting the sound emitted by the leak, and converting it to flow rate using a conversion chart. An example of these charts is given in Figure 33. The chart given in Figure 33 is for very small leaks, typically in the region of 0.033 mm^2 and 0.822 mm^2, and is only for demonstration purposes.

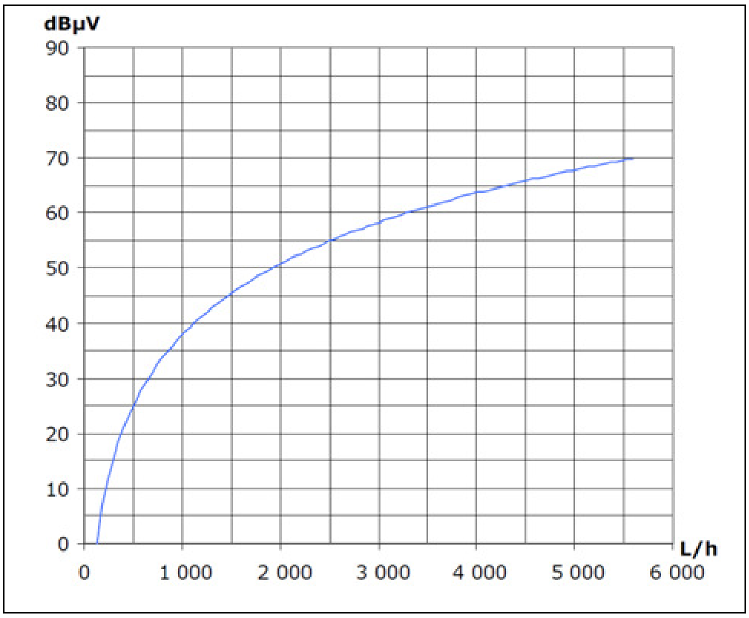


Figure 33 : Chart for converting ultrasonic readings to flow rate [42]

Awareness of the effects of leak management in the compressed-air network was highlighted by these reports. Because this process was outsourced by the mine, leak detection was still not part of their daily process management. The implementation of CALDS will enable mine personnel to perform ongoing leak management.

Implementation of CALDS

CALDS was implemented on each of the three shafts. The mine assigned one user per shaft responsible for documenting the leaks. This enabled the tracking of repairs on leaks detected by the outsourced company. Reports could now be generated on a weekly basis and used in weekly meetings for tracking purposes.

In service training was given to the responsible person, and leaks were documented. Reports were generated from the field data retrieved, and handed to the shaft engineers and shaft foremen. Leaks detected were converted to monetary terms, and compared with the values given by the company doing the initial detection. These were, however, based on leak sizes entered by the personnel doing the detection, and were only an approximation. These approximations were sufficient for reporting on whether the leaks were being repaired or not.

A report generated for Shaft 3, and the setup text file of the PDA, can be found in Appendix G and Appendix I respectively. Locations used in the setup of the PDA were obtained from the appropriate foreman of the shaft. The setup was done in conjunction with the foreman, teaching him how to add additional sections should further development take place on the shaft.

HVAC International personnel did the detection on Shaft 3, together with the foreman and junior engineer of the shaft. The nine most severe leaks, as found by the external detection company, were investigated to track the repair process of the leaks. Findings proved that most of the leaks documented by the out-sourced company were repaired. Leaks that had not been repaired were leaks that were in the section managed by the production department of the mine. CALDS reports could now be used to convey leak information between departments.

Leaks found in the piping network are repaired in various ways. Figure 34 shows a clamp used for fixing holes marked as *punch-hole leaks*. Fixing flanges and valve leaks requires the fitment of new seals and takes considerably more time, since compressed air needs to be shut off in the relevant section. This can only be done during non-production times.

Figure 34 : Clamp used for fixing punch-hole leaks

During the inspection, done together with the mine personnel, of the nine largest leaks on Shaft 3, other leaks were detected not previously documented by the out-sourced company. These were documented using CALDS and can be found in the existing-leaks section of the report in Appendix G. Because the leaks found by the external company had been repaired, the values of the financial impact of those as calculated by CALDS could not be compared.

Calculations made by CALDS on the costs are based on various inputs, as previously defined by HVAC International with the initial setup of the devices. The average pressure baseline was used to obtain the average working pressure of the shaft. This baseline is given in Figure 35, and the average pressure was calculated, using the 24-hour profile data, as 560 kPa.

Average cost for electricity was taken, as described in section 2.3.3, as 46.6 c/kWh. System characteristics were based on:

- Atmospheric pressure at 87 kPa;
- Air temperature at 25 ˚C;
- Line temperature at 28 ˚C;
- Compressor efficiency of 80%;
- Coefficient of leak assumed to be 0.65 [33]; and
- Electric motor efficiency taken at 0.98 (synchronous motors).

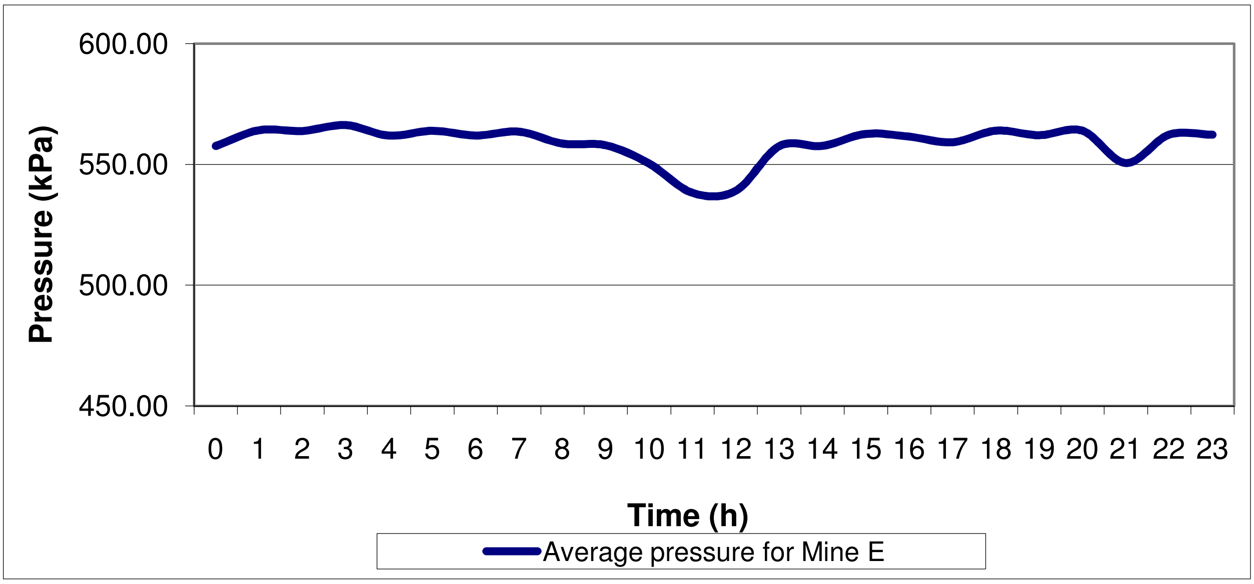


Figure 35 : Mine 2 average pressure baseline of compressed-air system

The effect of creating awareness of the leaks was evident with the follow-up study done by HVAC International and mine personnel. All the critical leaks detected within the shaft's responsibility area by the out-sourced company have been repaired, except for one leak at the West 4 cross-cut section.

This leak was documented as a defective valve by the out-sourced company, and the cost reported as R 24 951.81 per month. The leak was, however, found during the follow-up study to be on a water trap. The size of the hole was entered as 4 mm in diameter. According to the CALDS calculations used in the reporting, the financial impact of this leak is R 14 837.87 annually. For the leak cost to be in the region of the external report, it has to be entered as a hole with a diameter of approximately 18 mm into CALDS. The valve size was documented as a one-inch valve, or 25.4 mm. This makes this figure questionable, but not implausible, because it was unknown if the valve was partially closed off after being detected by the external company.

A leak found at West 7 cross-cut on a clamp was also detected by the external company, but was not one of the bigger leaks. The cost was calculated as R 546.01 per month. CALDS calculated the cost of this leak as R 483.00 monthly, 12 % less than the cost calculated using ultrasonic leak detection by the out-sourced company. Two additional leaks were found on defective valves, one at West 7 cross-cut, and one at West 4 cross-cut. These were new leaks not detected by the external company. This again illustrates the need for ongoing leak management.

An additional repaired leak was also found on the West 7 cross-cut section and was documented on the device. Existing leaks documented were either valve- or flange-type leaks. As discussed earlier, these leaks can only be repaired during non-production times. Some of these leaks were found to be on valves used to isolate unused piping, and could be closed off using blank-off flanges. This was entered in the additional-comment section on the device, but is not displayed in the report.

Comments can be viewed on the computer used to generate the reports, and on the device itself. When leaks are repaired, this section gives valuable information regarding the nature of the leak and how it can be repaired, provided it is entered correctly. Using the handheld device aided in managing the detected leaks, as well as the repair progress. Table 9 shows the comment section from the field data obtained during the investigation.

Table 9 : Field data displaying comment section

Size	Leak type	Comment	Location	Detected by	Date fixed
0.5	Valve leak	blank off pipe	South 7 X-cut	HVAC Personnel	Not fixed
5	Punch-hole leak		South 9 X-cut	HVAC Personnel	2010/11/01
5	Punch-hole leak	4th biggest 545l/s fixed	South 13 X-cut	HVAC Personnel	2010/11/01
2	Flange leak	150 m down x-cut	West 13 X-cut	HVAC Personnel	Not fixed
0.25	Clamp leak	fixed leak	West 7 X-cut	HVAC Personnel	2010/11/01
2	Clamp leak	plastic pipe	West 7 X-cut	HVAC Personnel	Not fixed
2	Manifold leak	reducer 50 to 25	West 6 X-cut	HVAC Personnel	Not fixed
4	Valve leak	blank off before valve, valve presently closed	West 4 X-cut	HVAC Personnel	Not fixed
3	Valve leak	damaged valve on water trap	West 7 X-cut	HVAC Personnel	Not fixed

Managing the repaired leaks was included in regular feedback meetings by making use of these reports generated by CALDS. Tracking could now be effectively managed because of the existing- and repaired-leaks sections in the reports. Feedback on why leaks had not been repaired had to be given and this resulted in leaks being repaired more regularly.

The aim of CALDS is to empower the mine to effectively manage its own compressed-air leaks. CALDS achieved this by enabling the mine to make leak detection part of everyday operations. This study showed that CALDS can successfully be used as a compressed-air leak management platform in the mining industry.

4.4. DSM project results where CALDS was implemented

It is difficult to accurately quantify the impact of CALDS on a compressed-air system's total energy efficiency. The sustainability of compressed-air DSM projects implemented by HVAC International was investigated. If the results are shown to be sustainable, it will imply that leak management is being effectively controlled. This implies the successful implementation of the

CALDS platform, even if CALDS only created an awareness of the effect of leaks among mine personnel. Data used were obtained from the M&V team at North West University in Potchefstroom, and is included in Appendix J.

Data from six mines were analysed from November 2009 until August 2010, and are summarised in Figure 36. This figure shows the average savings achieved in compressed-air management projects, accompanied by the CALDS system. The last six performance tracking reports of the six projects were used to construct the data.

On average, the system achieved a monthly performance of 125% of the target savings over the evaluation period. This could be ascribed to the effective management and reporting on compressed-air key-performance indicators (leaks, flow, pressure, etc.). February showed to be a good month in terms of savings achieved. This was because three of the mines used had an exceptionally good performance during this month.

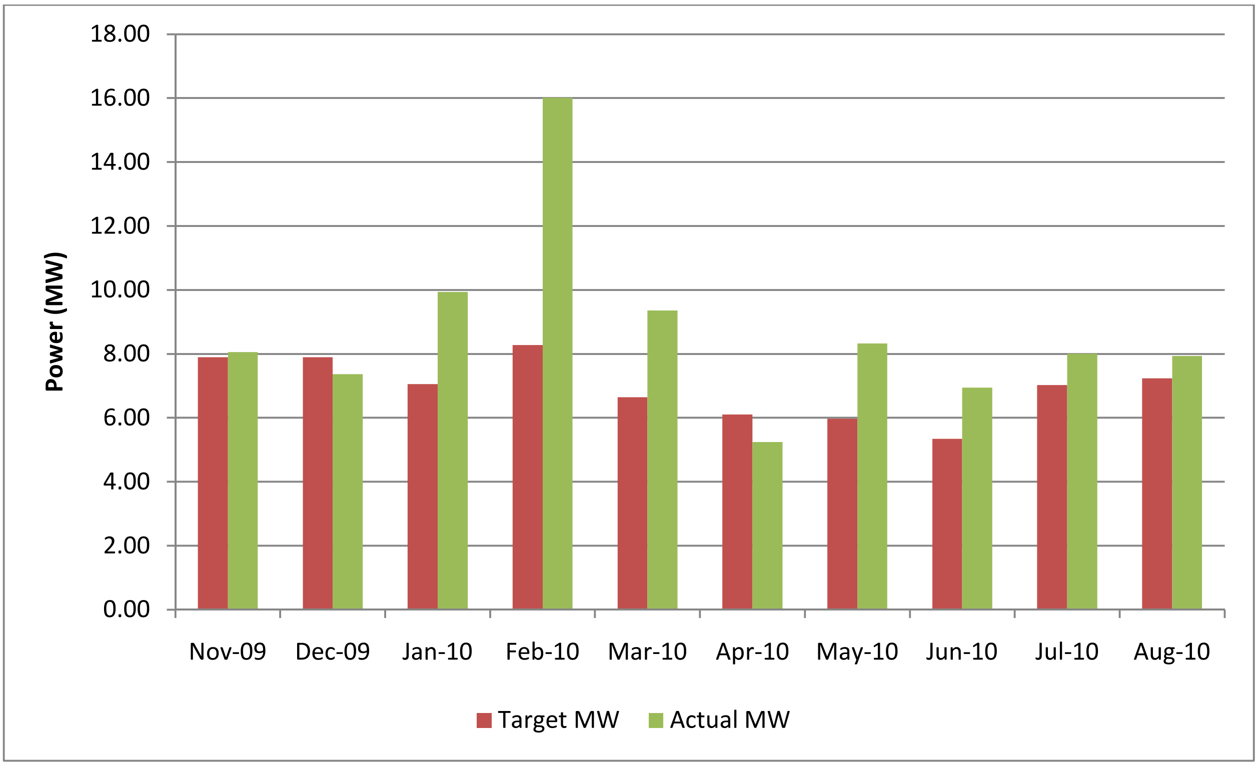


Figure 36 : Average power reduction performance increase of compressed-air system after implementation

It was also found that when personnel were focussed on the savings achievable, and awareness was created of these savings, performance of the project increased significantly.

Figure 37 shows the effect of active ownership on the management of compressed-air systems. Data sets one, two and three show data on system performance from November 2009 until January 2010. During this time, no one took responsibility for the system performance. Data sets four, five and six show performance data of the project from July 2010 until August 2010, with effective management in place. System performance increased from 34% during the first three months, to 102% during the last three months. These values are obtained from Mine 1 included in Appendix J.

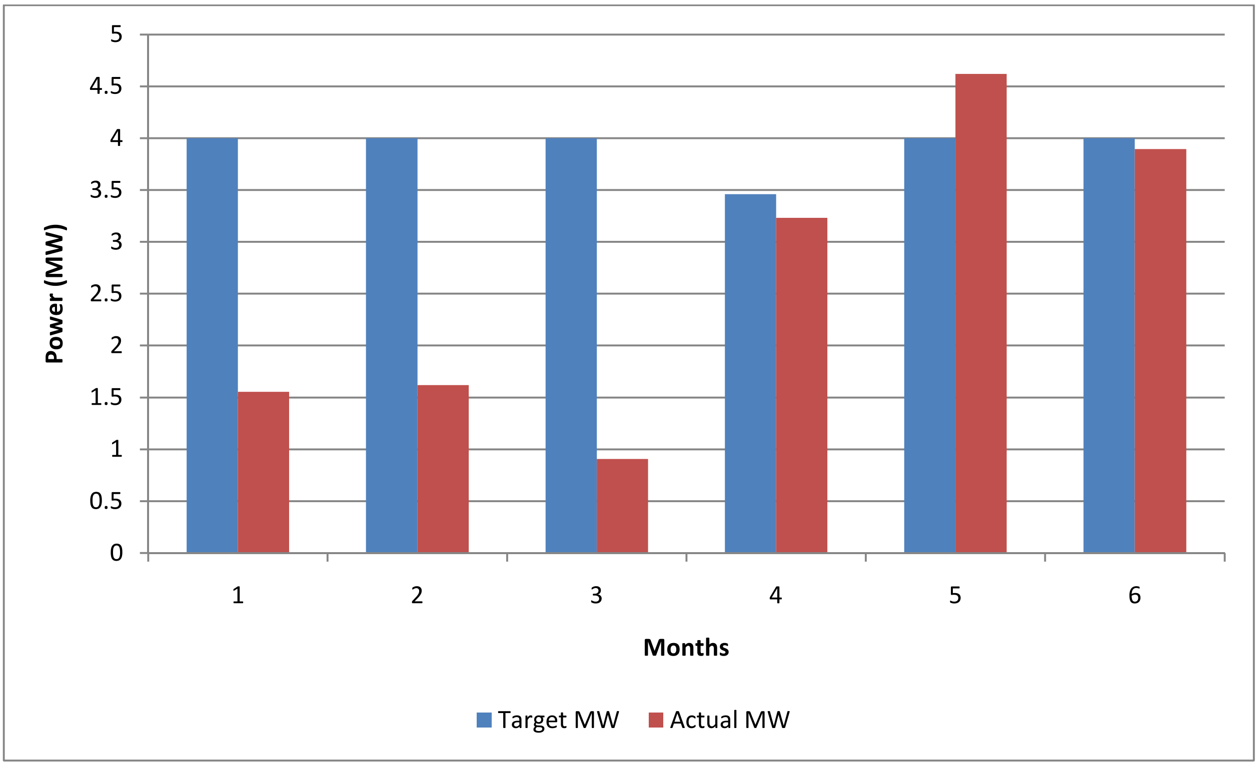


Figure 37 : Mine 1 power reduction performance increase over time of CAS

Figure 38 shows performance of Mine 4 in Appendix J. As can be seen from the figure, the project is constantly achieving its target. Performance figures vary between 119.34% and 188.22% of target values. These figures were obtained from February 2010 until July 2010. Here the performance figures are evidence of the effective management of the complete compressed-air system. The compressed-air network of Mine 4 supplies three mines with compressed air.

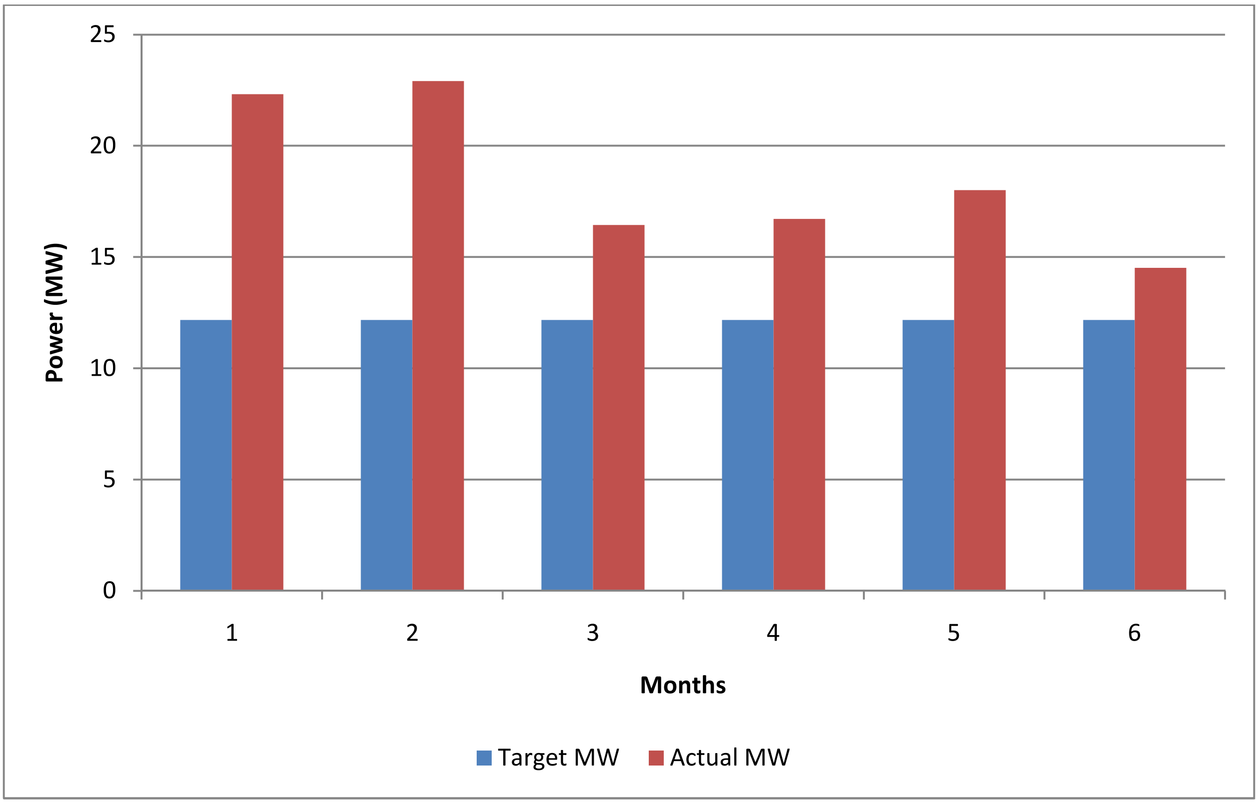


Figure 38 : Mine 4 CAS power reduction profile over time

4.5. Summary

CALDS is implemented as a method of aiding effective management of leaks on mines. This enabled leak detection to become a part of daily operations without the need to involve out-sourced companies to do the detection. Simplistic design and user-friendly interface of CALDS increased the acceptance of the system in the mining sector. Reporting on the status of leaks and dates repaired made the reports an important part of shaft engineers' planning meetings.

Unmanaged leaks in mines proved to be a big contributor to inefficiency in compressed-air systems. Results obtained from case study 1 showed that up to 45% of project savings can be lost because of mismanagement of the compressed-air system. Case study 2 showed the effectiveness of CALDS in the management of leaks on compressed-air systems.

5. Conclusion and future work

5.1. Conclusion

As discussed in the literature study, DSM initiatives will help to alleviate the electricity supply problems faced by Eskom. HVAC International, an Energy Services Company (ESCo), has implemented various types of energy management projects, including compressed-air optimisation projects. The challenge, however, is to ensure the sustainability of these projects. Some of the previous DSM project savings experienced significant decrease in performance over time.

Poorly maintained compressed-air systems have resulted in wastages which accounted for approximately 40% of energy cost. A Compressed Air Leakage Documentation System (CALDS) was developed and implemented on compressed-air DSM projects to reduce these wastages. This study focussed on addressing deficiencies in present methods by developing a user-friendly system that is robust and reliable for use in the mining industry.

Different leak-documentation strategies were implemented prior to the final solution and discussed in this study. Problems were encountered with PDA devices previously used. These PDAs were found to be neither robust enough nor user friendly, and were discontinued. A new system was developed, utilising PDAs operating on the industry standard Windows® mobile operating system.

Reporting structures were implemented to track the repairs done on leaks detected. These reports enabled engineers and managers to become more aware of, and sensitive to, the operational state of their compressed-air systems. Effective documentation on key compressed-air performance indicators (leaks, flow, pressure, etc.) proved to be a valuable asset in system optimisation.

Expressing the effects of leaks in monetary terms established awareness of the severity of leakages. Detecting the wastages caused by leaks, expressed in terms of financial costs, increased the probability of leaks being repaired. This study focussed on detection of larger leaks, because the maximum savings can be achieved with minimal repair costs. Leak detection was accomplished by listening to the hissing sound caused by air escaping through the orifice, which is purely a subjective method.

The influence of fixing leaks on a compressed-air system was investigated by implementing CALDS on a project that did not realise the contractual DSM target. On one of the development levels, open-ended piping was found during non-production times. A timer-controlled valve was fitted to isolate the compressed air to the development areas during Eskom peak times when compressed air was not required. The original DSM saving of this mine was 1.2 MW. After implementation of CALDS, power savings of 2.2 MW were achieved, resulting in an increase of 85%. The open-ended piping accounted for losses of up to 45% of the total DSM project savings achievable.

Managing leaks effectively by creating awareness of the existing leaks proved to be a valuable asset. Leaks detected by a company contracted by the mine were prioritised in order of severity. During a follow-up study done on the mine, it was found that the majority of these detected leaks were repaired. However, new leaks were detected, showing the need for continuous leak management.

Compressed-air projects implemented and supplied with the CALDS package showed a sustainable performance profile. Over a ten-month performance-assessment period, it was found that the projects on average returned 125% of the targeted savings. Although it is difficult to quantify the exact effect that CALDS had on the sustainability of these projects, the complete CALDS management package proved successful in the mining sector.

Even though this system is implemented as part of the complete energy solution by HVAC International, the sustainability of the projects is indicative of proper leak management on DSM projects. This is due to the effective reporting on all factors affecting the savings achievable. When compared with the deterioration in savings experienced in the Western Cape [11], managing through reporting is definitely a successful part of DSM projects.

5.2. Recommendations for future work

The set-up method of the handheld device is done through a text file written in a specific format. This resulted in the system having to be setup by HVAC International engineers. Improving on this set-up method entails the development of a drag and drop type of programming. The compressed-air reticulation can be created by dragging icon sets in hierarchical-level format, generating the code automatically. This will enable the personnel on the mine to expand the system as future development occurs.

On one of the projects where CALDS was implemented, the surface reticulation network was mapped using GPS coordinates. With the pipeline reaching lengths in excess of 75 km, a PDA with GPS capability can be very useful. The Archer field PC chosen for CALDS has a GPS attachment available. The software needs to be adjusted to access the GPS interface, but was excluded from the functional specification of the initial developed system. The attachment that enables the use of GPS is expensive and will double the cost of the combined GPS/PDA system.

A system presently in place on one of the mines used photos for indicating where the leaks occurred. This was established after the system had been developed, and small programming changes were made to allow for photos to be added to the report. Photos used were taken with a waterproof and robust camera supplied with the system. If the PDA was fitted with the optional camera adaptor, the need to carry a separate device would be eliminated. At the time of project implementation camera expansion units were not available in South Africa, and had to be ordered. Delivery time on these units resulted in insufficient time for testing and additional development.

Ultrasonic leak detectors were utilised by some of the mines to quantify the leaks using conversion charts. Readings obtained from ultrasonic leak detectors were also entered into the Archer field PC under the additional comments section in order to manage the recorded leaks. Further development is still required to incorporate the chart for quantifying the leaks based on ultrasonic leak detection readings.

As soon as the larger leaks in the system are managed effectively, focus can be shifted to smaller leaks. When this is done, ultrasonic leak detectors can be incorporated into the system to ease the detection of smaller leaks in noisy environments such as the mines. Ultrasonic add-ons for the Archer field PC that interface through USB or serial communication can be considered.

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Appendixes

A. Mine C leakage detection report

The report as generated by Mine C during the leak detection is given below.

Date	Level	Location	Drill water	Drinking water	Air leak	Severity	First follow up	Repaired	Second follow up	Repaired	Third follow up	Repaired
2010/12/05	16	East west split		x		30 ℓ pm	20/05/2010	No	27/05/2010	YES		
13/5/2010	20	West 57		x		Small						
13/5/2010	19	West 63			x	Big	28/05/2010	No				
13/5/2010	19	West 59			x	Big	28/05/2010	No				
14/5/2010	29	Station		x		Small						
14/5/2010	29	Tips	x			Small						
17/5/2010	19	West 35	x			Small	28/05/2010	No				
17/5/2010	19	Rail Joint 123	x			Big	28/05/2010	No				
17/5/2010	25	West 9			x	Big						
19/05/2010	16	Central J134	x			Small	20/05/2010	No	27/05/2010	YES		
19/05/2010	18	Rail Joint 18 (Central)			x	Small						
19/05/2010	18	Rail Joint 51 (Central)			x	Small						
19/05/2010	18	Rail Joint 55 (West)			x	Small						
19/05/2010	18	Rail Jiont 145 (West)			x	Small						
19/05/2010	18	Rail Jiont 155 (West)			x	Small						

19/05/2010	18	Rail Jiont 164 (West)			x	Small						
19/05/2010	18	Rail Jiont 180 (West)			x	Small						
19/05/2010	18	Rail Jiont 191 (West)			x	Small						
19/05/2010	18	Rail Jiont 212 (West)			x	Small						
19/05/2010	18	Rail Jiont 229 (West)			x	Small						
19/05/2010	18	Rail Jiont 257 (West)			x	Small						
19/05/2010	18	Rail Jiont 266 (West)			x	Small						
19/05/2010	18	Rail Jiont 283 (West)	x			Small						
19/05/2010	18	Rail Jiont 295 (West)			x	Small						
19/05/2010	18	Rail Jiont 296 (West)	x			Small						
19/05/2010	18	Rail Jiont 298 (West)			x	Small						
19/05/2010	18	Rail Jiont 299 (West)	x			Small						
19/05/2010	18	X - cut 72 (West)	x			Small						
19/05/2010	18	X - cut 72 (West)			x	Small						
20/05/2010	20	X - cut 45 Refuse Bay			x	Meduim						
20/05/2010	20	Before X - cut 57	x			Small						
20/05/2010	20	X - cut 65	x			Meduim						

28/05/2010	19	X - cut 27			x	Small						
28/05/2010	19	X - cut 29			x	Small						
28/05/2010	19	X - cut 31			x	Small						
28/05/2010	19	X - cut 33			x	Small						
28/05/2010	19	X - cut 35			x	Small						
28/05/2010	19	X - cut 41			x	Small						
28/05/2010	19	X - cut 51	x			Meduim						
28/05/2010	19	X - cut 57			x	Small						

B. Mine 2 leakage detection report for Shaft 1

The leaks, as detected by the out-sourced company for Shaft 1 of Mine 2, as discussed in case study 2, are given below.

Position	Description	Volume l/sec	Est R/month	Date
85 Haulage West 50m from reef tip	Punch hole leak	330.4	R 24 951.81	05-May-10
101 South 3 1 West Stope 20m into gully	Punch hole leak	320.0	R 24 166.40	06-Jul-10
101 West 17 Stope at tip no 5	Punch hole leak	259.6	R 19 604.99	03-Jul-10
106 South inside W28 x-cut 50m in travelling way to Doringkop	Punch hole leak	251.0	R 18 955.52	09-Jun-10
90 10m passed 11 West x-cut waiting place, hose left open	Personal cooling	245.0	R 18 502.40	12-May-10
101 South 3 1 West Stope gully entrance	Punch hole leak	243.0	R 18 351.36	06-Jul-10
95 10m passed Refuge chamber no 1	Tap leak	226.0	R 17 067.52	21-May-10
90 15m passed mini sub at bullnose	Joint leak	225.0	R 16 992.00	07-May-10
95 West 16 x-cut entrance	Punch hole leak	201.0	R 15 179.52	27-May-10
101 MIH 10m from South 1 x-cut	Punch hole leak	189.0	R 14 273.28	01-Jun-10
85 Haulage West at reef tip	Punch hole leak	178.5	R 13 480.32	05-May-10
90 Outside workshop	Valve leak	178.5	R 13 480.32	07-May-10
95 20m passed Refuge chamber no 1	Punch hole leak	178.0	R 13 442.56	21-May-10
95 90m passed West 11 x-cut	Punch hole leak	172.0	R 12 989.44	25-May-10
90 Inside West 22 x-cut 20m from ventilation door	Punch hole leak	154.0	R 11 630.08	19-May-10
95 Inside West 22 x-cut, 50m fom West 21 at boxfront	Control leak	125.0	R 9 440.00	28-May-10
95 30m into West 17 x-cut	Punch hole leak	119.6	R 9 032.19	28-May-10
95 at Timberbay	Punch hole leak	118.1	R 8 918.91	20-May-10
95 at Timberbay	Punch hole leak	105.0	R 7 929.60	20-May-10
95 at main reef tip	Punch hole leak	98.0	R 7 400.96	20-May-10
95 2 East box control	Control leak	75.2	R 5 679.10	21-May-10
95 5m into West 1 x-cut	Punch hole leak	75.0	R 5 664.00	24-May-10
106 travelling way to 109	Joint leak	63.5	R 4 795.52	11-Jun-10

90 3 West Stope 5m into travelling way	Punch hole leak	48.0	R 3 624.96	28-Jun-10
109 At station	Punch hole leak	44.6	R 3 368.19	11-Jun-10
90 10m passed ventilation door	Clamp leak	44.6	R 3 368.19	12-May-10
90 at 11 West x-cut waiting place	Clamp leak	44.6	R 3 368.19	12-May-10
95 level West 10m passed mini sub no 1	Punch hole leak	44.6	R 3 368.19	27-May-10
95 40m from main reef tip	Punch hole leak	38.6	R 2 911.30	20-May-10
95 20m into West 17 x-cut	Punch hole leak	37.1	R 2 801.79	28-May-10
101 West 10m from main reef tip	Punch hole leak	36.9	R 2 789.71	04-Jun-10
85 Haulage South 30m passed waiting place	Punch hole leak	35.4	R 2 673.41	05-May-10
90 at travelling way entrance to 85 level	Valve leak	35.4	R 2 673.41	11-May-10
90 10m from 14 Refuge chamber	Punch hole leak	30.6	R 2 310.91	17-May-10
90 3 West Stope at stope entrance	Manifold leak	30.6	R 2 310.91	28-Jun-10
101 South 4 x-cut at box no 1	Valve leak	30.6	R 2 310.91	03-Jun-10
106 South inside W17 x-cut at Refuge chamber	Punch hole leak	30.6	R 2 310.91	10-Jun-10
90 50m passed old Refuge chamber	Manifold leak	26.4	R 1 993.73	12-May-10
90 9 West Stope 10m into travelling way	Joint leak	26.4	R 1 993.73	25-Jun-10
90 West 20 B stope at air manifold in gully	Tap leak	23.2	R 1 752.06	30-Jun-10
90 10m inside West 1 x-cut	Valve leak	22.8	R 1 721.86	10-May-10
90 trackless section: 12m passed third entrance left	Punch hole leak	22.8	R 1 721.86	12-May-10
101 at main reef tip	Punch hole leak	22.8	R 1 721.86	31-May-10
101 MIH 30m passed Refuge chamber 108	Valve leak	22.8	R 1 721.86	02-Jun-10
90 15m from trackless workshop	Punch hole leak	21.8	R 1 643.32	11-May-10
90 20m from face	Valve leak	21.8	R 1 643.32	12-May-10
90 South 3 12F stope inside travelling way	Manifold leak	21.8	R 1 643.32	29-Jun-10
85 North 12 2AC stope in centre gully 30m from winch	Punch hole leak	21.0	R 1 582.14	21-Jun-10
90 100m passed ventilation door	Clamp leak	21.0	R 1 582.14	12-May-10
101 West 17 Stope at air manifold	Joint leak	21.0	R 1 582.14	03-Jul-10
101 South 2 7 West Stope 20m into centre gully	Joint leak	21.0	R 1 582.14	07-Jul-10
106 West 28 Stope 20m into travelling way	Tap leak	21.0	R 1 582.14	08-Jul-10
90 20m passed old Refuge chamber	Clamp leak	20.1	R 1 515.69	12-May-10

85 North 2B x-cut 35m from stope entrance	Clamp leak	19.2	R	1 452.25	24-Jun-10
90 20m from face	Clamp leak	19.2	R	1 452.25	12-May-10
106 West 17 Stope 6m from manifold	Joint leak	19.2	R	1 452.25	09-Jul-10
90 inside West 4 x-cut 5m passed first boxfront	Box control leak	18.4	R	1 390.32	11-May-10
101 115m into East 2 x-cut	Punch hole leak	18.4	R	1 390.32	31-May-10
106 West 28 Stope 6m from manifold	Punch hole leak	18.4	R	1 390.32	08-Jul-10
85 20m from waiting place no 2	Joint leak	17.6	R	1 332.17	06-May-10
90 9 West Stope 5m into travelling way	Punch hole leak	17.6	R	1 332.17	25-Jun-10
95 at shaft pillar stope entrance	Punch hole leak	17.6	R	1 332.17	20-May-10
95 South Stope at air manifold	Tap leak	17.6	R	1 332.17	30-Jun-10
85 North 13 2C stope in centre gully 40m from manifold	Clamp leak	16.9	R	1 277.04	23-Jun-10
90 20m up travelling way to 85 level	Joint leak	16.9	R	1 277.04	11-May-10
101 West 4 stope 10m from entrance	Clamp leak	16.9	R	1 277.04	02-Jul-10
106 South inside W17 170m into x-cut	Joint leak	16.9	R	1 277.04	10-Jun-10
106 South W17 x-cut 20m from box no 4	Joint leak	16.5	R	1 242.30	10-Jun-10
85 10m from waiting place	Joint leak	16.2	R	1 220.63	06-May-10
85 Haulage West between reef and waste tip	Boesman hose leak	16.2	R	1 220.40	05-May-10
90 40m passed ventilation door	Clamp leak	16.2	R	1 220.40	12-May-10
90 9 West Stope at stope entrance	Clamp leak	16.2	R	1 220.40	25-Jun-10
90 Inside battery bay	Punch hole leak	16.2	R	1 220.40	10-May-10
90 trackless section: 15m passed third entrance left	Clamp leak	16.2	R	1 220.40	12-May-10
95 10m from main reef tip	Punch hole leak	16.2	R	1 220.40	20-May-10
95 10m passed 2 East x-cut	Punch hole leak	16.2	R	1 220.40	21-May-10
101 East 2 stope FWD 5m in	Punch hole leak	16.2	R	1 220.40	31-May-10
101 West inside shaft pillar x-cut no 2	Blank flange leak	16.2	R	1 220.40	04-Jun-10
106 South W17 x-cut at mono winch	Punch hole leak	16.2	R	1 220.40	10-Jun-10
85 Haulage West 110m from reef tip	Joint leak	15.4	R	1 161.50	05-May-10
95 15m into West 14 x-cut	Manifold leak	15.4	R	1 161.50	25-May-10
95 MIH 100m from station	Joint leak	15.4	R	1 161.50	24-May-10
106 South W17 x-cut 5m from box no 2	Manifold leak	15.4	R	1 161.50	10-Jun-10

106 West 17 Stope 10m from manifold	Clamp leak	14.7	R	1 106.37	09-Jul-10
85 North 12 2AC stope at travelling way	Manifold leak	12.4	R	936.45	21-Jun-10
90 MIH 5m from West 20A x-cut	Valve leak	12.4	R	936.45	18-May-10
95 105m passed West 17 x-cut	Joint leak	12.4	R	936.45	28-May-10
95 30m from main reef tip	Joint leak	12.4	R	936.45	20-May-10
95 West 16 x-cut 40m from box no 5	Clamp leak	12.4	R	936.45	27-May-10
101 West 4 stope in centre gully at manifold	Tap leak	12.4	R	936.45	02-Jul-10
101 South 3 1 West Stope 10m into gully	Punch hole leak	12.4	R	936.45	06-Jul-10
101 South 2 7 West Stope travelling way top	Punch hole leak	12.4	R	936.45	07-Jul-10
113 10m from boxfront in travelling way	Punch hole leak	10.9	R	825.43	15-Jun-10
90 50m into travelling way to 8 East	Clamp leak	10.9	R	825.43	12-May-10
90 Inside Refuge chamber 145	Air open	10.9	R	825.43	10-May-10
95 30m passed West 1 x-cut	Punch hole leak	10.9	R	825.43	24-May-10
95 5m into West 13 x-cut	Clamp leak	10.9	R	825.43	25-May-10
101 MIH South 3A x-cut entrance	Joint leak	10.9	R	825.43	02-Jun-10
90 MIH 10m passed fittershop	Flange leak	10.9	R	823.17	17-May-10
95 West 16 x-cut 10m from box no 3	Clamp leak	10.9	R	823.17	27-May-10
90 9 West Stope 20m into centre gully	Manifold leak	10.8	R	815.62	25-Jun-10
90 10m into 11 West x-cut	Clamp leak	9.6	R	724.99	12-May-10
90 trackless section: 50m from waiting place	Valve leak	9.6	R	724.99	12-May-10
95 West 16 x-cut 10m from box no 5	Clamp leak	9.6	R	724.99	27-May-10
106 South W17 x-cut 5m from box no 3	Joint leak	9.6	R	724.99	10-Jun-10
106 West 17 Stope in centre gully tip no 2	Joint leak	9.6	R	724.99	09-Jul-10
85 North 13 2C stope in centre gully at air manifold	Tap leak	8.7	R	659.29	23-Jun-10
90 70m passed West 22 x-cut waiting place	Joint leak	8.7	R	654.76	19-May-10
95 West 16 x-cut 20m from box no 2	Clamp leak	8.7	R	654.76	27-May-10
101 West 110m passed Refuge chamber 101	Punch hole leak	8.7	R	654.76	04-Jun-10
106 60m from reef tip	Valve leak	8.7	R	654.76	08-Jun-10
85 North 12 2AC stope in centre gully 10m from winch	Manifold leak	7.8	R	591.32	21-Jun-10
101 West 40m into West 12 x-cut	Joint leak	7.8	R	591.32	07-Jun-10

106 South inside W28 x-cut 10m from box no 1	Box control leak	7.8	R	591.32	09-Jun-10
106 South W17 x-cut 10m from waiting place no 1	Joint leak	7.8	R	591.32	10-Jun-10
101 South 3 1 West Stope 20m up in travelling way	Clamp leak	7.8	R	590.57	06-Jul-10
113 Manifold at boxfront	Manifold leak	7.2	R	546.01	15-Jun-10
85 Haulage West 105m from reef tip	Joint leak	7.2	R	546.01	05-May-10
95 20m into West 13 x-cut	Punch hole leak	7.2	R	546.01	25-May-10
109 30m South of station	Punch hole leak	6.8	R	514.29	11-Jun-10
90 20m passed ventilation door	Clamp leak	6.8	R	514.29	12-May-10
90 20m passed West 22 x-cut waiting place	Joint leak	6.8	R	514.29	19-May-10
90 35m passed West 22 x-cut waiting place	Joint leak	6.8	R	514.29	19-May-10
90 50m from old Refuge chamber	Clamp leak	6.8	R	514.29	12-May-10
95 MIH 10m passed West 13 x-cut	Punch hole leak	6.8	R	514.29	26-May-10
95 West 14 x-cut at reef box	Joint leak	6.8	R	514.29	26-May-10
95 West 16 x-cut at waiting place	Valve leak	6.8	R	514.29	27-May-10
101 MIH 80m passed East 2 x-cut	Punch hole leak	6.8	R	514.29	01-Jun-10
101 West 130m passed Refuge chamber 101	Flange leak	6.8	R	514.29	04-Jun-10
101 West 4 stope in centre gully 15m from tip	Joint leak	6.8	R	514.29	02-Jul-10
101 West 17 Stope 10m passed tip no 5	Clamp leak	6.8	R	514.29	03-Jul-10
106 South W17 x-cut 30m passed waiting place no 1	Joint leak	6.8	R	514.29	10-Jun-10
101 West 9 x-cut entrance	Valve leak	6.8	R	513.54	07-Jun-10

C. Mine 2 leakage detection report for Shaft 2

The leaks, as detected by the out-sourced company for Shaft 2 of Mine 2, as discussed in case study 2, are given below.

Position	Description	Volume l/sec	Est R/month	Date
85 10m passed 16 x-cut 20m passed sets at toilet	Punch hole leak	550.0	R 41 536.00	25-Feb-10
90 South 12B at box front	Cylinder leak	545.0	R 41 158.40	04-Mar-10
130 20m passed MIH ventilation door	Flange leak	482.0	R 36 400.64	22-Mar-10
90 South 12 at boxfront at stope entrance	Punch hole leak	389.0	R 29 377.28	04-Mar-10
101 MIH 5m from dam	Tap leak	359.0	R 27 111.68	15-Mar-10
90 North 6 x-cut C 20m into x-cut	Punch hole leak	325.0	R 24 544.00	09-Mar-10
95 North 4 at N3 B x-cut	Punch hole leak	302.0	R 22 807.04	12-Mar-10
90 40m into North 6 x-cut	Punch hole leak	299.0	R 22 580.48	05-Mar-10
90 West Haulage at travelling way entrance to 85 level	Punch hole leak	298.0	R 22 504.96	11-Mar-10
106 passed waiting place at switch no 6	Punch hole leak	298.0	R 22 504.96	16-Mar-10
79 South 11 stope 110m from stope entrance	Punch hole leak	269.0	R 20 314.88	12-Apr-10
128 travelling way to Cooke 3	Punch hole leak	255.9	R 19 325.57	31-Mar-10
118 Station	Punch hole leak	229.0	R 17 294.08	18-Mar-10
79 South 11 stope 100m from stope entrance	Punch hole leak	225.0	R 16 992.00	12-Apr-10
136 at box control	Box control leak	221.3	R 16 712.58	08-Apr-10
128 2 West stope entrance	Punch hole leak	201.0	R 15 179.52	06-Apr-10
90 North 6 x-cut entrance	Punch hole leak	189.0	R 14 273.28	05-Mar-10
85 3 East stope 50m fom stope entrance	Clamp leak	179.0	R 13 518.08	14-Apr-10
90 South 12A 10m into x-cut	Punch hole leak	178.5	R 13 480.32	01-Mar-10
128 South 1B x-cut 15m passed waiting place	Flange leak	178.5	R 13 480.32	01-Apr-10
128 1 East 80m from entrance	Hose left open	178.0	R 13 442.56	30-Apr-10
85 2 East stope 35m fom stope entrance	Punch hole leak	123.0	R 9 288.96	15-Apr-10
118 Waste tip	Hose leak	115.0	R 8 684.80	18-Mar-10

85 2 East stope 40m fom stope entrance	Punch hole leak	115.0	R	8 684.80	15-Apr-10
79 South 10 stope entrance	Manifold leak	115.0	R	8 684.80	13-Apr-10
90 South 12B 45m into stope	Manifold leak	99.5	R	7 514.24	22-Apr-10
90 1 West 15m from manifold in centre gully	Punch hole leak	89.9	R	6 789.25	19-Apr-10
130 40m passed MIH ventilation door	Punch hole leak	75.2	R	5 679.10	23-Mar-10
128 3 West in centre gully 32m from manifold	Punch hole leak	55.3	R	4 176.26	30-Apr-10
128 3 West in centre gully 20m from manifold	Punch hole leak	51.3	R	3 874.18	30-Apr-10
128 3 West in centre gully	Punch hole leak	48.9	R	3 692.93	30-Apr-10
90 60m from split of South 12 VCR and 12A x-cut's, Boesman hose leak	Personal cooling	44.6	R	3 368.19	04-Mar-10
90 West Haulage 20m passed box front	Valve leak	44.6	R	3 368.19	11-Mar-10
79 South 10 stope entrance	Joint leak	44.6	R	3 368.19	13-Apr-10
90 North 10 x-cut at sets	Punch hole leak	38.6	R	2 911.30	05-Mar-10
79 South 7 x-cut entrance	Manifold leak	33.8	R	2 548.80	23-Feb-10
128 8 West raise 50m from entrance at manifold	Joint leak	33.8	R	2 548.80	30-Apr-10
90 South 12A x-cut 50m passed ventilation door	Punch hole leak	30.6	R	2 310.91	01-Mar-10
128 South 1B x-cut 25m passed waiting place	Flange leak	30.6	R	2 310.91	01-Apr-10
79 South 11 stope 100m from face	Manifold leak	30.6	R	2 310.91	12-Apr-10
79 South 10 stope entrance	Punch hole leak	30.6	R	2 310.91	13-Apr-10
85 2 East stope 10m from face	Joint leak	30.6	R	2 310.91	15-Apr-10
95 South 1 15m from first manifold 65m into x-cut	Joint leak	30.6	R	2 310.91	23-Mar-10
79 Station	Joint leak	26.4	R	1 993.73	23-Feb-10
79 15m from South 11B x-cut	Clamp leak	26.4	R	1 993.73	23-Feb-10
128 3 West in centre gully at manifold	Punch hole leak	26.4	R	1 993.73	30-Apr-10
79 South 6 x-cut at waiting place	Blank flange leak	22.8	R	1 721.86	23-Feb-10
79 20m passed South 11B waiting place	Clamp leak	22.8	R	1 721.86	23-Feb-10
90 South 12A at South 12 VCR bullnose	Joint leak	22.8	R	1 721.86	04-Mar-10
79 South 11 stope in centre gully	Punch hole leak	22.8	R	1 721.86	12-Apr-10
128 South 1B x-cut waiting place	Valve leak	21.8	R	1 643.32	01-Apr-10
79 South 5 x-cut at box front	Punch hole leak	21.0	R	1 582.14	23-Feb-10
90 45m into North 7 x-cut	Clamp leak	21.0	R	1 582.14	08-Mar-10

79 Refuge chamber in South 8 x-cut	Clamp leak	20.1	R 1 515.69	23-Feb-10
79 South 10 x-cut entrance	Valve leak	20.1	R 1 515.69	23-Feb-10
90 North x-cut C at stope entrance	Manifold leak	20.1	R 1 515.69	09-Mar-10
90 South 12A 100m into stope	Valve leak	20.1	R 1 515.69	20-Apr-10
90 MIH 150m from station	Flange leak	19.2	R 1 452.25	26-Feb-10
85 2 East stope 30m fom stope entrance	Joint leak	19.2	R 1 452.25	15-Apr-10
90 South 12B 45m into stope	Manifold leak	19.2	R 1 452.25	22-Apr-10
90 South 12A x-cut entrance	Valve leak	17.6	R 1 332.17	01-Mar-10
79 10m from South 11B x-cut	Clamp leak	16.9	R 1 277.04	23-Feb-10
79 South 11B x-cut at manifold	Manifold leak	16.9	R 1 277.04	23-Feb-10
85 20m from fittershop passed ventilation doors	Punch hole leak	16.9	R 1 277.04	24-Feb-10
128 as sidewall marker no: 28	Flange leak	16.9	R 1 277.04	01-Apr-10
128 development East x-cut 50m into x-cut	Valve leak	16.9	R 1 277.04	06-Apr-10
90 1 West manifold in centre gully	Manifold leak	16.9	R 1 277.04	19-Apr-10
Surface compressor room	Valve leak	16.2	R 1 220.40	22-Feb-10
79 20m from South 11B x-cut	Clamp leak	16.2	R 1 220.40	23-Feb-10
79 South 10 x-cut at air manifold	Manifold leak	16.2	R 1 220.40	23-Feb-10
85 50m from fittershop between ventilation doors	Punch hole leak	16.2	R 1 220.40	24-Feb-10
90 South 11 x-cut 70m passed ventilation door	Clamp leak	16.2	R 1 220.40	04-Mar-10
101 on station	Flange leak	16.2	R 1 220.40	15-Mar-10
128 2 West B raise 50m from entrance	Joint leak	16.2	R 1 220.40	29-Apr-10
128 8 West raise 50m from entrance at manifold	Manifold leak	15.4	R 1 161.50	30-Apr-10
90 North 6 x-cut C at stope entrance	Clamp leak	14.7	R 1 106.37	09-Mar-10
85 3 East stope 100m fom stope entrance	Clamp leak	14.5	R 1 095.04	14-Apr-10
90 South 12A Box front controle	Joint leak	13.8	R 1 045.20	01-Mar-10
79 Back of South 8 x-cut	Punch hole leak	12.4	R 936.45	23-Feb-10
90 South 12A x-cut entrance	Valve leak	12.4	R 936.45	01-Mar-10
95 South 1 5m from first manifold 55m into x-cut	Punch hole leak	12.4	R 936.45	23-Mar-10
128 1 East 60m from entrance at manifold	Joint leak	12.4	R 936.45	30-Apr-10
90 30m from split of South 12 VCR and 12A x-cut's	Manifold leak	10.9	R 825.43	04-Mar-10

90 South 12B 5m passed box front	Clamp leak	10.9	R	825.43	04-Mar-10
95 North 4 40m into x-cut	Valve leak	10.9	R	825.43	12-Mar-10
101 MIH at switch no 8	Manifold leak	10.9	R	825.43	15-Mar-10
128 development East x-cut at boxhole	Manifold leak	10.3	R	777.86	06-Apr-10
79 South 6 x-cut	Joint leak	9.6	R	724.99	23-Feb-10
79 South 11B x-cut entrance	Clamp leak	9.6	R	724.99	23-Feb-10
90 South 12 x-cut 5m from entrance	Joint leak	9.6	R	724.99	04-Mar-10
90 35m into North 7 x-cut	Clamp leak	9.6	R	724.99	08-Mar-10
112 Inside Refuge chamber	Air open	9.6	R	724.99	18-Mar-10
128 travelling way to 130 level	Valve leak	9.6	R	724.99	31-Mar-10
90 South 11B 100m into stope	Clamp leak	9.6	R	724.99	21-Apr-10
79 South 10 x-cut at stope entrance	Manifold leak	8.7	R	654.76	23-Feb-10
90 South 12B 5m into x-cut	Joint leak	8.7	R	654.76	04-Mar-10
130 Back of shaft section	Valve leak	8.7	R	654.76	23-Mar-10
128 travelling way to Cooke 3 at ventilation seal	Punch hole leak	8.67	R	654.76	31-Mar-10
79 South 10 stope entrance	Manifold leak	8.7	R	654.76	13-Apr-10
79 South 10 50m into x-cut	Joint leak	7.8	R	591.32	23-Feb-10
90 South 12B 5m passed box front	Joint leak	7.8	R	591.32	04-Mar-10
90 North 6 25m into x-cut	Clamp leak	7.8	R	591.32	09-Mar-10
130 10m passed MIH ventilation door	Joint leak	7.3	R	551.30	22-Mar-10
79 25m from South 11B x-cut	Clamp leak	7.2	R	546.01	23-Feb-10
90 30m from split of South 12 VCR and 12A x-cut's	Manifold leak	7.2	R	546.01	04-Mar-10
90 South 12 x-cut end of compressed air pipe	Blankflange leak	7.2	R	546.01	04-Mar-10
85 Station breakaway North	Valve leak	6.8	R	514.29	24-Feb-10
90 Tip line at tip cylinder	Hose leak	6.8	R	514.29	26-Feb-10
90 North 6 10m into x-cut	Clamp leak	6.8	R	514.29	09-Mar-10
118 Waste tip	Hose leak	6.8	R	514.29	18-Mar-10
130 10m from shaft ventilation doors	Manifold leak	6.8	R	514.29	22-Mar-10
130 50m passed ventilation doors	Flange leak	6.8	R	514.29	22-Mar-10
130 60m passed ventilation doors	Flange leak	6.8	R	514.29	22-Mar-10

128 inside 128 - 123 travelling way	Valve leak	6.8	R	514.29	31-Mar-10
85 2 East stope 55m fom stope entrance	Joint leak	6.8	R	514.29	15-Apr-10
90 South 12A 135m into stope	Joint leak	6.8	R	514.29	20-Apr-10
90 South 12B 35m into stope	Clamp leak	6.8	R	514.29	22-Apr-10

D. Mine 2 leakage detection report for Shaft 3

The leaks, as detected by the out-sourced company for Shaft 3 of Mine 2, as discussed in case study 2, are given below.

Position	Description	Volume l/sec	Est R/month	Date
140 West 13 x-cut at box cylinder	Joint leak	795.0	R 60 038.40	01-Feb-10
128 in South 9 x-cut 100m from South 10A entrance in sweepings area	Punch hole leak	750.0	R 56 640.00	18-Jan-10
128 South 22 x-cut East end of Boesman hose	Boesman hose leak	550.0	R 41 536.00	22-Jan-10
128 South 13 x-cut East 150m into x-cut	Punch hole leak	545.0	R 41 158.40	21-Jan-10
128 West 6 stope in travelling way 6m passed manifold	Punch hole leak	450.0	R 33 984.00	16-Feb-10
128 Entrance of 4 West x-cut	Valve out of order	330.4	R 24 951.81	20-Jan-10
128 South 16 stope in travelling way 5m passed manifold	Punch hole leak	220.0	R 16 614.40	15-Feb-10
128 50m into West 18 x-cut	Punch hole leak	178.5	R 13 480.32	25-Jan-10
128 West 6 stope in travelling way 2m passed manifold	Joint leak	85.0	R 6 419.20	16-Feb-10
128 Entrance of 3 West x-cut at manifold	Hose leak	75.2	R 5 679.10	20-Jan-10
128 MIH 20m passed West 18 x-cut entrance	Boesman hose leak	44.6	R 3 368.19	25-Jan-10
128 At entrance of West 17A x-cut	Punch hole leak	26.4	R 1 993.73	25-Jan-10
118 West 17 x-cut 20m into x-cut	Clamp leak	22.8	R 1 721.86	14-Jan-10
128 South 13 x-cut East 152m into x-cut	Punch hole leak	21.0	R 1 582.14	21-Jan-10
128 150m into South 10 A5	Clamp leak	20.1	R 1 515.69	18-Jan-10
118 at reefbox controle box in N5 hlge South	Clamp leak	19.2	R 1 452.25	08-Jan-10
140 level East passed ventilation door in Refuge chamber	Joint leak	18.4	R 1 390.32	27-Jan-10
118 South 8 x-cut East at tip	Hose leak	17.6	R 1 332.17	13-Jan-10
128 Connecting x-cut between 21 x-cut East and 22 x-cut East	Punch hole leak	16.9	R 1 277.04	22-Jan-10
140 South 10 x-cut East second boxfront controler	Boxfront control	16.9	R 1 277.04	26-Jan-10
128 60m from entrance of West 17 x-cut	Punch hole leak	16.2	R 1 220.40	25-Jan-10
128 MIH 10m passed West 18 x-cut entrance	Punch hole leak	16.2	R 1 220.40	25-Jan-10
140 25m into South 16 x-cut West	Punch hole leak	16.2	R 1 220.40	27-Jan-10

140 West 15 x-cut West 50m passed trackless workshop	Clamp leak	16.2	R	1 220.40	01-Feb-10
106 MIH 50m from S8	Manifold leak	15.8	R	1 190.20	07-Jan-10
128 South 16 stope in travelling way	Manifold leak	15.0	R	1 132.80	15-Feb-10
128 South 22 x-cut East at manifold	Boesman hose leak	14.7	R	1 106.37	22-Jan-10
140 at reef tip	Hose leak	14.7	R	1 106.37	26-Jan-10
140 West 15 x-cut West 20m passed trackless workshop	Punch hole leak	14.7	R	1 106.37	01-Feb-10
118 at waste tip controle box	Hose leak	14.0	R	1 057.28	08-Jan-10
118 West 20 x-cut at entrance	Reducer leak	13.8	R	1 045.20	14-Jan-10
118 West North x-cut 10m passed gully box	Clamp leak	12.4	R	936.45	11-Jan-10
118 West North 2 x-cut 80m into x-cut	Clamp leak	12.4	R	936.45	12-Jan-10
128 MIH 38m from 7 West x-cut	Punch hole leak	12.4	R	936.45	20-Jan-10
128 50m into South 10 E	Punch hole leak	12.4	R	936.45	20-Jan-10
128 South 250m into16 East x-cut	Clamp leak	12.4	R	936.45	21-Jan-10
140 West 15 x-cut West 40m passed trackless workshop	Clamp leak	12.4	R	936.45	01-Feb-10
106 15m passed trackless pumpstation	Punch hole leak	11.5	R	866.21	07-Jan-10
118 Trackless workshop	Punch hole leak	10.9	R	825.43	08-Jan-10
140 South 10 x-cut East first boxfront controler	Boxfront control	10.9	R	825.43	26-Jan-10
140 60m into West 18 x-cut West	Punch hole leak	10.9	R	825.43	01-Feb-10
118 at station air winch	Hose leak	9.8	R	740.10	08-Jan-10
118 Station	Flange leak	9.6	R	724.99	08-Jan-10
128 West 5 stope in travelling way	Clamp leak	8.8	R	664.58	17-Feb-10
128 15m into 6 West x-cut at manifold	Tap leak	8.7	R	654.76	20-Jan-10
140 South 15 x-cut entrance	Joint leak	8.7	R	654.76	27-Jan-10
140 10m into West 9A x-cut West at box control	Boxfront control	8.7	R	654.76	29-Jan-10
106 40m passed Refuge chamber	Clamp leak	8.3	R	629.08	06-Jan-10
118 at reefbox controle box 100m passed N5 hlge South	Hose leak	7.8	R	591.32	08-Jan-10
118 South 8 x-cut East entrance	Blank flange leak	7.2	R	546.01	13-Jan-10
128 Entrance of West 7 x-cut	Clamp leak	7.2	R	546.01	20-Jan-10
128 Connecting x-cut between 21 x-cut East and 22 x-cut East	Hose leak	7.2	R	546.01	22-Jan-10
128 Connecting x-cut between 21 x-cut East and 22 x-cut East	Boxfront control	7.2	R	546.01	22-Jan-10

140 10m into West 9A x-cut West at box control	Boxfront control	7.2	R	546.01	29-Jan-10
106 MIH between S4 x-cut and S5 x-cut	Punch hole leak	7.2	R	542.23	05-Jan-10
118 West 17 x-cut 30m into x-cut	Clamp leak	6.8	R	514.29	14-Jan-10
118 West 17 x-cut 10m passed booster pump	Clamp leak	6.8	R	514.29	14-Jan-10
128 South 10 x-cut , 10m from South 10A5 entrance	Clamp leak	6.8	R	514.29	15-Jan-10
128 Entrance of West 9A x-cut	Clamp leak	6.8	R	514.29	19-Jan-10
128 South 12 x-cut East 150m into x-cut	Punch hole leak	6.8	R	514.29	21-Jan-10
128 Entrance of 22 x-cut East	Clamp leak	6.8	R	514.29	25-Jan-10
128 Between west 17 x-cut and West 16 x-cut	Valve leak	6.8	R	514.29	25-Jan-10
128 20m into West North 1 x-cut	Clamp leak	6.8	R	514.29	25-Jan-10
140 Box cylinder between reef and waste tip	Hose leak	6.8	R	514.29	26-Jan-10
140 at entrance of West 1 x-cut West	Joint leak	6.8	R	514.29	29-Jan-10
140 50m into West 18 x-cut West	Punch hole leak	6.8	R	514.29	01-Feb-10

E. Questionnaire used to determine shortages in presently applied methods

Compressed Air Leakage Documentation System (CALDS) questionnaire

HVAC INTERNATIONAL

Date :____________________

Mine :____________________

Shaft :____________________

Mine representative :____________________

Email :____________________

Tel :____________________

Designation :____________________

REMS
UNDER PROMISE OVER DELIVER

ESKOM ETA AWARDS
1991,2004,2006,2007,2008

OSIMS
SPECIAL ETA AWARD

1. Is there currently any form of leakage detection being done on the mine?

2. Is there a dedicated team assigned to this task?

3. How many people? Names?

4. Is there any device, like ultrasonic leak detectors, cameras, PDAs etc being used for this purpose?

5. How often is this being done? Weekly? Monthly?

6. What happens to the information collected?

____

7. Is there any form of reporting done on the leaks detected? Is a report example available?

____

8. Any additional comments or suggestions?

____

____

____

____

____

____

____

____

F. Device setup with text file-Archer field PC

[GENERAL]

ProjectName=Mine A //Project name or mine name

[LOGTYPE]

LogType=Air Leak //Type of log recorded, may include water leaks, but not for the outcome of this study

[PIPESIZE] //Predefined pipe sizes as used in the specific mine group

PipeSize=50

PipeSize=100

PipeSize=150

[LEAKSIZE] //Size of leak (estimated)

LeakSize=0.5

LeakSize=1

LeakSize=1.5

LeakSize=2

LeakSize=3

LeakSize=12.57

LeakSize=25.4

LeakSize=100

[LEAKTYPE] //Type of leak

LeakType=Gasket

LeakType=Open ended blowing

LeakType=Pipe punch hole

LeakType=Open valve

[USERS] //Name of person responsible for recording the leak

User=User 1

User=User 2

User=User 3

[LOCATIONS] //Detailed layout of mine (format 1.2.3 with 1 depicting shaft number, 2 the level and 3 the location)

1.0.0=Shaft A //Shaft name

1.1.0=Level 1 //Level

1.1.1=Tipping area //Location

1.1.2=Loading boxes //Location

1.2.0=Level 2 //Level

1.2.1=Battery bays //Location

1.2.2=Cross-cut 33 //Location

2.0.0=Shaft B //Shaft name (if more than one)

2.1.0=Level 1 //Level

2.1.1=Tipping area //Location

2.1.2=Chairlifts //Location

2.2.0=Level 2 //Level

```
2.2.1=Railway switch 68                  //Location

2.2.2=Cross-cut 45                  //Location

[END]
```

G. Report generated for Mine 2, shaft three

Compressed Air Leakage Documentation System (CALDS) report for Cooke OAN

1 November 2010 to 1 November 2010

Generated by OSIMS (Special ETA Award Winner 2008) on 1 November 2010

1. Introduction

This report gives the status of the leaks on the compressed air system of Cooke OAN as generated by the Compressed Air Leakage Documentation System (CALDS). The savings period covered in this report is from 1 November 2010 to 1 November 2010. Data collected on the mobile handheld units are used for leak management of the compressed air system. This information can be used to improve the efficiency of the compressed air system.

Please contact HVAC International (Pty) Ltd at reports-info@rems2.com should there be any queries or suggestions.

2. Existing air leaks

Table 1 summarises the leaks detected and documented by CALDS for this period. Leaks documented in Table 1 are not repaired at this stage. The total accumulated cost for these leaks is estimated at R 82. This cost is estimated with an average air pressure of 560 kPa.

3. Repaired air leaks

Table 2 summarises the leaks that have already been repaired after being detected and documented by CALDS. The total cost for these leaks until repaired was R 200. This cost is estimated with an average air pressure of 560 kPa.

4. Summary of existing air leaks

Table 1 : Existing air leaks

ID	Date detected	Shaft	Level	Location	Pipe Size [mm]	Leak Size [mm]	Leak Type	Detected by	Cost to date [R]
C3-11	2010-11-01	Cooke 3#	Level 128	South 7 X-cut	200 (8")	0.5	Valve leak	HVAC Personnel	0
C3-13	2010-11-01	Cooke 3#	Level 128	West 13 X-cut	150 (6")	2	Flange leak	HVAC Personnel	8
C3-16	2010-11-01	Cooke 3#	Level 128	West 7 X-cut	100 (4")	2.5	Clamp leak	HVAC Personnel	16
C3-17	2010-11-01	Cooke 3#	Level 128	West 6 X-cut	50 (2")	2	Manifold leak	HVAC Personnel	8
C3-18	2010-11-01	Cooke 3#	Level 128	West 4 X-cut	150 (6")	4	Valve leak	HVAC Personnel	32
C3-19	2010-11-01	Cooke 3#	Level 128	West 7 X-cut	25 (1")	3	Valve leak	HVAC Personnel	18
									82

5. Summary of repaired air leaks

Table 2 : Repaired air leaks

ID	Repair Leak period	Shaft	Level	Location	Pipe Size [mm]	Leak Size [mm]	Leak Type	Detected by	Total Cost [R]
C3-12	2010-11-01 to 2010-11-01	Cooke 3#	Level 128	South 9 X-cut	150 (6")	5	Punch hole leak	HVAC Personnel	50
C3-14	2010-11-01 to 2010-11-01	Cooke 3#	Level 128	South 13 X-cut	150 (6")	5	Punch hole leak	HVAC Personnel	50
C3-15	2010-11-01 to 2010-11-01	Cooke 3#	Level 128	West 7 X-cut	200 (8")	0.25	Clamp leak	HVAC Personnel	0

6. Summary of other types of leaks

Table 3 : Other types of leaks

ID	Date detected	Shaft	Level	Location	Type	Pipe Size [mm]	Leak Size [mm]	Leak Type	Detected by

H. Calculations – Sample mine calculator

Expressing of leaks in monetary terms was done with equations as given in section 2.3.3. In order to evaluate how this correlates with values obtained in the industry, the compressed-air-leak calculator of AngloGold's energy engineer, Andrew Garbers, was used for comparison. The calculator uses input parameters of pipeline gauge pressure, absolute atmospheric pressure, leak diameter, air temperature in pipeline and cost per kilo Watt hour. Calculations are based on first-order approximations and empirical analysis, and are used to express cost of leaks in monetary terms.

Figure 39 shows the correlation between the two calculation methods at 500 kPa and 200 kPa. Temperatures used were the same, with ambient temperatures taken at 298 K, and line temperature taken as 301 K. In both instances, the atmospheric pressure was taken as 87 kPa, the average for mines close to the Gauteng region.

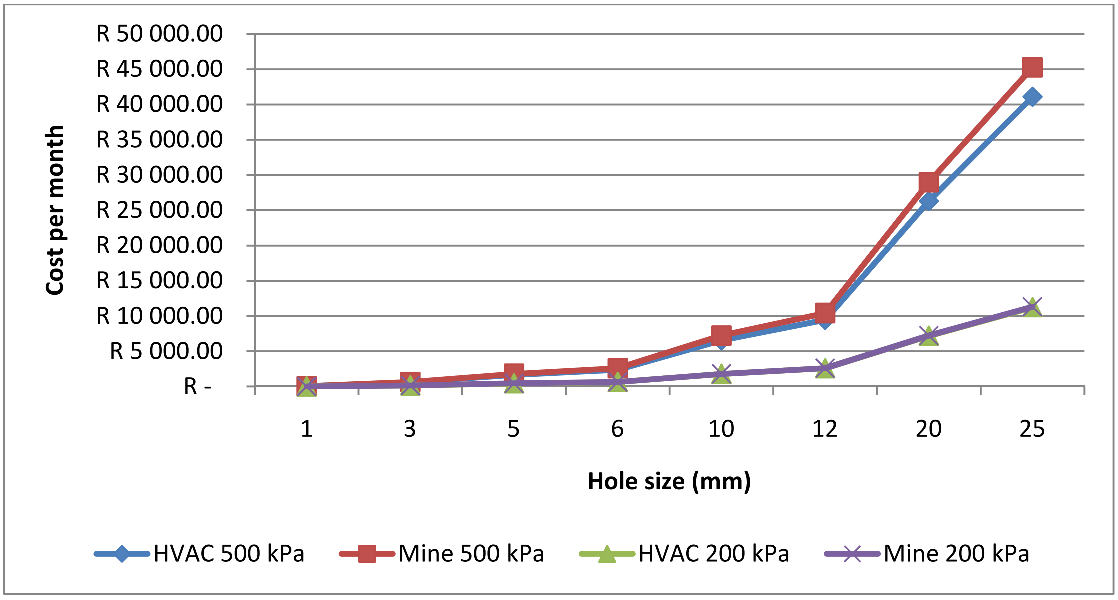

Figure 39 : Correlation between calculation methods

With the pressure at 200 kPa, the percentage deviations in savings were diminutive, with an average deviation of 0.64%. At 500 kPa, the deviation increased to 9.28%. In both cases the calculations used by AngloGold were of higher value. With values being within 10%, and dependent on assumptions made by the person doing the leak detection, it was found to be sufficient for the outcome of the study. Table 10 gives the spreadsheet as used by AngloGold's energy engineer.

Table 10 : Compressed air leak calculator

Compressed air leak Calculator	
Input data:	
Upstream Pressure (kPa)	200
Abs Atmospheric pressure (kPa)	87
Leak Diameter (mm)	1
downstream air temperature (deg C)	28
Cost per kWh	0.466
Answer:	
CFM (at downstream pressure)	0.57
Upstream Air Density (kg/m3)	2.315
Down Stream Air Density (kg/m3)	1.007
Leak flow (m3/s)	0.000
Leak flow (l/s)	0.268
Leak mass flow (kg/s)	0.0002696
Tons/month leaked	0.71
Compressor Input Power (kW) required to Produce kg/s @ Upstream Pressure	0.05
kWh	38.87
Compressed air workable power wasted (kW)	0.02
Cost per month	R 18.11

COMPRESSED AIR FLOW CALCULATION

$$Q = 0.000155 \text{ x } \frac{Pin}{Patm} \text{ x } D^2$$

WHERE

Q = m^3/s

Pin = Pressure in pipe in kPa absolute

Patm = 87 kPa Constant

D = Diameter of pipe in mm

EXAMPLE

An air column with 5 BAR gauge pressure and a pipe diameter of 10 mm. What is the air flow ?

1. Convert gauge pressure to absolute
   5 BAR = 500 kPa
   Absolute pressure = GAUGE + ATMOSPHERIC
   =500 kPa + 87 kPa
   = 587 kPa
2. Q = 0.000155 x 587/87_ x 10^2
   = 0.092 m^3/s open end

Change green cells to customise calculations:

Atmospheric Pressure	87	kPa	87	kPa	87	kPa
Diameter	10	mm	50	mm	10	mm
Gauge Pressure	5	bar	4.8	bar	4	bar
	500	kPa	480	kPa	400	kPa
Absolute Pressure	587	kPa	581	kPa	501	kPa
Air Flow in m³/s	0.105	m³/s	2.588	m³/s	0.089	m³/s
R - specific gas constant	0.287	kJ/kg.K				
ρ - density @ std conditions	1.2754	kg/m³ @ 0ºC and 100kPa				
ρ - density @	40	ºC	20	ºC	50	ºC
and	87	bar				
Air Density @ 5 bar &40 ºC	6.534	kg/m³	6909.182	kg/m³	5404.472	kg/m³
Air Flow in kg/s	0.683	kg/s	17 879.493	kg/s	482.396	kg/s
Air Flow in kg/hour	2 460	kg/h	64 366 175	kg/h	1 736 625	kg/h
Air Flow in kg/day	59 044	kg/day	1 544 788 204	kg/day	41 678 993	kg/day
Air Flow in kg/month	1 795 923	kg/mth	46 987 307 859	kg/mth	1 267 736 046	kg/mth
Air Flow in TON/annum	21 551	ton/yr	563 847 694	ton/yr	15 212 833	ton/yr

I. Text file used for programming shaft three's PDA

[GENERAL]

ProjectName=Cooke OAN

[LOGTYPES]

LogType=Air Leak

LogType=Water Leak

LogType=Trolley Line

[PIPESIZES]

PipeSize=25 (1")

PipeSize=50 (2")

PipeSize=100 (4")

PipeSize=150 (6")

PipeSize=200 (8")

PipeSize=250 (10")

PipeSize=300 (12")

PipeSize=350 (14")

PipeSize=600 (24")

[LEAKSIZES]

LeakSize=1

LeakSize=2

LeakSize=3

LeakSize=4

LeakSize=5

LeakSize=7

LeakSize=10

LeakSize=12

LeakSize=15

LeakSize=20

LeakSize=25

LeakSize=50

LeakSize=100

LeakSize=150

LeakSize=200

[LEAKTYPES]

LeakType=Valve leak

LeakType=Clamp leak

LeakType=Manifold leak

LeakType=Punch hole leak

LeakType=Flange leak

LeakType=Joint leak

LeakType=Air open

LeakType=Blank flange leak

LeakType=Hose leak

LeakType=Tap leak

LeakType=Box control leak

LeakType=Hose left open

LeakType=Boesman hose leak

LeakType=used as ventilation or cooling

[USERS]

User=Chris Ntlekeni

User=Steven Kyle

User=Anderson Chibona

User=Mike van Moorst

User=HVAC Personnel

[LOCATIONS]

1.0.0=Cooke 3#

1.1.0=Surface

1.1.1=Compressor House

1.1.2=Surface conveyor belts

1.1.3=Skip loading chutes

1.1.4=Silo loading chutes

1.1.5=Surface workshops

1.2.0=Shaft

1.2.1=Column

1.3.0=Level 106

1.3.1=Station

1.3.2=Refuge bay

1.3.3=Pump station

1.3.4=N1 workshop

1.3.5=South 4 X-cut

1.3.6=South 7 X-cut

1.3.7=South 7 workshop

1.4.0=Level 118

1.4.1=Station

1.4.2=Refuge bay shaft

1.4.3=South 1 Loco shop

1.4.4=N5 Break-away

1.4.5=N5 Haulage

1.4.6=N5 Box

1.4.7=N6 Box

1.4.8=S1 X-cut

1.4.9=s2 X-cut

1.4.10=West-North x-cut

1.4.11=West-North 1

1.4.12=West-North 2

1.4.13=West-North 3

1.4.14=West-North 4

1.4.15=South 4 Haulage

1.4.16=South 7 X-cut

1.4.17=West 7 Haulage

1.4.18=South 8 X-cut

1.4.19=South 8A X-cut

1.4.20=South 9 X-cut

1.4.21=South 10 X-cut

1.4.22=South 11 X-cut

1.4.23=South 12 X-cut

1.4.24=South 13 X-cut

1.4.25=South 14 X-cut

1.4.26=South 15 X-cut

1.4.27=South 16 X-cut

1.4.28=South 12 West X-cut

1.4.29=South 15 West X-cut

1.4.30=West 15 X-cut

1.4.31=West 16 X-cut

1.4.32=West 17 X-cut

1.4.33=West 18 X-cut

1.4.34=West 19 X-cut

1.4.35=West 20 X-cut

1.4.36=West 21 X-cut

1.4.37=Deep 18 West X-cut

1.4.38=Deep 19 West X-cut

1.4.39=Deep 20 West X-cut

1.4.40=Deep 21 West X-cut

1.4.41=Deep 22 West X-cut

1.4.42=West 12 Haulage (Raw)

1.4.43=Deep 18 West X-cut (Raw)

1.5.0=Level 128

1.5.1=Station

1.5.2=Refuge bay

1.5.3=Tip line at tip cylinder

1.5.4=Cooke 2 apex

1.5.5=South 1 Break-away

1.5.6=West North 1 Haulage

1.5.7=Box 200 & 500

1.5.8=South 1 X-cut

1.5.9=South 2 X-cut

1.5.10=South 3 X-cut

1.5.11=South 4 X-cut

1.5.12=South 5 X-cut

1.5.13=South 6 X-cut

1.5.14=South 7 X-cut

1.5.15=West 7 X-cut

1.5.16=West 6 X-cut

1.5.17=West 5 X-cut

1.5.18=West 4 X-cut

1.5.19=West 3 X-cut

1.5.20=South 8 X-cut

1.5.21=South 9 X-cut

1.5.22=South 10 X-cut

1.5.23=South 11 X-cut

1.5.24=South 10 Tip

1.5.25=West 8 X-cut

1.5.26=West 9 X-cut

1.5.27=West 10 X-cut

1.5.28=West 11 X-cut

1.5.29=West 12 X-cut

1.5.30=West 13 X-cut

1.5.31=South 12 X-cut

1.5.32=South 13 X-cut

1.5.33=South 14 X-cut

1.5.34=South 15 X-cut

1.5.35=South 16 X-cut

1.5.36=South 17 X-cut

1.5.37=South 18 X-cut

1.5.38=South 19 X-cut

1.5.39=South 20 X-cut

1.5.40=South 21 X-cut

1.5.41=South 22 X-cut

1.5.42=West 15 X-cut

1.5.43=West 16 X-cut

1.5.44=West 17 X-cut

1.5.45=West 18 X-cut

1.5.46=West 19 X-cut

1.5.47=West 20 X-cut

1.5.48=West 21 X-cut

1.5.49=West 22 X-cut

1.5.50=South 15 X-cut West

1.6.0=Level 140

1.6.1=Station

1.6.2=Refuge bay

1.6.3=Station Tip

1.6.4=Haulage East

1.6.5=O-line

1.6.6=South Haulage

1.6.7=South 7 A X-cut

1.6.8=South 7 Loco Workshop

1.6.9=South 9 X-cut

1.6.10=South 10 X-cut

1.6.11=South 11 X-cut

1.6.12=South 12 X-cut

1.6.13=South 13 X-cut

1.6.14=South 14 X-cut

1.6.15=South 15 X-cut

1.6.16=South 16 X-cut

1.6.17=South 17 X-cut

1.6.18=West 7 Haulage

1.6.19=Control Room

1.6.20=West 7 X-cut

1.6.21=West 6 X-cut

1.6.22=West 5 X-cut

1.6.23=West 4 X-cut

1.6.24=West 3 X-cut

1.6.25=West 2 X-cut

1.6.26=West 1 X-cut

1.6.27=West 7 X-cut

1.6.28=West 8 X-cut

1.6.29=West 9 X-cut

1.6.30=West 10 X-cut

1.6.31=West 11 X-cut

1.6.32=West 12 X-cut

1.6.33=West 13 X-cut

1.6.34=West 14 X-cut

1.6.35=West 15 X-cut

1.6.36=West 16 X-cut

1.6.37=West 17 X-cut

1.6.38=West 18 X-cut

1.6.39=West 19 X-cut

1.7.0=Level 150

1.7.1=Station

1.7.2=Refuge bay

1.7.3=Vacuum Machine

1.7.4=Transfer Box

1.8.0=Level 155

1.8.1=Station

1.8.2=Pump station

1.8.3=Conveyor belt

1.8.4=Transfer Box

1.9.0=Level 156

1.9.1=Loading Boxes

1.9.2=Muddy Pumps

[END]

J. M&V reports used in case studies

Attached is a compact disk containing reports as used in case study 1 and section 4.4. The report in case study 1 was used to compared data from the HVAC International database.