



Efficient monitoring of mine compressed air savings

by
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Abstract

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In 2011 South Africa's main electricity supplier, Eskom, experienced a peak electricity demand of 89% of their total installed generation capacity. The high utilisation rate makes it difficult to perform essential maintenance on the system. Eskom implements Demand-Side Management (DSM) projects in various industries, in order to reduce the demand and to ensure sustainable electricity supply.

The mining sector consumes 14.5% of the total amount of electricity generated by Eskom. Mine compressed air systems can consume as much as 40% of a mine's total electricity requirements. This makes mine compressed air systems an ideal target for DSM. Electricity load seems to be reduced, but many DSM savings are not sustained throughout the project lifetime.

An existing project feedback method of a specific Energy Services Company (ESCO) includes the manual collection of data from the mines and manual generation of reports. These reports show energy savings of the DSM projects to help the ESCo and their clients to improve and sustain the performance of the projects. A great amount of man-hours is used which results in large time delays in the feedback-loop. In order to address this, the need for a new automatic feedback reporting system was identified.

This study mainly focusses on the development and implementation of a new method to monitor DSM savings on mine compressed air systems. It includes the reliable collection of data from mines, processing and storing of the data in a central database and generating savings reports. This is done automatically on a daily basis. In order to complete the feedback-loop, the reports are verified and emailed to clients and ESCo personnel on a daily basis.

The new reporting system is implemented at a number of mines. Four of these project implementations are used as case studies to measure and interpret the effectiveness and value of this system. It saves a significant amount of man-hours and proves to be of great

value in the sustainability of DSM project savings. Both Eskom and mining companies benefit from the efficient monitoring of mine compressed air savings.

Opsomming

Titel: Effektiewe monitering van myn druklug besparings
Outeur: Mnr. P. Goosen
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Sleutelwoorde: Myn druklug besparings, elektrisiteitsbesparings, "Demand-Side Management" (DSM), verslaggewingstelsel

Suid-Afrika se hoof elektrisiteitsverskaffer, Eskom, het in 2011 'n piek elektrisiteits-aanvraag van 89% van hulle totale geïnstalleerde opwekkingskapasiteit bereik. Dié hoë benuttings-verhouding van die stelsel maak dit moeilik om noodsaaklike onderhoud op die stelsel uit te voer. Eskom implimenteer "Demand-Side Management" (DSM) projekte in verskeie industrieë om sodoende die elektrisiteits-aanvraag te verminder en volhoubare elektrisiteits-verskaffing te verseker.

Die myn sektor verbruik 14.5% van die totale elektrisiteit wat deur Eskom opgewek word. Myn-druklug-stelsels kan soveel as 40% van 'n myn se totale elektrisiteitsvereistes verbruik. Dit maak myn-druklug-stelsels ideale kandidate vir DSM. Dit wil voorkom asof die elektrisiteitslas verminder word, maar baie DSM besparings word nie volhou gedurende die leeftyd van die projek nie.

'n Bestaande projek-terugvoer-metode van 'n sekere "Energy Services Company" (ESCO) sluit die versameling van data van die myne, asook die opstel van verslae in. Nie een van die twee take is outomaties nie. Die verslae toon die energiebesparings van DSM projekte, om sodoende die ESCo en hulle kliënte te help om die projekte se werkverrigting te verbeter en te volhou. 'n Groot hoeveelheid man-ure word hieraan afgestaan wat groot vertraging in die terugvoerlus veroorsaak. Om hierdie probleem aan te spreek is 'n behoefte vir 'n outomatiese terugvoer verslaggewingstelsel geïdentifiseer.

Hierdie studie fokus hoofsaaklik op die ontwikkeling en implimentering van 'n nuwe metode om DSM besparings op myn-druklug-stelsels te monitor. Dit sluit die betroubare versameling van myndata in, die verwerking en stoor van die data in 'n sentrale databasis en die generasie van verslae. Hierdie take word outomaties op 'n daaglikse basis uitgevoer. Die verslae word daaglik geverifieer en aan kliënte en ESCo personeel gestuur via e-pos om sodoende die terugvoerlus te sluit.

Die nuwe verslaggewingstelsel is op verskeie myne geïmplimenteer. Vier van die projekte is gebruik as gevallestudies om die effektiwiteit en waarde van die stelsel te meet. 'n Beduidende hoeveelheid man-ure word gespaar deur die stelsel en is van groot waarde vir die volhoubaarheid van DSM besparings. Beide Eskom en die myn-maatskappye vind baat by die effektiewe monitering van myn druklug besparings.

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Nomenclature

CSV	Comma Separated Values
DBA	Database Administrator
DBMS	Database Management System
DSM	Demand Side Management
EE	Energy Efficiency
EIC	Energy Information Concentrator
EID	Energy Information Display
EM	Energy Meter
EMRS	Energy Management Reporting System
EMS	Energy Management System
ENIS	Energy Information System
ESCo	Energy Services Company
ERD	Entity Relationship Diagram
FMRS	Facilities Management Reporting System
GPL	General Public License
ISO	International Standards Organisation
IT	Information Technology
LS	Load shifting
M&V	Measurement and Verification
MR	Maintenance ratio
OPC	Open Platform Communications
PDCA	Plan-Do-Check-Act
PDF	Portable Document Format
PC	Peak clipping
PK	Primary Key
PLC	Programmable Logic Controller
ROI	Return on Investment
SCADA	Supervisory Control And Data Acquisition
SQL	Structured Query Language
TOU	Time-of-use
VPN	Virtual Private Network
XML	Extensible Markup Language

Units:

kg/s	kilogram per second	Airflow
kPa	kilo-pascal	Air pressure
kW	kilowatt	Power
kWh	kilowatt-hour	Energy
GW	Gigawatt	Power
GWh	Gigawatt-hour	Energy
MW	Megawatt	Power
MWh	Megawatt-hour	Energy
R	South African Rand (ZAR)	Currency

Formula Symbols:

C_{ZAR}	Cost saving in South African Rand
I_{EE}	Energy Efficiency Impact
I_{PC}	Peak Clipping Impact

Chapter 1

Introduction



Moab Khotsong mine in South Africa. (Source: www.anglogoldashanti.co.za)

1.1 Background on compressed air savings

Eskom generates 95% of South Africa's total electricity usage [1]. During the 2010/2011 financial year (ending 31 March 2011), the peak electricity demand in South Africa was 36 664 MW [2]. The peak electricity demand was 37 065 MW during the following financial year ending 31 March 2012 [3]. The increasing electricity demand in South Africa is putting a lot of pressure on Eskom.

The internationally accepted standard for an electricity reserve margin is 15% [4–6]. Figure 1.1 shows a comparison between the peak electricity demand and Eskom's installed capacity during the last seven years [2, 3, 7]. The electricity reserve margin of 15% is also shown. During 2011 the peak electricity demand in South Africa reached 89% of Eskom's total installed capacity, 4% more than the reserve margin.

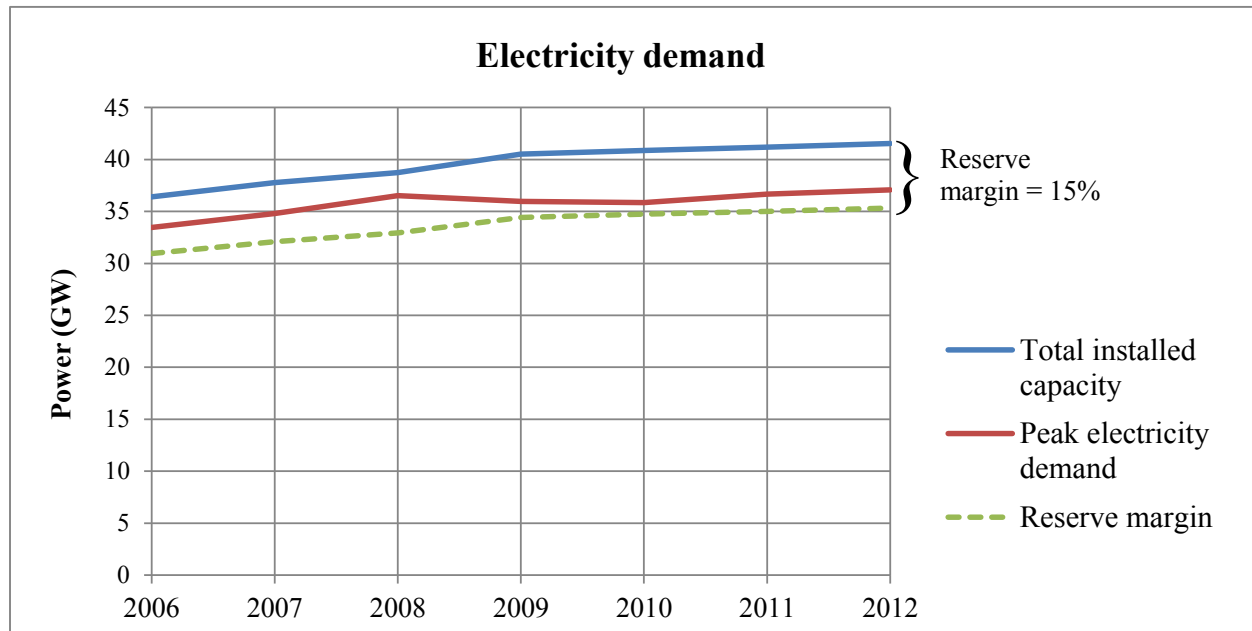


Figure 1.1: *Peak electricity demand in relation to electricity reserve margin*

The increasingly high electricity demand makes it difficult for Eskom to perform regular maintenance. The ideal annual maintenance ratio (MR) for Eskom is 10%, but the planning schedule for 2011 included only 7% maintenance [8]. MR is the ratio between the cumulative number of man-hours spent on maintenance, and the cumulative operating hours of the system.

Eskom sold 224 785 GWh of electricity during the 2011/2012 financial year. Figure 1.2 classifies Eskom's electricity sales by customer type [3]. The mining industry is the third largest electricity consumer, and consumes 14.5% of the electricity generated by Eskom. One solution that the utility company implements to reduce electricity demands of the mining

sector, is Demand Side Management (DSM) projects [9].

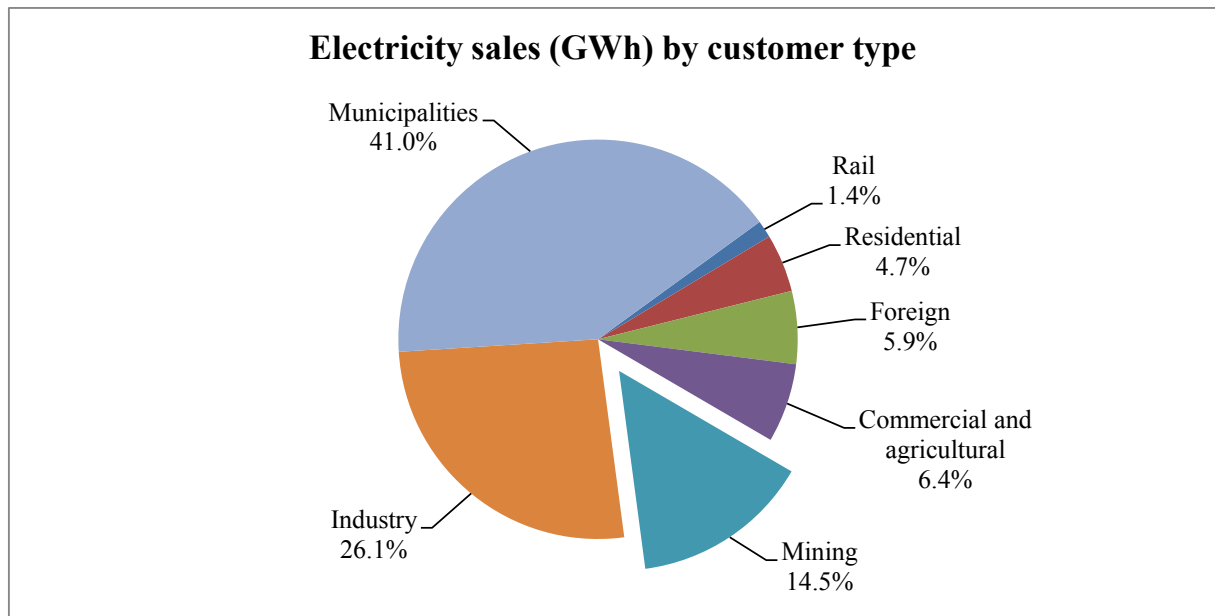


Figure 1.2: Eskom electricity sales distribution for the year ending 31 March 2012

Eskom subsidises DSM projects on R/kWh or R/kW benchmarks [10, 11]. Up to 100% of the financial benchmark value is funded for DSM projects [11]. The maximum benchmark values for energy efficiency (EE) and peak clipping (PC) projects are R 4.4 million/MW and R 3.9 million/MW, respectively [11]. In previous years, the cost for load shifting (LS) and PC projects was funded 100%, while only 50% of EE projects were funded by Eskom [12–14]. The consumers funded the remaining 50% of EE projects.

PC and EE are the two types of Eskom DSM projects implemented on mine compressed air systems. Figure 1.3 shows the difference between PC and EE DSM projects. The aim of a PC project is to reduce electricity usage during Eskom’s evening peak hours (18:00 - 20:00). EE projects aim to reduce electricity usage throughout the entire day.

The performance of DSM projects is measured against the energy usage (or “baseline”) of the system before the implementation of the project [15]. Each project has a contractual target saving to achieve each day. The example projects shown in Figure 1.3 have target savings of 2.5 MW. In most cases the contractual target saving of DSM projects only apply for weekdays.

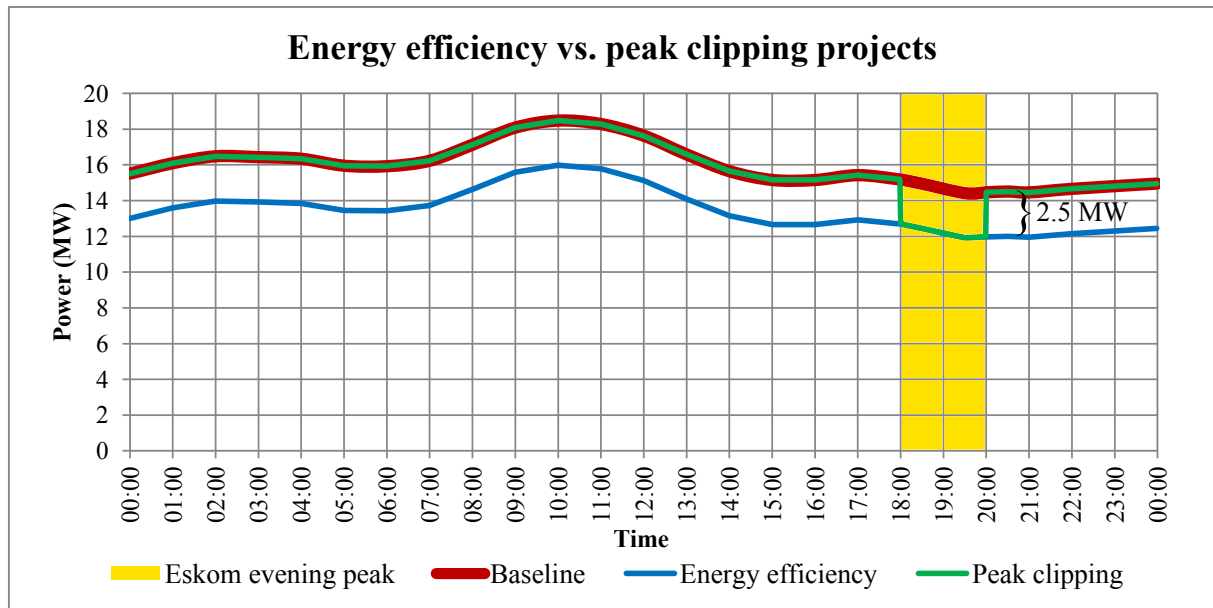


Figure 1.3: Comparison between peak clipping and energy efficiency projects

DSM projects on mine compressed air systems

Compressed air is an important part of most industries around the world. It is easy to produce and relatively safe to handle. However, the production of compressed air is expensive and inefficient [16]. The most significant role compressed air plays in the mining industry is with the production process. Compressed air can account for as much as 21% of a mine's electricity bill [17]. On shallow platinum mines compressed air can consume up to 40% of the total electricity requirements [18].

The compressed air system on a mine is investigated and analysed before a proposal for a DSM project can be submitted to Eskom. Figure 1.4 shows the hypothetical requirements of compressed air for a mine. Historical data are used to calculate the average weekday air pressure before the implementation of the project. The minimum air pressure requirements of the compressed air system are investigated to propose a new reduced system pressure. Reducing the air pressure reduces the amount of energy required to generate the compressed air.

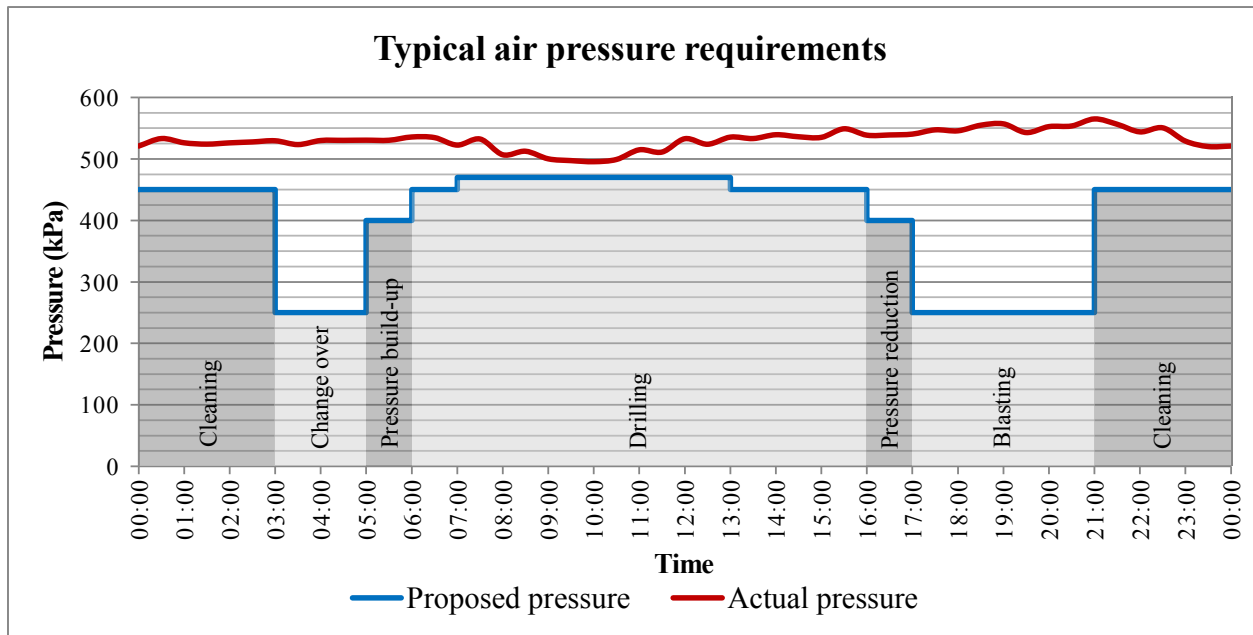


Figure 1.4: *Compressed air pressure requirements on a typical mining level*

Both Eskom and the applicable mine benefit from a compressed air savings project. This makes mine compressed air systems ideal targets for the Eskom DSM programme. Compressed air savings directly imply electricity savings, relieving pressure on Eskom. The electrical energy savings also imply financial savings for the mine. However, many of the DSM projects are unable to sustain their target savings, while others fail altogether to achieve their targets. These failures can be attributed to inefficient compressor control, inefficient control of air usage, air leaks and various other factors [16, 19].

This creates a need for an automatic reporting system for mine compressed air systems. The purpose of such a reporting system will be to give feedback on the control of the compressed air system as well as air usage. This feedback can in turn be used to improve the compressed air system in order to achieve target savings. Various feedback-reporting systems already exist and will be discussed in the following section.

1.2 Limitations of existing reporting methods

1.2.1 Introduction

This section explores four examples of monitoring and reporting systems designed for energy management. Each example is briefly described and a number of limitations are mentioned. Two examples are energy management tools designed for residential and commercial use. The other examples are specifically designed for monitoring DSM performance on mines. A

summarised comparison of all the examples are given at the end of this section.

1.2.2 Energy Information Collection System

The first system was developed by Chen and Hwang from Yuan-Ze University in Taiwan [20]. This Energy Information System (ENIS) helps residential customers to consume less energy during peak times by voluntarily changing the running time of their appliances. Real-time pricing signals are sent to the consumers to indicate peak demand periods. Figure 1.5 shows an overview of the ENIS.

Energy Meter (EM) units are retrofitted to appliances. The EM units use power-line communication and radio frequency channels to communicate with Energy Information Display (EID) units and an Energy Information Concentrator (EIC). The EID and EIC connect via broadband internet connections to make the data available via the internet in real-time. It is also possible to control the appliances via the above-mentioned communication channels.

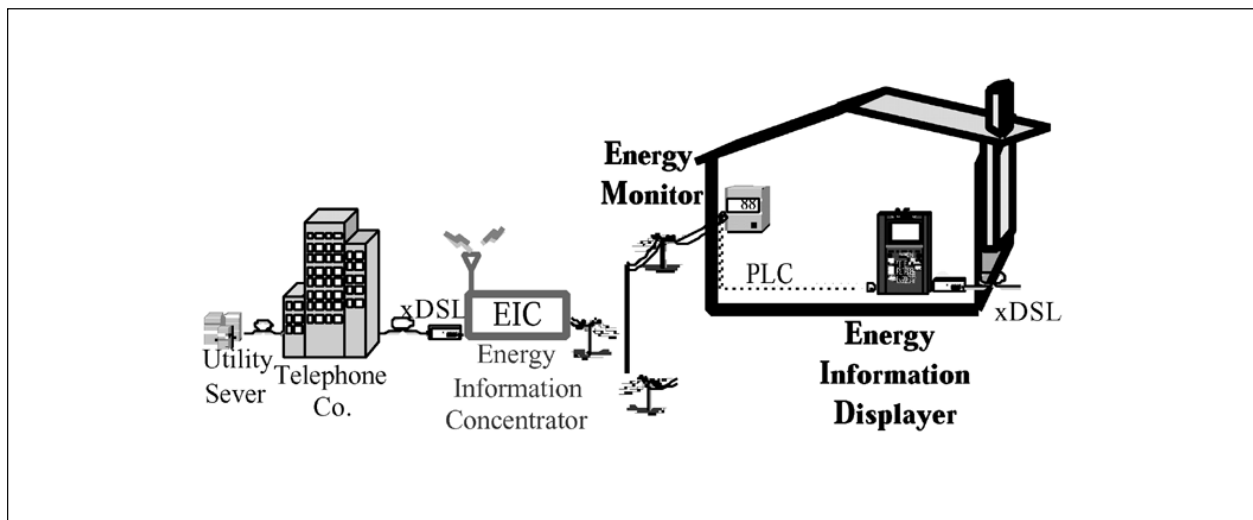


Figure 1.5: *Overview of Chen's Energy Information System (ENIS)* [20]

The ENIS of Chen and Hwang does, however, have a few limitations:

- It is specifically designed for residential or commercial use and not for larger industries.
- It can only display the energy usage of appliances. In the mining environment, monitoring additional system parameters, such as system air pressure and airflow, can be useful.
- It does not include any form of reporting system.

1.2.3 Energy and Facilities Management Reporting Systems

The second system of Lee *et-al.* from Hong Kong includes an Energy Management Reporting System (EMRS) and a Facilities Management Reporting System (FRMS) [21]. Lee suggests that the system could improve energy efficiency of high rise buildings and shopping centres. The EMRS provides feedback on the energy management of the system, while the FRMS provides maintenance management feedback.

Data from the energy management and facilities management systems are consolidated into a single SQL database. The data are then used to generate energy and facility management reports in order to increase the energy efficiency and maintenance of a building or shopping centre. Figure 1.6 shows example report graphs generated by the EMRS.

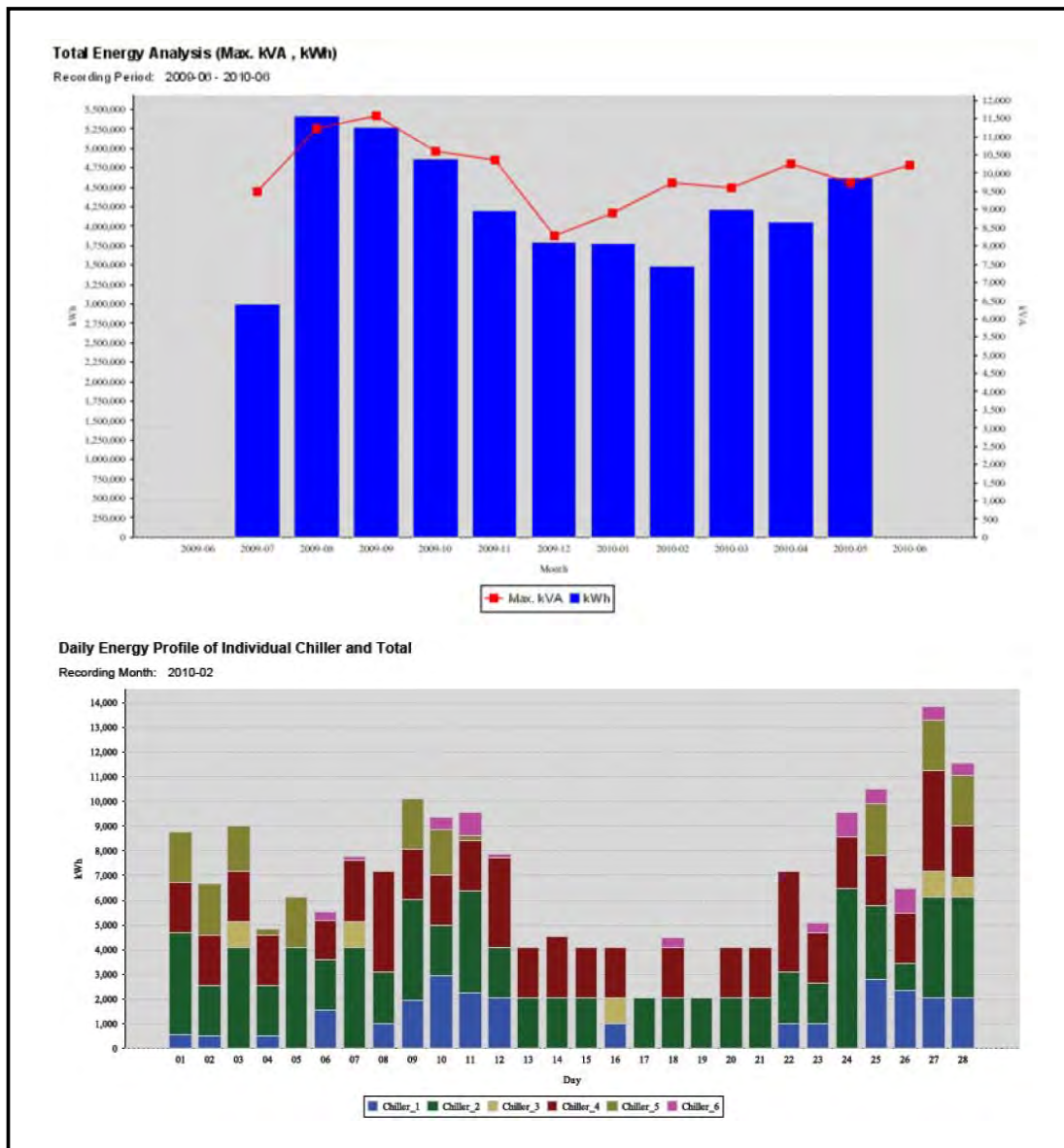


Figure 1.6: Example report graphs from Lee's EMRS [21]

Lee's EMRS and FMRS have the following limitations:

- Similar to the ENIS, the EMRS and FMRS are not designed for large industries.
- Although this system does have the capability to generate reports and charts, there is no automatic feedback-loop. Reports appear to be generated manually on request.

1.2.4 An IT application for sustainable load shift projects

The third system by Pretorius was an application specifically designed to ensure sustainable DSM savings on LS projects [22]. Figure 1.7 shows an overview of the the data storage and data transfer of the system. The system stores data monitored by an Energy Management System (EMS) in an on-site database. Data are stored for various system parameters that are useful to monitor the effectiveness and performance of the EMS.

Performance data are sent to a centralised database on the ESCo premises. The data can be accessed via a web page on a computer or a mobile phone with internet access. The performance data are used to generate daily reports. These reports were sent to the mine and the Energy Services Company (ESCo). Pretorius does, however, mention that the communication method to transfer the data between the on-site and central database is not very reliable. This results in delays and even data loss.

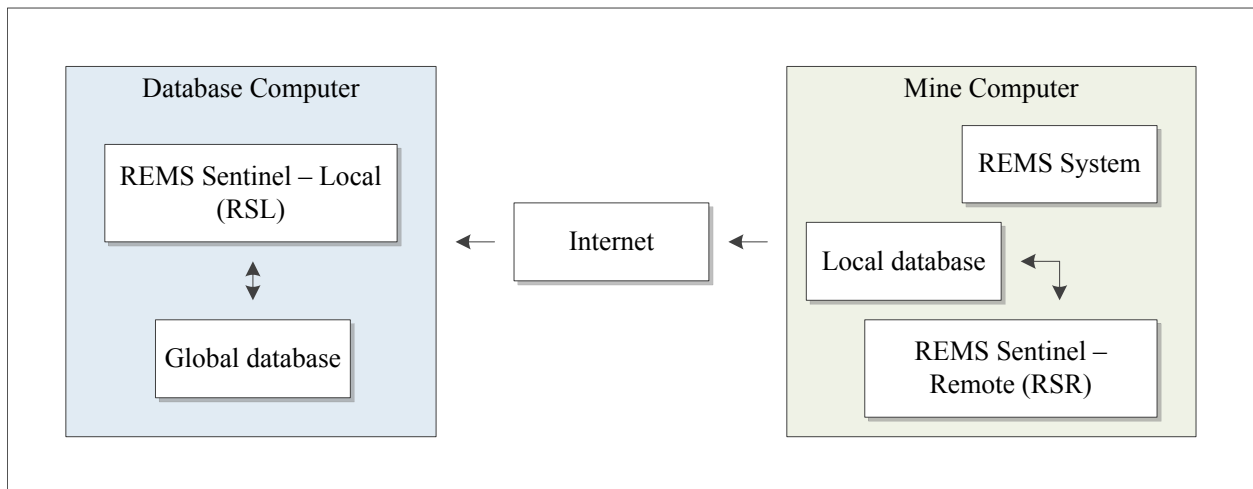


Figure 1.7: *Overview of data storage and data transfer of Pretorius's system [22]*

Limitations of the application:

- It was designed for LS projects and in particular clear water pumping systems on mines.

- The communication between the client site and the centralised database was unreliable and usually resulted in data loss and delays.

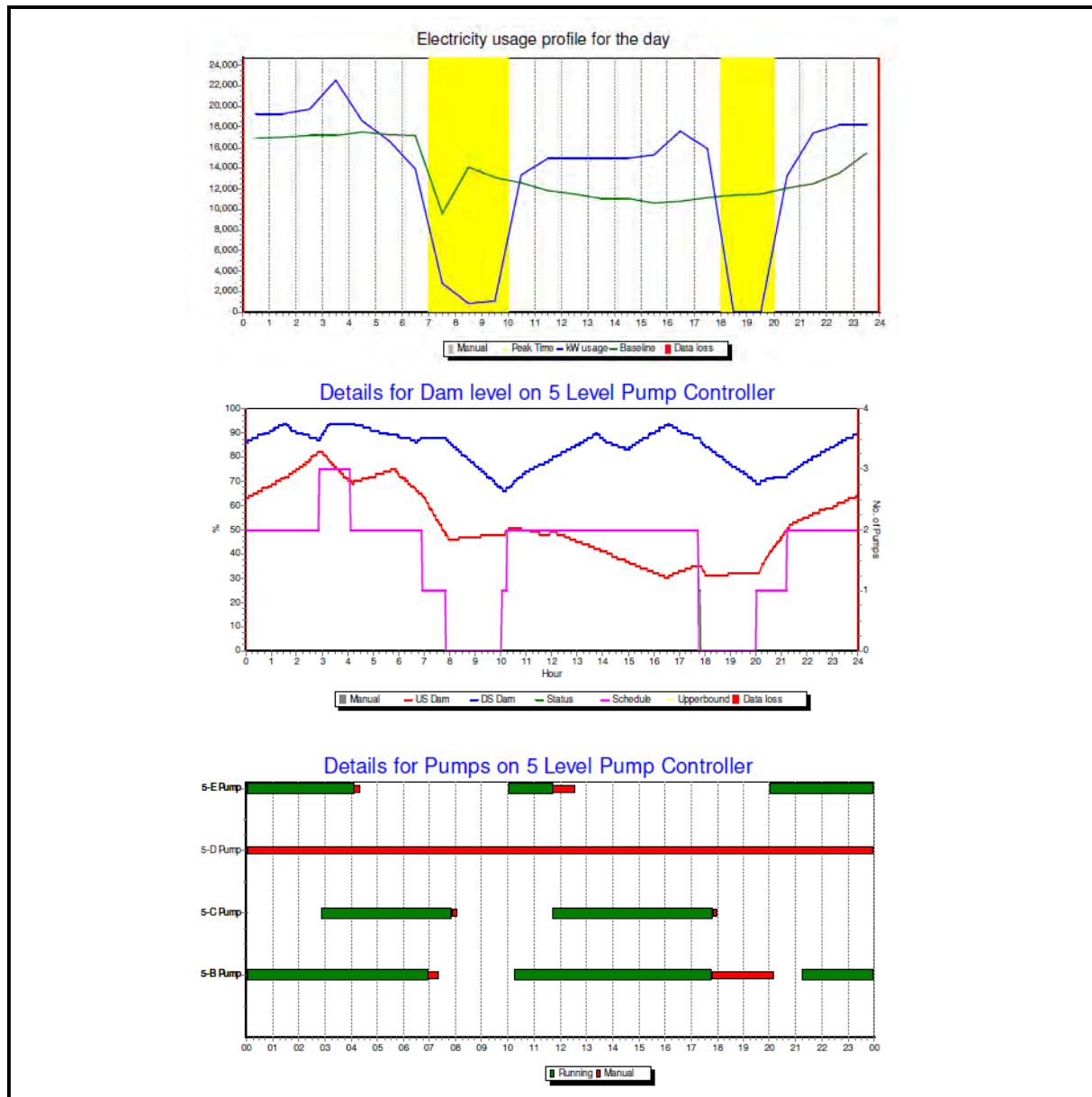
1.2.5 A solution for sustainable DSM on mines

Steyl introduced a similar system to that of Pretorius, but with some improvements [23]. His system also used data from an EMS, but instead of transferring data between two databases, he used emails to transfer the data in text files. The email communication method proved to be more reliable.

Steyl's system also includes additional detail in the reports, including pump running times, dam levels and so on. Figure 1.8 shows example report graphs. This made it possible for the recipient to not only see the performance of the DSM project, but also potential shortfalls or opportunities in the control philosophy of the EMS. Different reports were also introduced including daily, weekly and monthly reports.

Limitations of Steyl's system:

- The system was unstable and did not support multi-user access.
- This system was also only designed for LS projects.
- No web interface was available. Clients only had access to the reports that were sent to them via email.

Figure 1.8: *Example report graphs of Steyl's System* [23]

1.2.6 Summary of existing systems

Table 1.1 shows a summary of the limitations with existing reporting systems. The new reporting system should be a helpful tool for monitoring mine compressed air systems. It should also be easily accessible and give meaningful information regarding the compressed air system. As shown in Table 1.1, the existing systems investigated in Section 1.2 do not meet all of these requirements.

Table 1.1: *Summary of existing energy feedback systems*

	ENIS (Chen <i>et-al.</i>)	EMRS & FMRS (Lee <i>et-al.</i>)	Application for sustainable LS projects (Pretorius)	Solution for sustainable DSM on mines (Steyl)
Designed for residential use	Yes	-	-	-
Designed for commercial use	Yes	Yes	-	-
Designed for industries/mines	No	No	Yes	Yes
Reliable data transfer	-	-	No	Yes
Display energy consumption	Yes	Yes	Yes	Yes
Display additional system information	No	Yes	Yes	Yes
Generate basic reports	No	Yes	Yes	Yes
Generate detailed reports	No	No	No	Yes
Data accessible via web-interface	Yes	No	Yes	No
Feedback-loop (emailed reports)	No	No	Yes	Yes
Designed for LS DSM projects on clear water pumping systems on mines	No	No	Yes	Yes
Designed for EE or PC DSM projects on mine compressed air systems	No	No	No	No

1.3 Objectives of this study

The goal of this research is to develop a new system to monitor DSM projects on mine compressed air systems. This can be done by generating reports on a daily basis regarding the compressed air usage of a specific mine. More detailed reports can also be generated on a monthly basis to monitor the performance of a DSM project.

This system will require the modification of existing systems and development of new systems. Compressed air data on mines should be retrieved automatically on a daily basis. This data should then be processed and reports should be generated. The reports will give feedback to ESCo and mining personnel on the performance of the project.

Mines will be the primary beneficiaries of this research. The reports will be tailored to benefit most compressed air DSM projects on mines. These reports can reduce the workload of mine employees when writing reports and also when searching for leaks or other system issues. Energy and money will be saved by repairing leaks quickly.

Eskom is a secondary beneficiary of this research. Although they will not be using the reports directly, they will benefit from the results of the reports. If mines save additional

energy, the pressure on Eskom to supply the high electricity demands is reduced.

The ESCo will also benefit from this system. Automatic generation of daily and monthly reports will reduce the workload on ESCo personnel. If data from all DSM projects are readily available in a central location, more detailed reports can be generated to further validate the performance of all the DSM projects implemented by the ESCo.

1.4 Overview of this dissertation

Chapter 1: Introduction

In this chapter the need of the electricity supply company to implement energy saving projects is investigated. Energy saving initiatives on mine compressed air systems are discussed and the need for an efficient feedback system is identified. Thereafter existing systems are investigated and analysed. Finally the objectives of this study are stipulated.

Chapter 2: A new reporting method

This chapter investigates the difficulties and shortcomings of the existing methods used to calculate the performance of a DSM project. Thereafter the requirements and specifications of a new reporting system are identified. The new reporting system is then developed according to the specifications.

Chapter 3: Results

The reporting system is implemented on sixteen mine compressed air projects. Five of the sixteen projects are used to test the performance and reliability of the reporting system. Two projects are used as case studies to demonstrate the impact and value of the reporting system. Finally the specifications of the system is reviewed to ensure the successful development and implementation of the system.

Chapter 4: Conclusion

Based on the results presented in chapter 3, conclusions are made regarding the reporting system. Recommendations for future work on the system are also presented.

Chapter 2

A new reporting method



(Source: <http://greennigeria.wordpress.com>)

2.1 Preamble

Existing reporting systems for energy savings projects have limited functionality and do not meet the required needs for mine compressed air savings. Designing a new method for monitoring compressed air savings will improve the performance and sustainability of DSM projects.

In 2011 the International Standards Organisation (ISO) announced the ISO 50001 energy management standard [24,25]. PPC SA as well as Toyota SA started with the implementation of an energy management system in the same year based on this standard [26,27]. The ISO 50001 introduced a Plan-Do-Check-Act (PDCA) cycle in order to ensure continuous improvement of energy management systems [24,27].

Figure 2.1 shows a simplified illustration of the PDCA cycle. The new method for monitoring mine compressed air savings will aim to improve the "Check" and "Act" stages of the PDCA cycle. This chapter focuses on the technical side of the objectives and development of this reporting system.

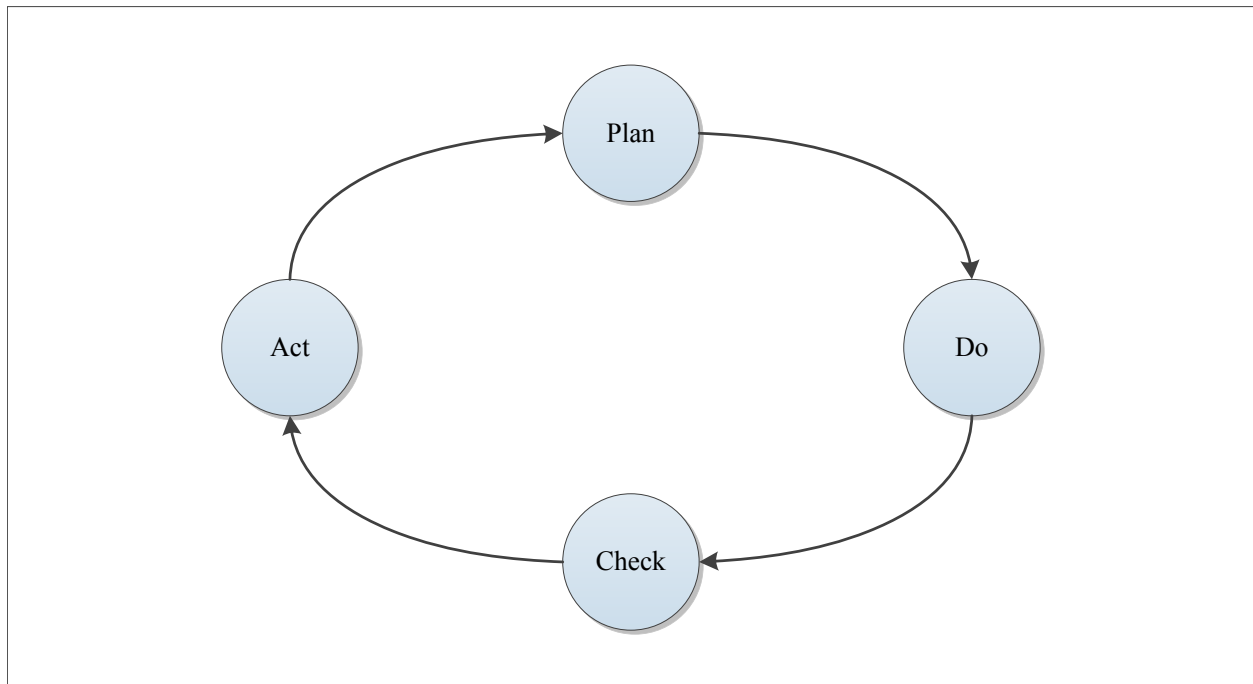


Figure 2.1: *Continuous improvement cycle of the ISO 50001 standard*

2.2 Problem statement

2.2.1 Introduction

In order to accurately define user requirements and specifications for the new reporting system, the problems and shortcomings of existing performance tracking methods need to be identified. Discussions with ESCo project engineers identified practical difficulties with calculating the project savings.

Further meetings with mine personnel identified the need to measure the performance of DSM projects on a more frequent basis. The shortcomings and problems with existing methods for performance tracking of DSM projects are divided into the following categories: practical limitations, performance issues, compliance issues and financial risks.

2.2.2 Practical limitations

There are a few practical limitations with the existing method for monitoring DSM projects. Retrieving the appropriate compressed air data from the mines is one of the limitations. The data are used to calculate and analyse the energy savings of the project. It is possible to get feedback from the mines when mine personnel send the data via email. However, due to the busy schedule of mine personnel, this usually results in a significant time delay before the data can be analysed.

The ESCo can also send an employee to the mine to retrieve the data. However, most of the mines are located hundreds of kilometres from the ESCo offices. This is very expensive and takes a lot of time. It is definitely an impractical way to retrieve the data on a daily basis. Therefore, data are usually retrieved when there are site meetings or when someone is in the area for other project meetings.

Data availability and integrity are also a problem. A variety of data is required to efficiently monitor a compressed air system. Examples of the data include compressor power readings, system air pressure and airflow at various nodes in the compressed air network. Figure 2.2 shows a typical mine layout. Mines do not always store the required data. Some of the data are stored, but are not always accurate or in a convenient format. This requires additional data processing before it can be analysed.

Problems with the availability and integrity of the data make it more difficult to detect anomalies within the system. Consider, for example, that the air consumption of the compressed air system in Figure 2.2 increases. A change in airflow will then be measured at

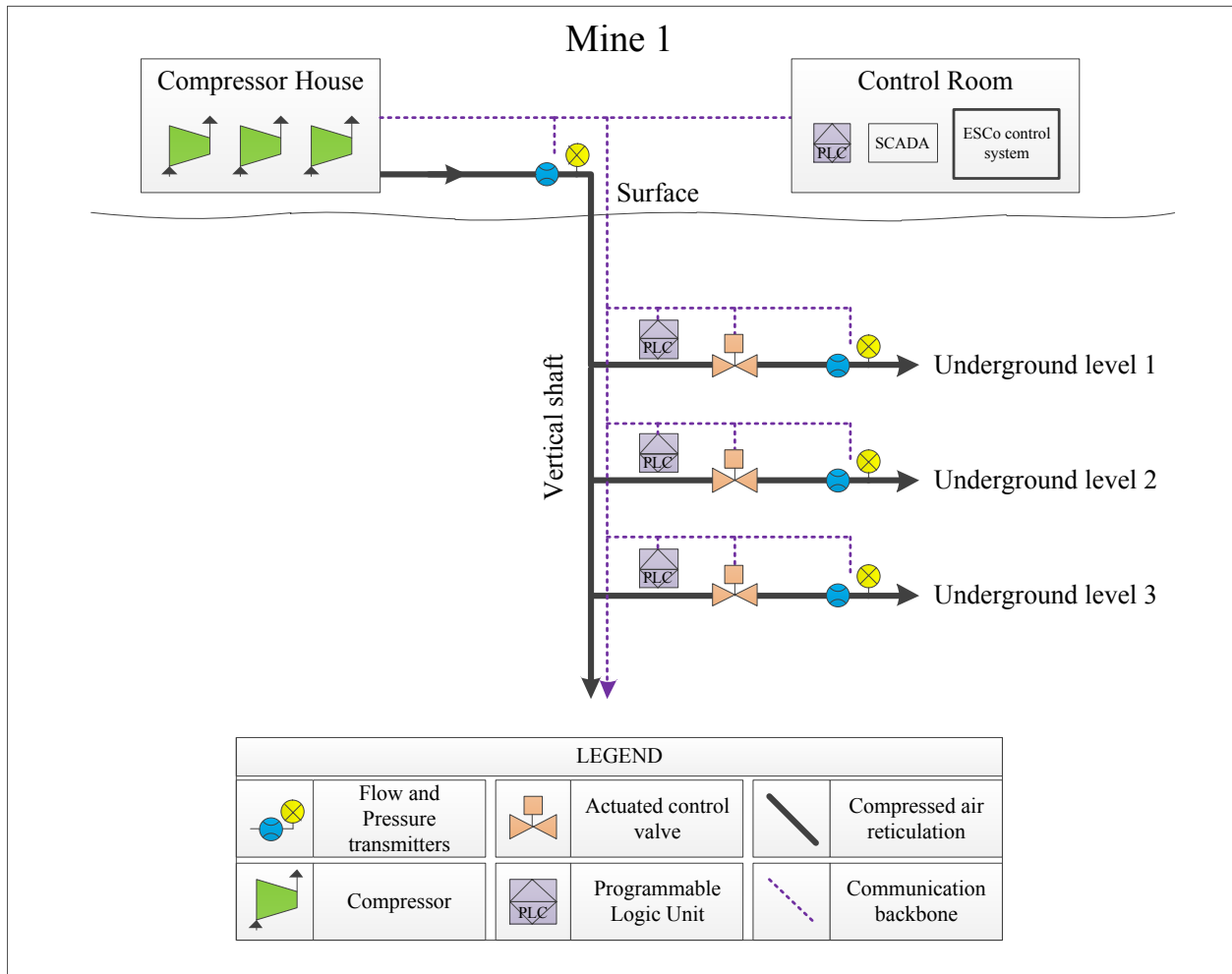
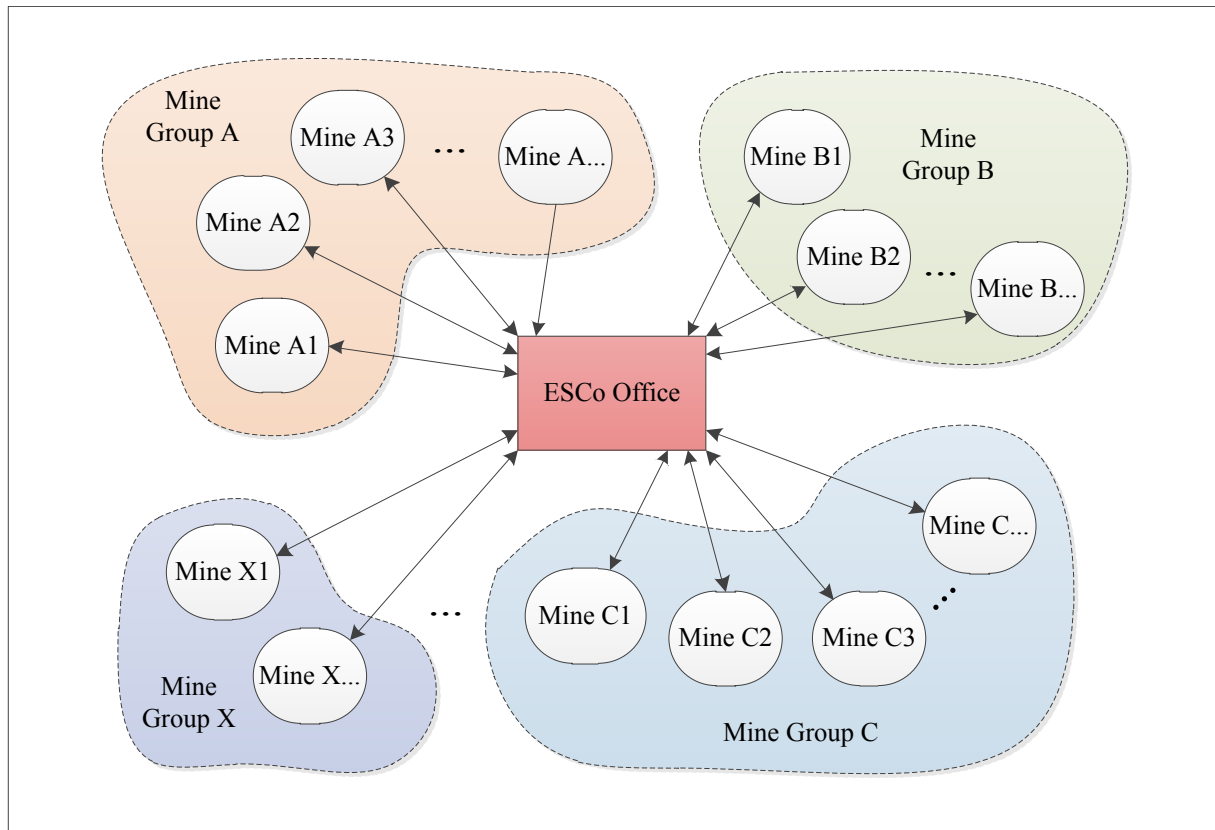


Figure 2.2: *Simplified layout of a compressed air system on a mine*

the surface flow meter. If the flow meters on the underground levels are not working, it will not be possible to identify on which level the increase in airflow originated.

In order to track the performance of a project in more detail the data need to be processed on a regular basis. If possible, the energy savings of the project should be processed every day. This constant data processing can put a massive strain on human resources. Figure 2.3 shows the potential scale of multiple projects. Each of these mines will have a similar layout as shown in Figure 2.2.

The data standards of each mine or mine group can also differ in various ways. This means that only the project engineer of a specific project knows how to calculate that project's savings. If only one person knows how to retrieve the data or calculate the savings of a project, it creates another issue if that person is not available. Because nobody else knows how to process the data, the savings for that project cannot be calculated until that person is available again.

Figure 2.3: *Overview of multiple projects*

2.2.3 Performance issues

The distance between the ESCo and some of its clients makes it difficult to continually monitor the remote control system. Regular feedback is required to successfully sustain the performance of a project. If the system malfunctions and stops controlling the compressed air system according to the proposed schedule, the project will lose some of its potential savings.

With frequent feedback, a closed-loop system is formed as shown in Figure 2.4. An ESCo engineer analyses and interprets the data from the mine. With sufficient data, the engineer can make suggestions for the control philosophy of the compressed air system. Problems with instrumentation can be detected and mine personnel can be notified.

If the frequency of this feedback loop is high enough, problems can be detected earlier and the savings of the project can be maximised. However, because of the practical limitations mentioned above, this is not always possible. Consider a project with a 48 MWh energy efficiency per day (an average of 2 MW power reduction per hour). During Eskom's high demand season in 2012, that equates to a potential cost saving of more than R 43 000 per working weekday.

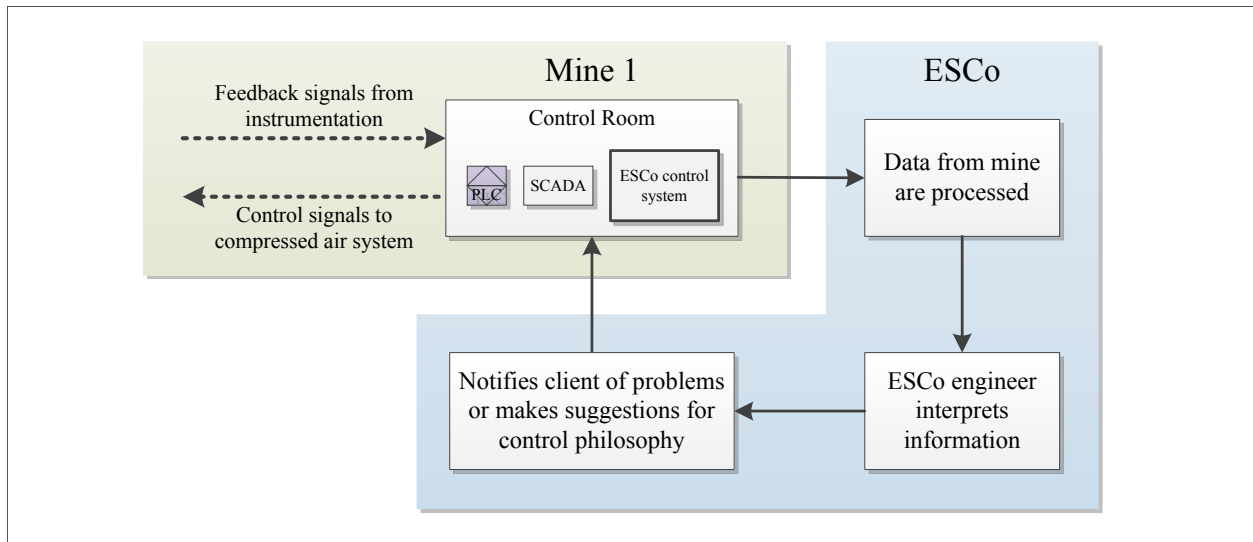


Figure 2.4: *Closed feedback loop between ESCo and client*

2.2.4 Compliance issues

Energy efficiency projects are partly funded by Eskom, as mentioned in Section 1.1. Because of this Eskom assigns an independent Measurement and Verification (M&V) team from a university to monitor the performance of a DSM project [14, 28]. The M&V team also requires data from the mine to calculate the project's performance. Due to the difficulties with retrieving the data, the M&V team gets the data from the ESCo each month. This puts more strain on the ESCo to retrieve, process and manage the data.

The mines also want reports that summarise the performance of the projects. ESCo engineers create reports with the data received from the mine. However, as mentioned earlier, each project engineer manages only his own projects. The reports are, therefore, not always consistent and on the same standard. Reports also take significant time to create, again putting strain on the ESCo.

The vast amount of data acquired over irregular intervals makes it difficult to create reports for a custom period. It takes a lot of processing to create a weekly or monthly report for one project. If a monthly overview of all the mines of a specific mine group is required, it takes even more time. However, if all the data from every project are stored in a well-defined format, larger reports will be easier and less time consuming to generate.

Storing all the data received for a project has another advantage for the ESCo. If the project is not performing satisfactorily despite the intervention of the ESCo's control system, the data can be used to find the root of the problem. Sometimes the ESCo control system is disabled by mine personnel to increase the air pressure of the compressed air system for their

own convenience. If the control system is disabled, the project will not achieve its target savings and the ESCo cannot be held responsible.

2.2.5 Financial risks

Eskom's funding is seen as an investment to increase the gap between electricity supply and demand. If a DSM project does not achieve the contractual target savings after performance assessment, the mine is also liable for financial penalties towards Eskom. It is, therefore, essential for the mine to increase the performance of a DSM project in order to maximise the project's return-of-investment (ROI) and avoid financial penalties.

Another concern for mines is scope 2 carbon emission tax. Scope 2 emissions are energy indirect emissions and are associated with the use of purchased grid electricity [29]. The South African Treasury proposed a tax rate of between R75 and R200 per ton CO₂ emitted, although this tax is not yet implemented [30,31]. For a typical South African mining group the annual carbon tax could be more than R 500 million. This tax amount can be reduced by increasing the DSM savings.

2.3 User requirements

2.3.1 Introduction

Considering the problem statement in Section 2.2, the user requirements for the new energy monitoring system can be defined. The requirements are divided into four categories: data collection, data processing, report generation and report distribution.

2.3.2 Data collection

The first step is to create a file structure that is generic and well defined. All the data required to calculate the savings of the project should be organised in a simplified format. This way the data will be easier to process automatically. It should also be suitable for M&V use without requiring further processing from any ESCo personnel.

Figure 2.5 shows a preview of the new reporting system. The new modules are coloured in orange. The next step in the data collection process is to automatically send the data from the client site to a centralised web server. In Figure 2.5 this is shown as the ESCo

communication module. This module should be able to send the data to the hosted web server and the assigned M&V team on a daily basis.

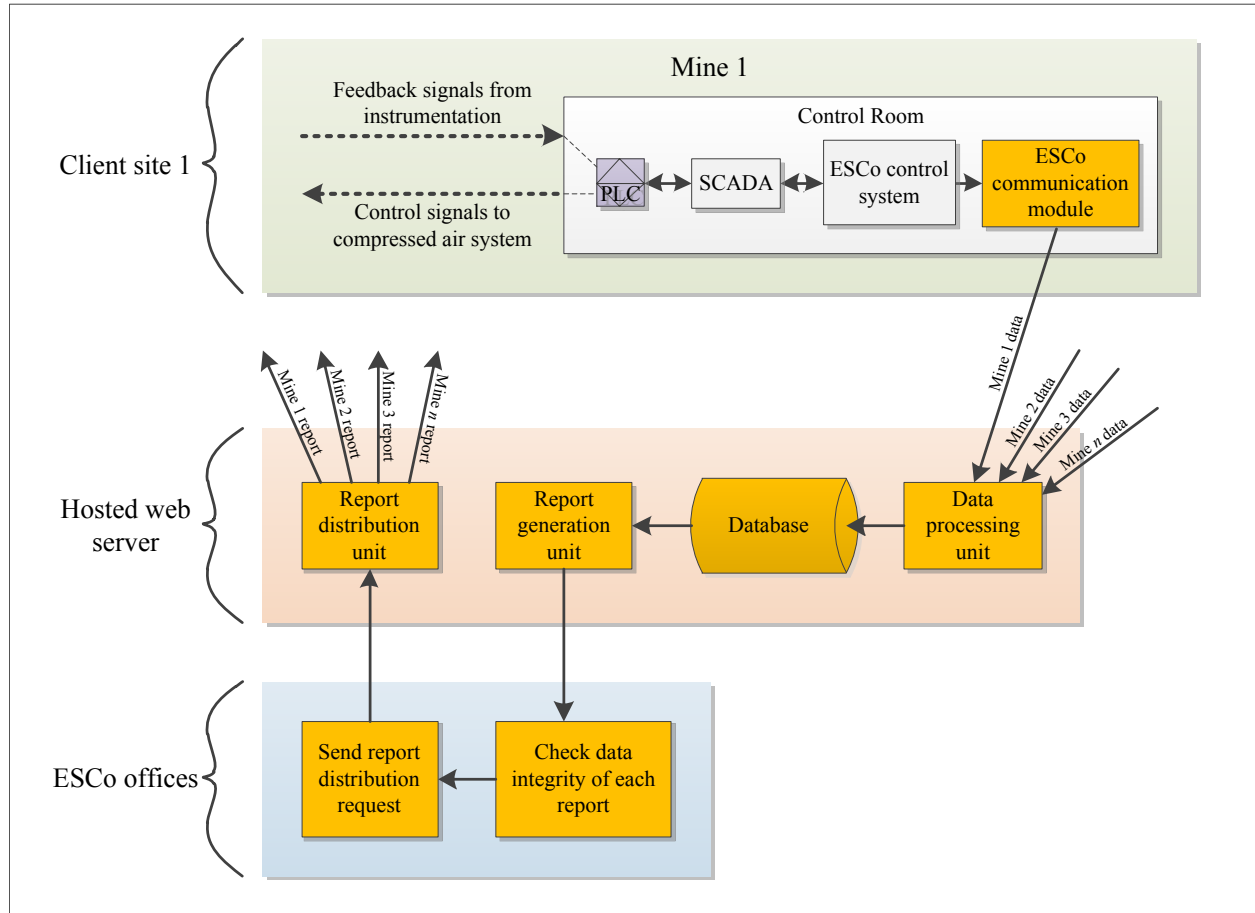


Figure 2.5: *Layout of the new reporting system*

Another requirement for the ESCo communication module is to send out alarm messages generated by the ESCo control system. The control system generates alarms to notify mine personnel of potential unwanted or unsafe conditions in the compressed air system. These alarms are only shown on the display of the ESCo control system. If the ESCo communication module can send out these messages via SMS or email, it will greatly improve the mine's response to unsafe conditions. Each of the components shown in Figure 2.5 are described in more detail in Section 2.5.1.

2.3.3 Data processing

The hosted web server, shown in Figure 2.5, contains four modules. The first module is the data processing unit. This unit should receive data from the client site on a daily basis and process it into data that are more manageable. It should be able to receive multiple sets of data from projects on different sites.

The processed data should then be stored in a database. One of the compliance issues mentioned in Section 2.2.4 is generating reports for custom periods and multiple projects. With all the data stored in one centralised database, it should be easier to manage the data required for the reports.

2.3.4 Report generation

The report generation unit should extract the processed data from the database and generate reports on a daily basis. Once the processing unit has processed the data from all the mines, this unit should generate a daily report for each project. As shown in Figure 2.5, the generated reports should be sent to the ESCo offices.

Before the report can be sent out by the report distribution unit, ESCo personnel should check it. A specifically assigned operator from the ESCo should check each report to make sure that it was generated successfully. The formatting of the reports should also adhere to the ESCo standards. If the operator is satisfied with the report a request should be sent to the report distribution unit.

Custom reports will not always be the same and will, therefore, require a user interface. This user interface should be able to connect to the web server and extract the required report. To ensure that the data stay secure, the web interface must require login details from the user before any information is shown. The user should only have access to pre-assigned projects and should not be able to view data of any other project.

2.3.5 Report distribution

Once the ESCo operator is satisfied with the report of a specific project, a request should be sent to the report distribution unit on the web server. The report distribution unit should have a list of email recipients for each project. When the unit receives a request to distribute a report for a specific project, the report should be emailed to all the email recipients of the project. It should be possible to easily manage the mailing lists of all the projects using the web-interface mentioned above.

2.4 Specifications of the new reporting system

Based on the user requirements in Section 2.3, the reporting system has the following requirements and specifications:

- Raw compressed air data required by the system should be available on a daily basis.
- The data should be processed automatically on a daily basis.
- It should be able to report on several projects or groups of projects.
- Reports should be sent out to the relevant persons on a daily and monthly basis.
- It should be a centralised system that allows web access to clients and ESCo personnel.

Three types of reports are required:

- *Daily savings report for each project*

ESCo project engineers and mine personnel who maintain the performance of the project on a daily basis will use this report. The daily report should include the following:

- an overview of the day's target savings
- actual energy efficiency and cost savings for the day
- a graph comparing the 24-hour energy consumption profile and the energy baseline
- time-of-use (TOU) graph

- *Monthly savings report for each project*

The engineering manager or energy manager of a mine concerned with the performance of the DSM project will use this report. The monthly report should include the following:

- an overview of target savings for the project
- a summary of the average daily impact for the period
- a graph comparing the average 24-hour energy consumption profile and the energy baseline
- time-of-use (TOU) graph
- performance tracking table showing the energy and financial impact of each day
- graphs visualising the performance tracking of the project

- *Group report*

This report will summarise all the DSM projects of a mining group. The higher-level management of a mining group concerned with energy and financial savings for the DSM projects of the entire mining group will use this report. The group report should include the following:

- summary tables of each project type showing targets and actual impacts for each project
- short summary of each project showing an average 24-hour profile graph as well as a cumulative performance analysis graph

2.5 Development methodology

2.5.1 Overview of the system

Figure 2.6 shows an overview of a DSM system on a mine. Blocks A1, A2 and A3 in Figure 2.6 are existing mine components. Blocks A4 and A5 are components developed by the ESCo. The control functionality of block A4 was already developed, but modifications are required to log the data of the compressed air system.

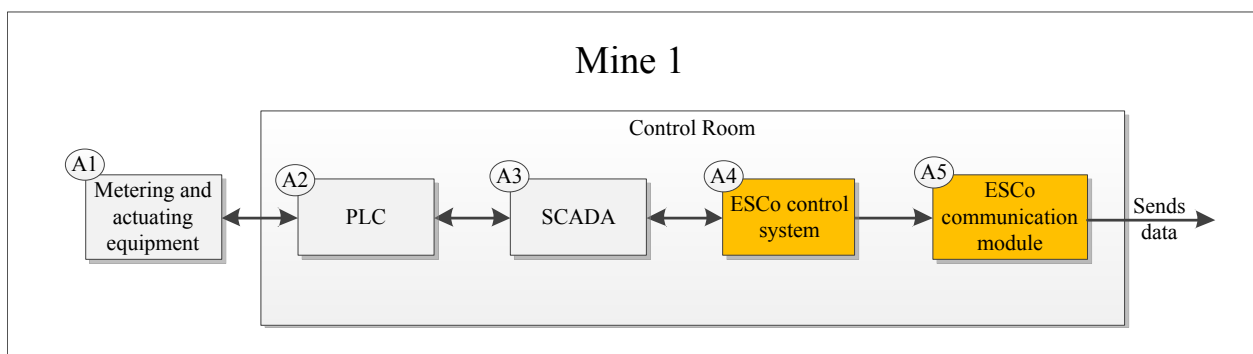


Figure 2.6: *Overview of the compressed air control system on a mine*

A1 - Metering and actuating equipment

This includes all the field equipment used to monitor and control the compressed air system. Control valves are installed at key locations in the air network in order to manage the compressed air usage. These valves are usually controlled according to downstream pressure set-points.

Pressure transmitters are installed downstream from the valves for feedback. Flow meters are installed to monitor the amount of air used by particular sections in the

compressed air network. Instrumentation on each compressor is also monitored. This includes power usage, guide-vane position, blow-off valve position and delivery air pressure.

A2 - Programmable Logic Controller (PLC)

The existing PLC control system on the mine controls the above-mentioned equipment in block A1. Using the mine's existing infrastructure saves installation costs. Mining companies prefer to implement new equipment on their own systems, because it reduces maintenance cost and time. They also prefer to standardise on certain brands of equipment. Different brands of PLC's encountered at mines include Allen-Bradley and Siemens.

The PLC receives feedback signals from the compressor power meters, pressure meters, flow meters and many more. Control signals from the SCADA system are sent to the PLC. In order to control a valve in the compressed air system, the PLC requires a downstream pressure set-point value from the SCADA. The PLC then analyses the feedback signals of the valve and the set-point value from the SCADA, and controls the valve position accordingly.

A3 - Supervisory Control And Data Acquisition (SCADA)

For monitoring and controlling the PLC a SCADA system is used. The SCADA provides a user-interface to the equipment controlled by the PLC. An Open Platform Communications (OPC) server is hosted on the SCADA. This allows the ESCo control system to establish an OPC connection with the SCADA and access data of the compressed air system. Different mines standardise on different SCADA packages. These packages include but are not limited to Adroit, Wonderware Intouch® and Simatic WinCC.

A4 - ESCo control system

As mentioned above, the ESCo control system establishes an OPC connection with the mine's SCADA system. The control system uses this connection to receive data of the compressed air system. It also sends control instructions to the PLC through this connection. The control system is able to establish OPC connections with various types of SCADA systems.

Data from the compressed air system are logged into text files. The log files have a generic layout that simplifies data processing. This simplified layout is also acceptable for M&V use and can be sent directly to the project's corresponding M&V team. Data logging is explained in more detail in Section 2.5.3.

A5 - ESCo communication module

This module is an independent application that sends the data logged by ESCo control system to the hosted web server. The data are compressed and sent via email. To further minimise the size of the emails, the data of each day are compressed and sent in individual emails. This module also sends alarm messages generated by the control system, via email or SMS. Section 2.5.3 explains this module in more detail.

As shown earlier in Figure 2.5, the data that are sent from the mine by the communication module, are received by the processing unit on the hosted web server. The hosted web server is also known as the reporting system. Figure 2.7 shows an overview of the reporting system. A brief overview of each component is given below.

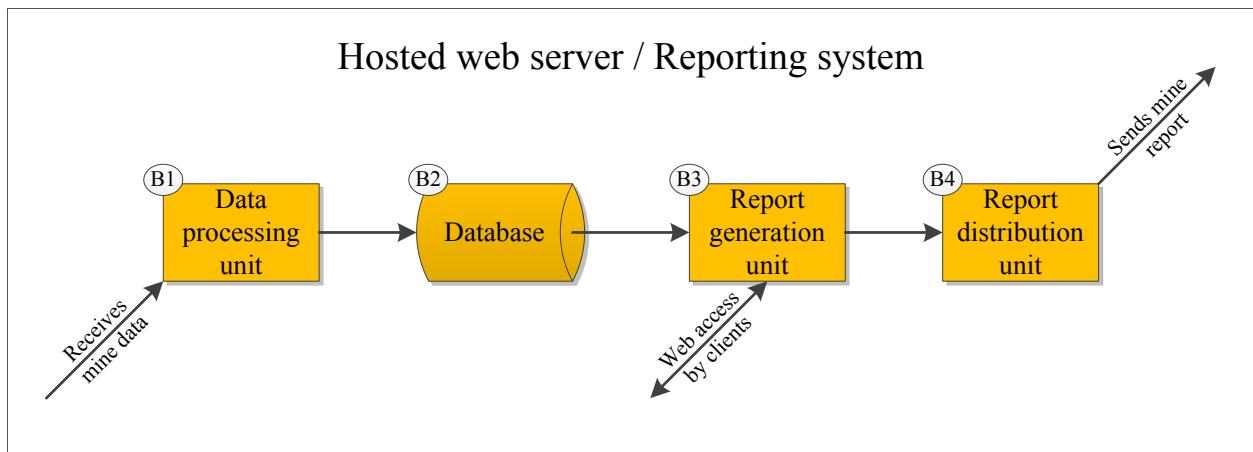


Figure 2.7: Overview of the reporting system

B1 - Data processing unit

The data processing unit of the reporting system has four major subcomponents which include receiving the data, processing the data, calculating the savings and storing the results. Data received from the mines via email are downloaded and extracted. The extracted files are then processed into more manageable formats before the savings of the project can be calculated. Each project's savings are saved in a SQL database. Data processing is explained in more detail in Section 2.5.4.

B2 - Database

The savings of all the projects are stored in a single database where it is accessible for report generation. Important project information that contributes to the reports is also stored in the database. Because data from all the projects are available in a central location, it is easier to generate group reports. The design of the database is explained in more detail in Section 2.5.5.

B3 - Report generation unit

The report generation unit uses the project data stored in the database to generate different types of reports. These reports include daily savings reports, monthly reports and group reports. All the reports are generated in PDF format. This unit also consists of web-based user interface. The user interface gives clients and ESCo engineers access to project data and reports.

B4 - Report distribution unit

In order to ensure that the feedback loop in Figure 2.4 is accomplished, the reports should be sent to relevant people on a regular basis. The report distribution unit sends the daily report of each project to a predetermined set of people including mine personnel and ESCo engineers. The report generation and distribution are further explained in Section 2.5.6.

2.5.2 Advantages of a centralised system

There are several advantages for developing the reporting system to work from a central remotely accessible location. First, it simplifies fault-finding. If there is a problem with the received raw data or with the processing of the data, an ESCo operator or developer can attend to the problem. All the data will be in one location. Fixing the problem for one project might also fix it for all the other projects.

Software upgrades will be easier to do. Because the data of all the projects are processed by the same system, only one upgrade is required. If separate applications are used for every project, all the applications should be upgraded individually. Consequently ESCo project engineers do not have to upgrade their own project's software.

The web server is hosted by a professional company. They are responsible for the maintenance and availability of the system. Therefore, system up-time is guaranteed. The hosting company is also responsible for backups. Because all the data are in one location it is easier to make backups.

The reports should be checked each day to ensure that the information is correct, before they are sent to the mine personnel. If one system receives all the data from several projects, one person can monitor all the reports. If there is a problem with a report, a developer with remote access can assist.

In most cases, reports are only sent during the performance assessment period of the project. After the performance assessment period it becomes the mine's responsibility to maintain the

project and ensure that target savings are achieved. Some mines then prefer to pay licensing fees. This gives them access to the web interface where they can access the performance reports. These reports are vital for mines to monitor the performance and ensure long-term sustainability of the DSM projects.

2.5.3 Logging and sending data

The control functionality of the ESCo control system was already designed and is therefore not in the scope of this study. It is however an important part of the reporting system, because it has access to the compressed air system. The ESCo control system connects to the mine's SCADA system by establishing an OPC connection. With this connection the control system has access to real-time data and control of the compressed air system. The control system can establish OPC connections with various types of SCADA systems and is therefore easy to implement on new projects.

The fact that the ESCo control system has access to compressed air data makes it the ideal ESCo component to collect the data. Data are stored in text files. The files are in a "comma separated values" (CSV) format and are referred to as log files. There are two main advantages of the CSV file format. Firstly, CSV files can be opened by commercial and open-source spreadsheet applications like Microsoft Office Excel and Apache OpenOffice Calc. This makes it easy to access the data in the file for manual calculations.

Another advantage of a CSV file is the fact that it is a plain text file format. This means that the file is a sequence of alphanumerical characters and the data do not have to be interpreted as binary code. Plain text files are relatively easy to access programmatically and are highly compressible. It is also easier to debug plain text files, because it can be opened and edited by basic text editors like Notepad, or more advanced text editors like Notepad++.

The ESCo communication module, shown in Figure 2.6, sends the logged data to the reporting system. Figure 2.8 shows a more detailed overview of the communication module. The ESCo control system creates new log files each day and saves them in a folder, referred to in this context as the spooler. The communication module can then access the log files in the spooler.

The process shown in Figure 2.8 is executed once a day, because the control system creates new files each day. It is, therefore, usually executed shortly after midnight and only files from the previous day (or older) are sent out. The first step is collecting the log files from the spooler. Thereafter, the files are grouped according to the date of the data. Each group of files is then compressed and saved in an archived folder. The Zip file-format is used for

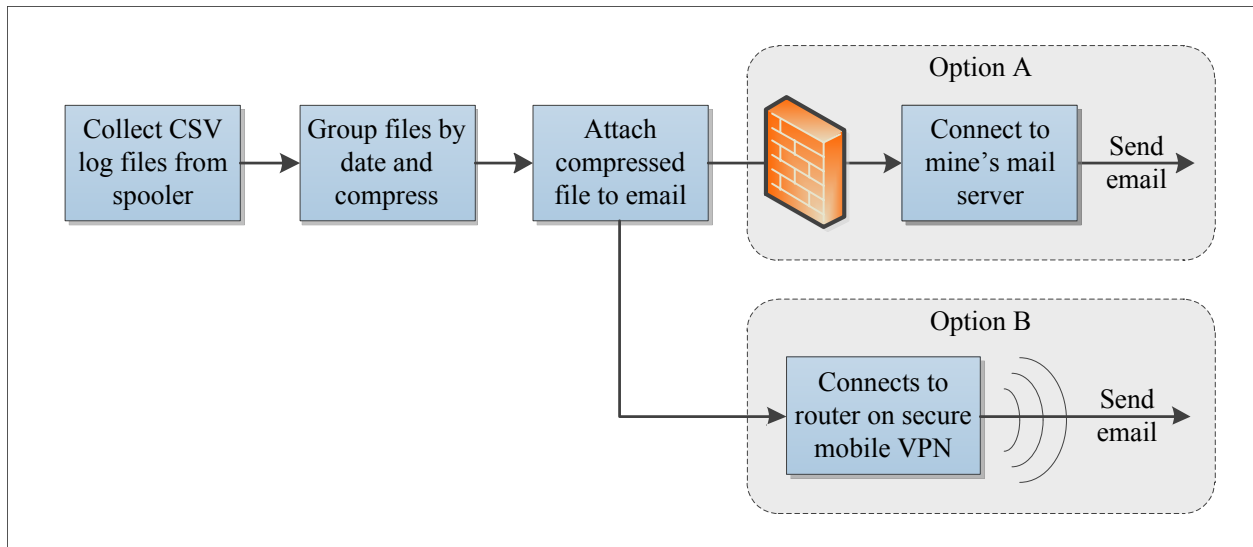


Figure 2.8: *Functional diagram of the ESCo communication module*

the archived folder. The name of the zip-file contains the name of the project and the date of the data.

The Zip file-format works across a wide variety of operating systems, including Windows [32]. This means that the zip-files can be sent directly to the reporting system as well as the M&V team of the project. However, the most important reason for compressing the log files is to reduce the amount of data that is sent via email. The zip-file of each day is then attached to an email. To identify the email at a later stage, the email subject contains the unique name of the project.

The final step is to send the email. There are two different configurations for sending the emails, option A and option B shown in Figure 2.8. Option A requires a connection to the mine's mail server. In order to do that, the mine's network administrators have to allow access through their firewall for the communication module. However, in a number of cases, the network administrators consider this method to cause network vulnerabilities and prefer option B.

Option B requires additional hardware. In order to send the email, the communication module has to connect to a router that has access to local mobile networks. The router connects to a Virtual Private Network (VPN) hosted on the mobile network by a VPN service provider. The VPN provider ensures that data sent through the VPN connection is isolated from other systems on the network [33]. It is, therefore, possible to send emails without causing additional vulnerability to the mine's network.

Log file layout

The ESCo control system has a number of different types of components that it needs to monitor and control. These types of components include compressors, valves, compressor controllers and valve controllers. Each type of component will have similar parameters to monitor, for example, a compressor will have parameters like power usage, pressure set-points and guide-vane positions. A valve elsewhere in the compressed air network will have different parameters like valve position, downstream air pressure, upstream air pressure and airflow.

Each type of component is, therefore, logged in a different file with a unique structure. However, if all the files have completely random structures, it will make the processing more difficult. It will also create difficulty when the system expands and a new file structure is introduced. Therefore, each type of file has a generic layout and is only different in limited areas.

Figure 2.9 shows the generic layout of the files. The value $P_n T_m C_k$ represents the n th parameter of component k at time T_m . $Param_n$ is the heading of the n th parameter for each component. M_m is the mode of the control system at time T_m and can be auto, manual or idle. The mode is the same for all components and is, therefore, a global value like the time. The values for all the components are logged at two minute intervals.

Time	Mode	Param ₁	Param ₂	...	Param _n	Param ₁	Param ₂	...	Param _n	...	Param ₁	Param ₂	...	Param _n	Headings
T ₁	M ₁	P ₁ T ₁ C ₁	P ₂ T ₁ C ₁	...	P _n T ₁ C ₁	P ₁ T ₁ C ₂	P ₂ T ₁ C ₂	...	P _n T ₁ C ₂	...	P ₁ T ₁ C _k	P ₂ T ₁ C _k	...	P _n T ₁ C _k	Data
T ₂	M ₂	P ₁ T ₂ C ₁	P ₂ T ₂ C ₁	...	P _n T ₂ C ₁	P ₁ T ₂ C ₂	P ₂ T ₂ C ₂	...	P _n T ₂ C ₂	...	P ₁ T ₂ C _k	P ₂ T ₂ C _k	...	P _n T ₂ C _k	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	
T _m	M _m	P ₁ T _m C ₁	P ₂ T _m C ₁	...	P _n T _m C ₁	P ₁ T _m C ₂	P ₂ T _m C ₂	...	P _n T _m C ₂	...	P ₁ T _m C _k	P ₂ T _m C _k	...	P _n T _m C _k	
Global values		Component ₁				Component ₂				...	Component _k				

m = number of data entries for the day
 n = number of parameters per component
 k = number of components in the file

Figure 2.9: Generic layout of the log files

As mentioned earlier, the ESCo control system creates new log files every day. Consequently a single log file will only have data of one day. It also limits the size of the files which in turn limits the size of the emails that have to be transmitted. When a new component is added to the control system, that component will automatically be logged in the log files. This will however disrupt the layout of the log file. To mitigate this problem, the control system also creates new log files when new components are added.

2.5.4 Data processing

The main requirements for processing data are speed and cost. PHP is used for processing the data. "PHP is a widely-used general-purpose scripting language that is especially suited for Web development and can be embedded into HTML" [34]. This made it easy to integrate the processing unit and the web-application . Figure 2.10 shows an overview of the processing unit. The processing unit consists of two separate algorithms, executed one after the other. The first algorithm receives the data and the second algorithm processes the data.

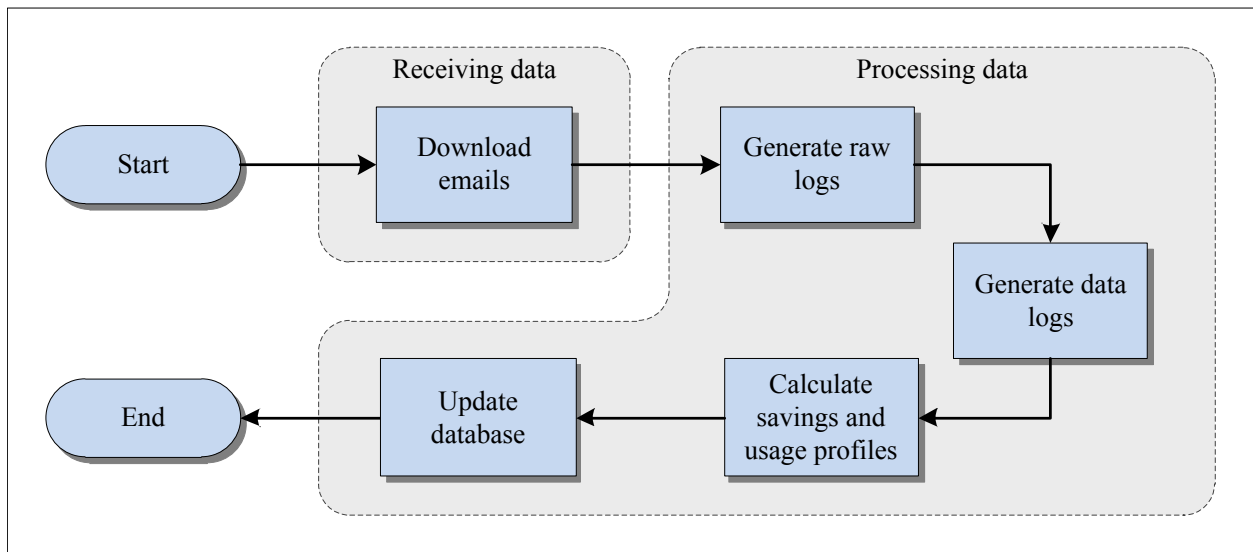
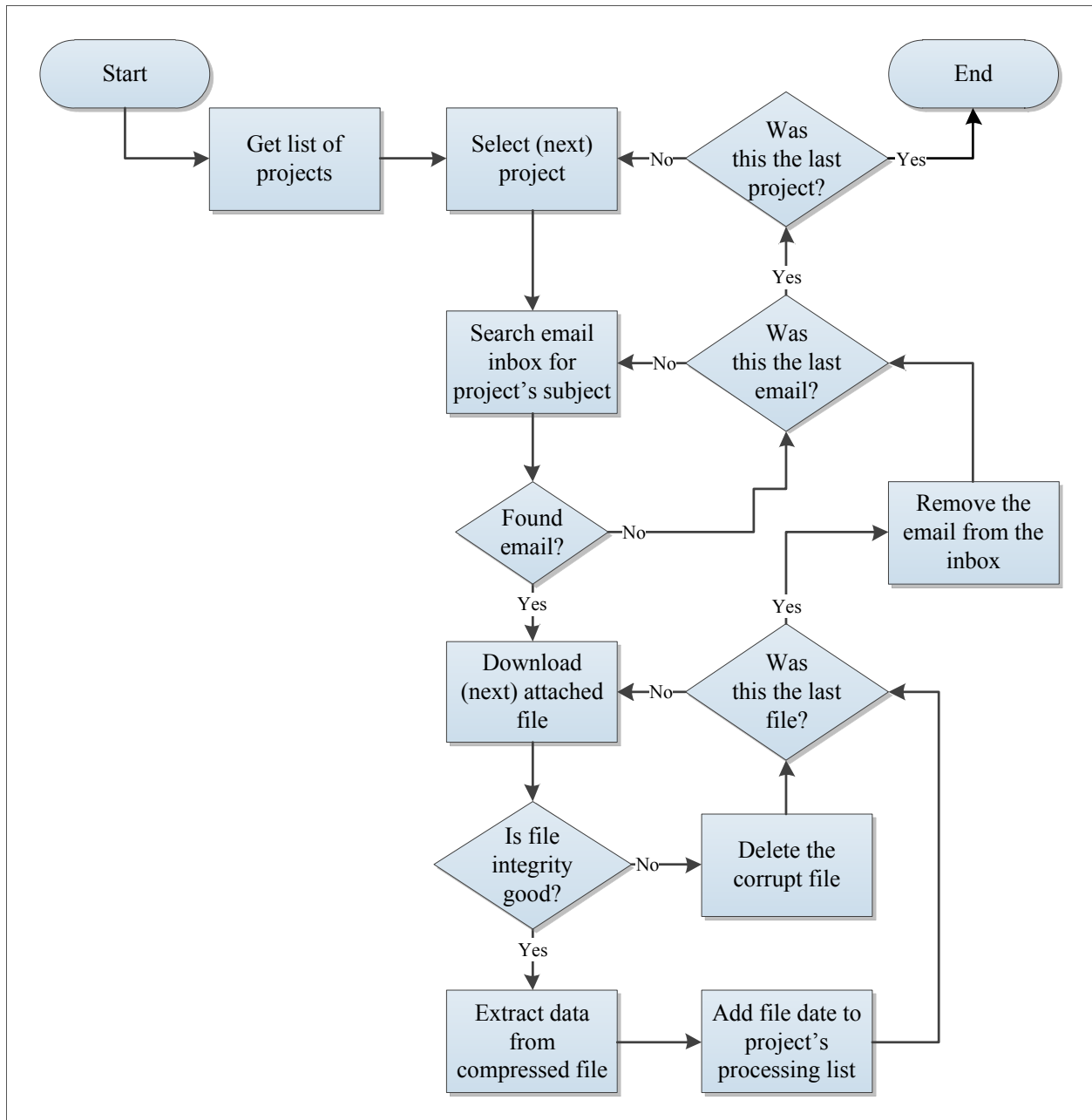


Figure 2.10: *Overview of the processing unit*

Receiving the data

As mentioned in Section 2.5.3, the data from each DSM project are emailed to the processing unit every day. The email subjects are unique for each project. This means that a specific project's data are identified by the subject of the email. The date of the data is derived from the name of the compressed file. Figure 2.11 shows a flow diagram of the data retrieval process.

The processing unit searches the email inbox for the unique subject of each project. If an email is found for a specific project, the attached files are downloaded into a temporary folder. All the files are also backed-up for each project. Thereafter, the integrity of each file is tested. If the file type and name format are correct, the file is extracted in the project's work folder. Corrupt files are deleted from the temporary folder. When all the attached files are extracted or removed, the email is also removed from the email inbox.

Figure 2.11: *Downloading project data files****Processing the data***

After the data from all the projects are downloaded and extracted into their individual folders, the data can be processed. When a data file for a specific project is downloaded, the date of the data is added to that project's processing list as shown in Figure 2.11. Therefore, each project has a list with dates of which the data should be processed.

Figure 2.12 shows a flow diagram of the basic processing unit. In order to minimise the amount of data to process, each project has a settings file in XML format. This settings file contains the different types of files to process, for example, compressor logs, valve logs and controller logs. By choosing only the file types that are required for the reports, it reduces the amount of files to process.

Refer to Figure 2.12. The processing of the project data consists of three nested loops. The first loop steps through all the projects. If there are any dates to process in the project's process list, the settings file is loaded. From the settings file the structure and requirements of each file type are loaded. This includes whether raw-logs, data-logs or both should be processed.

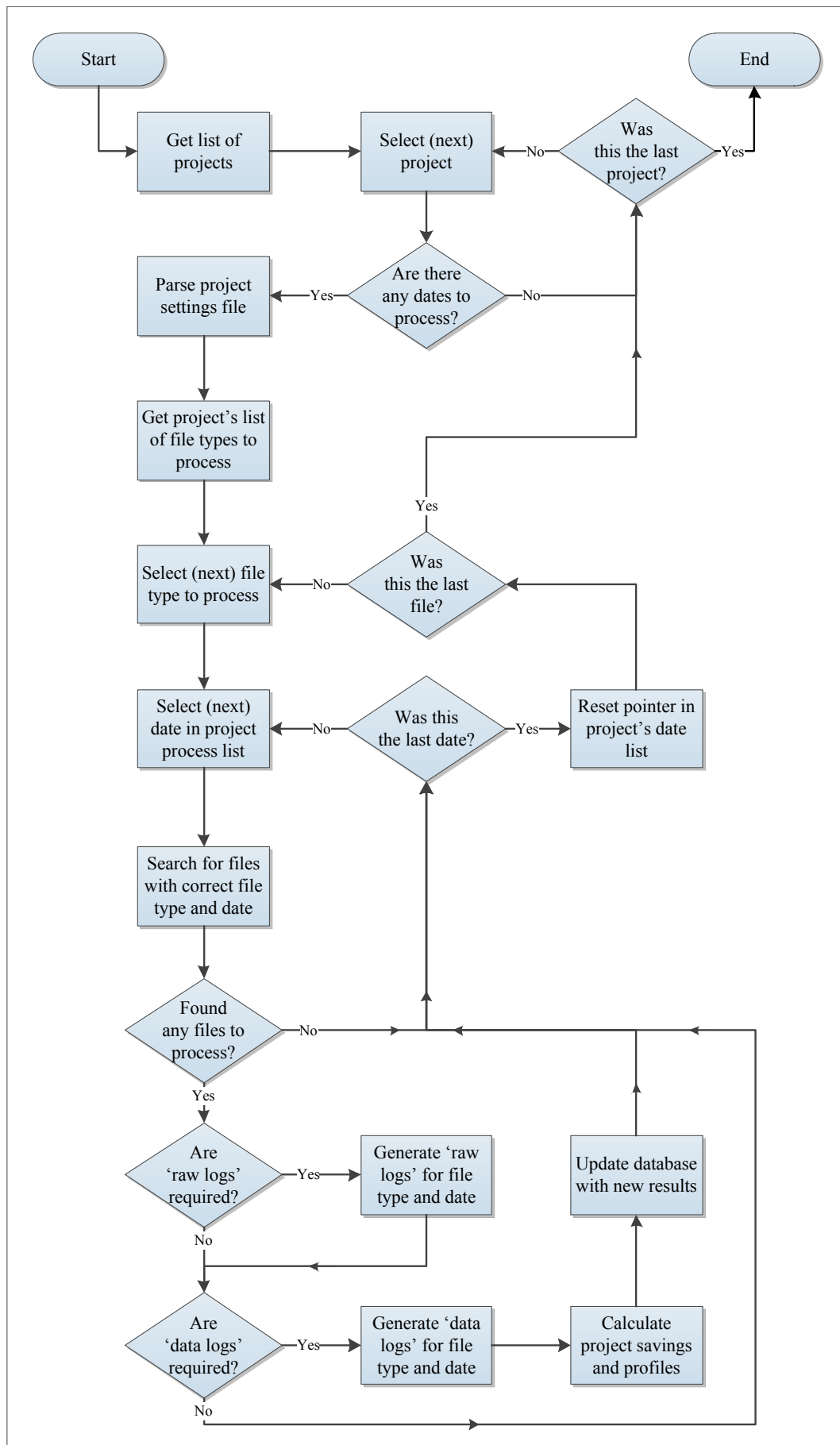
The second loop steps through each file type and the third and final loop steps through each date in the project's process list. Therefore, each file type is processed for each date. For each file type and date, the project's work folder is searched for corresponding files. If the search is successful then raw-logs and data-logs are generated for each file type.

Raw-logs are used by the reporting unit to generate detailed graphs. These graphs show data in two minute intervals. The reason the raw-logs need to be created is to merge any separate files logged by the ESCo control system. As mentioned earlier, the log files are split when new components are added. The raw-logs then combine all these separate files into a single file in CSV format.

Data-logs are used to calculate the savings of the project. These files are similar to the raw-logs, but data are saved in one-hour intervals. The hourly average of each component parameter is calculated for each hour. This means that each component parameter consists of a series of 24 values $[x_0, x_1, \dots, x_{23}]$. Each value is calculated using Equation 2.1 and the collection of the 24 values is referred to as a 24-hour profile.

$$x_h = \frac{1}{n} \sum_{i=0}^{n-1} v_i \quad (2.1)$$

where n is the number of data entries v in hour h where $\{0 \leq h \leq 23; h \in \mathbb{Z}\}$.



The data-logs are also saved in CSV format. Unlike the raw-logs, the data-logs are not directly used by the reporting unit. These files are only used for the calculation of project savings. There are some advantages for saving these files. If project savings need to be recalculated with the same data, it is not necessary to reprocess the original files logged by the ESCo control system. Project savings for each project are stored in a database. Design considerations and requirements for the database are discussed in Section 2.5.5.

Calculating the savings

There are two types of compressed air DSM projects, namely peak clipping (PC) and energy efficiency (EE). To calculate the performance of a project, the actual energy usage of all compressors is measured against a baseline energy consumption. The baseline is a 24-hour power profile calculated before the implementation of the project and is given by $[b_0, b_1, \dots, b_{23}]$. Each value b_h is the average power consumption during a specific hour h .

The daily energy usage profile of the project is calculated by adding the power consumption of each compressor. The power profile of compressor i is calculated by Equation 2.1 and is given by $[x_{i0}, x_{i1}, \dots, x_{i23}]$. The energy usage profile is given by $[p_0, p_1, \dots, p_{23}]$ and calculated with Equation 2.2.

$$p_h = \sum_{i=0}^{n-1} x_{ih} \quad (2.2)$$

where n is the number of compressors and h represents each hour $\{0 \leq h \leq 23; h \in \mathbb{Z}\}$.

The daily energy impact of a project depends on the project type. Energy efficiency projects require a reduction in energy usage throughout the whole day and is calculated by

$$I_{EE} = \frac{1}{24} \sum_{h=0}^{23} (b_h - p_h) \quad (2.3)$$

where b_h represents the baseline and p_h the energy usage profile values at hour h . Peak clipping projects require a reduction in energy usage only during the Eskom's evening peak periods. That is an energy reduction from 18:00 to 20:00 or during hours 18 and 19 and is given by

$$I_{PC} = \frac{1}{2} \sum_{h=18}^{19} (b_h - p_h) \quad (2.4)$$

where b_h represents the baseline and p_h the energy usage profile values at hour h $\{18 \leq h \leq 19; h \in \mathbb{Z}\}$.

The financial impact for both types of projects is calculated throughout the whole day. In this way the financial saving is more accurate compared with the actual cost savings on the mine's electricity bill. The electricity tariffs can vary for each mine based on the transmission zone and the voltage of the supply. It also depends on the season and the time of day. Table 2.1 gives the active energy charge of the Megaflex tariff structure. The majority of mines are billed on the Megaflex tariff structure.

Table 2.1: Eskom's Megaflex electricity tariff structure for 2012/2013 [35]

Transmission zone	Voltage	Active energy charge (ZARc/kWh)					
		High demand season (Jun-Aug)			Low demand season (Sep-May)		
		Peak	Standard	Off Peak	Peak	Standard	Off Peak
$\leq 300\text{km}$	$< 500\text{V}$	247.85	64.36	34.34	69.14	42.34	29.58
	$\geq 500\text{V} \ \& \ < 66\text{kV}$	239.92	62.36	33.32	66.98	41.04	28.69
	$\geq 66\text{kV} \ \& \ \leq 132\text{kV}$	231.23	60.16	32.21	64.63	39.62	27.76
	$> 132\text{kV}$	223.19	58.15	31.14	62.42	38.32	26.86
$> 300\text{km} \ \& \ \leq 600\text{km}$	$< 500\text{V}$	250.29	64.97	34.70	69.81	42.70	29.86
	$\geq 500\text{V} \ \& \ < 66\text{kV}$	242.27	62.95	33.63	67.62	41.42	28.97
	$\geq 66\text{kV} \ \& \ \leq 132\text{kV}$	233.52	60.75	32.50	65.27	40.00	27.99
	$> 132\text{kV}$	225.38	58.70	31.43	63.05	38.68	27.09
$> 600\text{km} \ \& \ \leq 900\text{km}$	$< 500\text{V}$	252.77	65.62	35.00	70.49	43.13	30.12
	$\geq 500\text{V} \ \& \ < 66\text{kV}$	244.68	63.58	33.93	68.27	41.80	29.20
	$\geq 66\text{kV} \ \& \ \leq 132\text{kV}$	235.83	61.31	32.78	65.88	40.36	28.23
	$> 132\text{kV}$	227.60	59.25	31.71	63.66	39.20	27.35
$> 900\text{km}$	$< 500\text{V}$	255.28	66.23	35.32	71.12	43.51	30.40
	$\geq 500\text{V} \ \& \ < 66\text{kV}$	247.11	64.18	34.23	68.92	42.17	29.49
	$\geq 66\text{kV} \ \& \ \leq 132\text{kV}$	238.19	61.89	33.09	66.50	40.74	28.49
	$> 132\text{kV}$	229.88	59.78	32.01	64.23	39.40	27.57

Figure 2.13 shows the time-of-use (TOU) structure for the Megaflex tariffs. The electricity tariffs are, therefore, also a 24-hour profile given by $[t_0, t_1, \dots, t_{23}]$. For the purpose of this study a transmission zone less than 300 km and a supply voltage between 500 V and 66 kV are used. Using Table 2.1 and Figure 2.13 the weekday electricity tariffs are shown in Figure 2.14. The daily financial saving in South African Rand (C_{ZAR}) for a DSM project is given by

$$C_{ZAR} = 100 \sum_{h=0}^{23} t_h(b_h - p_h) \quad (2.5)$$

From Figure 2.13 it is obvious that the 24-hour tariff profile will differ depending on the day of the week. Saturdays, Sundays and weekdays have different values for $[t_0, t_1, \dots, t_{23}]$. Because

of this, the baseline of the project also differs depending on the day of the week. However, contractually DSM projects only have to achieve energy savings during weekdays. Therefore, only the weekday savings are taken into consideration when, for example, calculating the total savings for a monthly report.

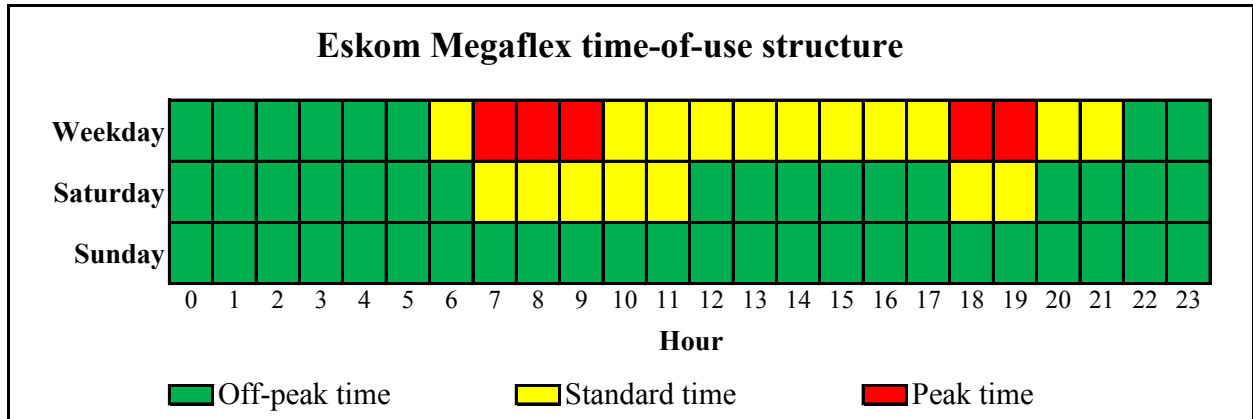


Figure 2.13: Eskom's Megaflex electricity Time-Of-Use structure

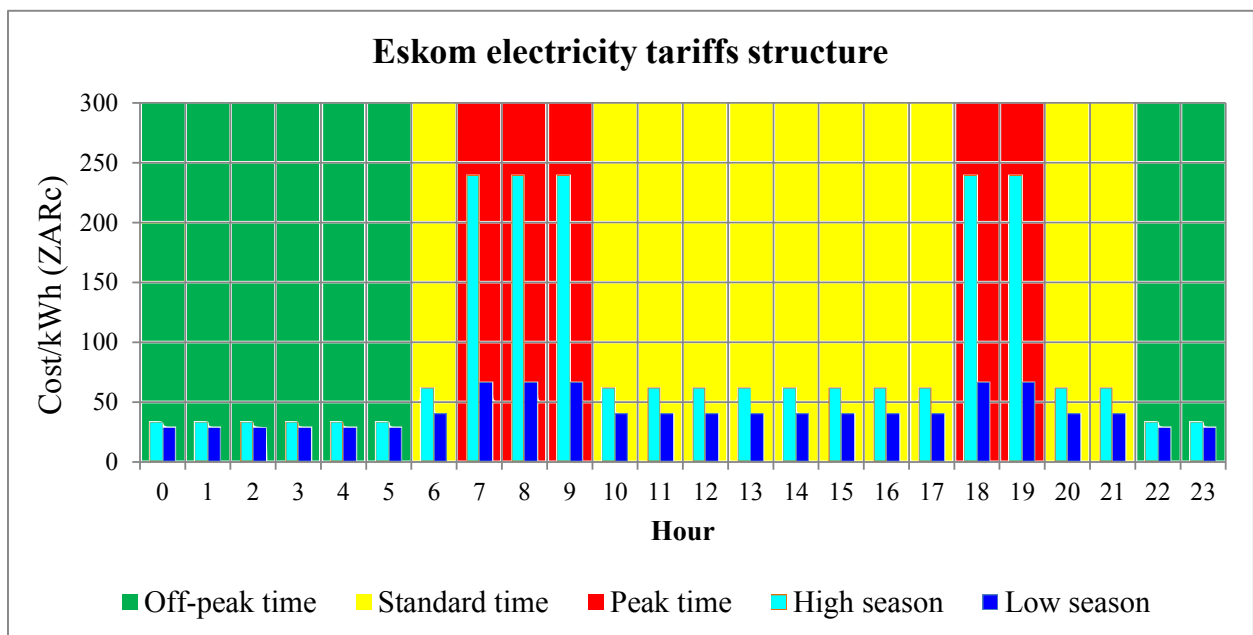


Figure 2.14: Eskom's Megaflex electricity tariffs for a weekday

2.5.5 Database design

There are a number of aspects to consider when choosing and designing a database. For this study, data volume, performance, security, cost and multiple user access are important. A DSM project can have a large amount of data that is logged by the ESCo control system each day. It is fortunately not necessary to save all the data. For minimal report requirements the daily data of a project only include the savings for the day, and two 24-hour profiles.

The database should be able to expand when more projects are added. Each new project will also accumulate more data every day over a number of years. The performance of the database should not be affected by the increase in data. Database design plays a big role in the performance of the database. "Even a good DBMS will perform poorly with a badly designed database" [36].

If the database is properly designed from the beginning, it will reduce the amount of performance tuning required in future. Database performance tuning is required to reduce the amount of time a Database Management System (DBMS) takes to execute a query [36]. This is a challenging and time-consuming task [37].

The project data will be available through the web-interface. This means that multiple authorised users should have access to the database at the same time. The database should be protected from unauthorised users. Unauthorised access is, however, not the only threat to database systems. There are many more potential threats to a database, as Rob summarised in his publication on database systems, shown in Figure 2.15 [36].

The database threats are grouped into four main categories: external, internal, natural disasters and poor database administration. External threats include viruses, hacking and fraud. Untrained employees and sabotage are two internal database threats. Disasters like floods, fires and power surges can damage or destroy the database hardware. Database security for both software and hardware is, therefore, imperative when designing a database.

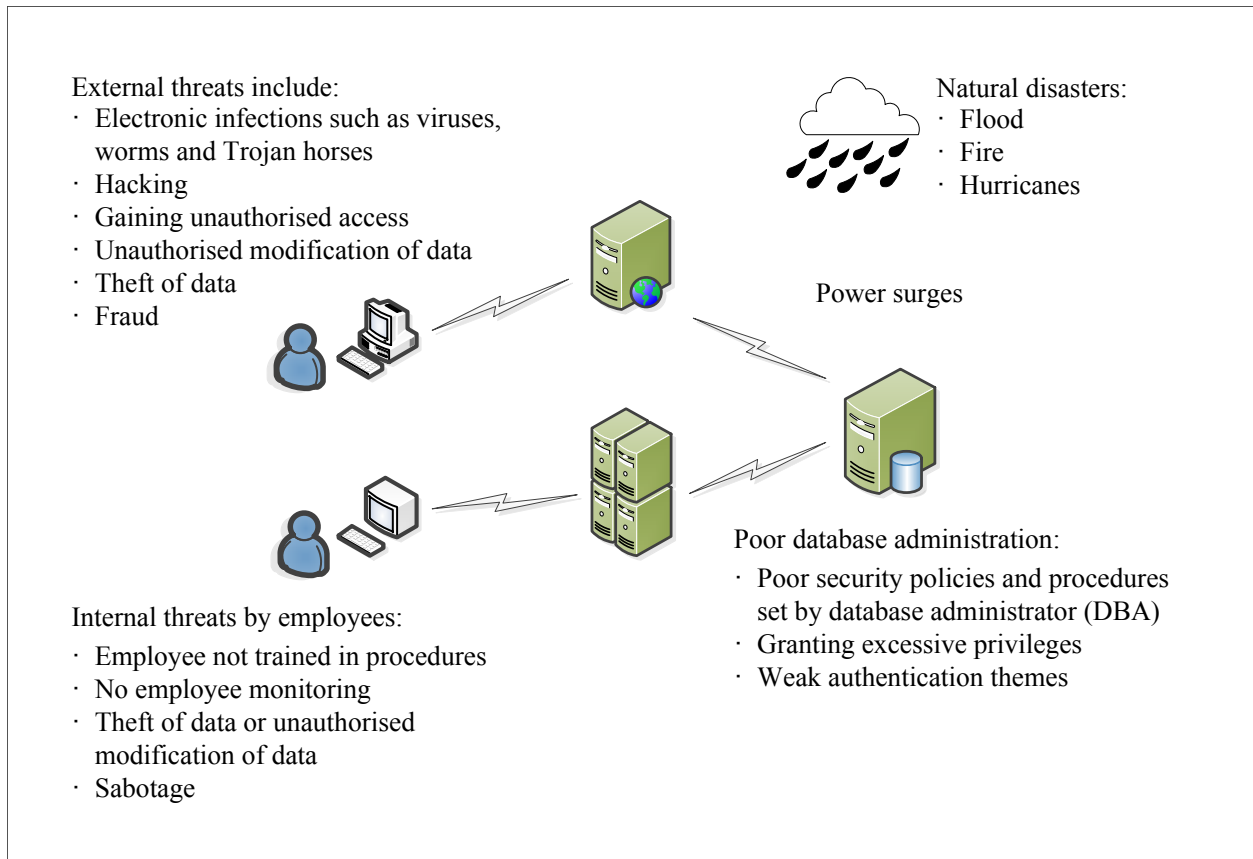
Figure 2.15: *Security threats to a database system* [36]

Table 2.2 shows a comparison of different database management systems. It is clear from the table that a compromise between different database features is necessary. As mentioned above, database size is important, which makes the Express editions of Oracle and Microsoft SQL Server potential future risks.

Table 2.2: *Comparison of different Database Management Systems (DBMS)*

Database	Edition	Cost	License	Database size	Security	Support
MySQL [38]	Community edition	Free	GPL	Unlimited	Medium	No
	Standard edition	US\$ 2 000 p.a.	Proprietary	Unlimited	Medium	Yes
PostgreSQL [39]	-	Free	PostgreSQL	Unlimited	High	Optional
Oracle [40]	Express edition	Free	Proprietary	4 GB	Medium	No
	Standard edition	US\$ 9 744 p.a.	Proprietary	Unlimited	High	Yes
SQLite [41]	-	Free	Public Domain	128 TB	Low	Optional
Microsoft SQL Server [42]	Express edition	Free	Proprietary	4 GB	Medium	No
	Standard edition	US\$ 7172 p.a.	Proprietary	512 PB	High	Yes

Cost is also a major factor. Commercial database management systems are expensive as shown in Table 2.2. Dedicated support is available for these commercial systems, but support is not such a high priority. Because of the widespread use of free database management systems like MySQL, there is a vast amount of online support available. This makes a free DBMS very attractive.

Because there are very few differences between MySQL, PostgreSQL and SQLite, MySQL is used for this project. MySQL meets all the above mentioned needs for the database of the reporting system. More deciding factors for using MySQL include experience and familiarity, because it was used in previous ESCo software systems. MySQL has a General Public License (GPL). The GPL is a free software license, which gives the licensee the freedom to use and/or modify the software for any purpose [43].

Logical design of the database

Figure 2.16 shows an entity relationship diagram (ERD) of three tables in the database. These three tables contain the bulk of the data in the database. In the following paragraphs the table names are written in *italic*. The *project* table stores all basic project information regarding each project including the name of the project, the project target, the tariff structure type and the mining group. The primary key (PK) of the *project* table is also part of the composite keys in the *day_profile* and *day_saving* tables.

The *day_profile* and *day_saving* tables store the daily data of each project. As mentioned in Section 2.5.4, each project has a 24-hour baseline and a 24-hour energy usage profile for each day. These profiles are stored in the *day_profile* table. The primary key of this table is a composite of the project ID, the date and the name of the profile (i.e. baseline / energy usage). Each *project* entry can therefore have zero-to-many *day_profiles* entries, but each *day_profile* entry will only refer to one *project*.

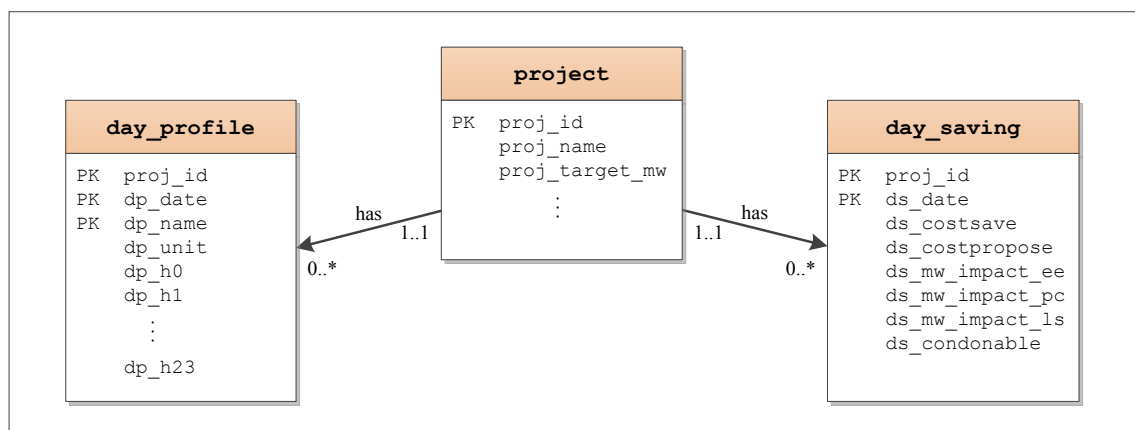


Figure 2.16: *Partial ERD of the database*

Section 2.5.4 also mentions that the financial and energy impacts of each project are calculated every day. These savings are stored in the *day_saving* table. The primary key of this table is a composite key of the project ID and the date. Each *project* can therefore have zero-to-many *day_saving* entries, but each *day_saving* can refer to only one *project*.

There are many more tables in the database that are not mentioned here. This includes tables that define the tariff structure shown in Table 2.1. There are also user and user-rights tables that store user information to allow them access to the web-interface. With all the data of all the projects stored in one database it is easy to generate useful reports.

2.5.6 Report generation and distribution

Reports are generated to give feedback on the performance of DSM projects. The reports are then distributed to relevant mine personnel and ESCo engineers via email. Distributing each report to a number of people limits the physical specifications of the reports. Each report should be as small as possible. A small report means less data to attach to each email.

Each person receiving a report should be able to open the file and read its contents. The reports are generated in the Portable Document Format (PDF) to allow anyone to open it. In 2008, the PDF format became an ISO standard - ISO 32000-1 [44]. The PDF format allows electronic documents to be viewed or printed independent of the user's operating system or platform [44].

The reports should contain the minimum amount of information. Section 2.4 stipulates the specifications for each report. Daily reports contain very little information and can almost fit on one page. Because people will receive this report every day, a small report is more likely to be read. Appendix A shows an example of a daily report.

Monthly reports contain more information about each day of the month. However, the first page is similar to the daily reports, but summarised for a whole month. The monthly performance of the project can, therefore, be determined by only glancing at the first page. Thereafter, more detailed information and graphs are given. Appendix B shows an example of a monthly report.

Group reports follow the same principle as the monthly reports. First, tables containing the energy and financial impacts of each project is given. Thereafter, a short one-pager summary of each project is given on the subsequent pages. If the minimum information given in a daily, monthly and group reports are insufficient the user should be able to access more detailed information. Appendix C shows an example of a group report.

For more detailed information regarding the control and performance of a DSM project, a user-friendly web-interface was developed, also referred to as the web-application. The web-application only grants access to authorised mine personnel and ESCo engineers. Mine personnel will only have access to the web-application and project reports if they sign maintenance contracts.

The web-application allows the user to view daily and monthly overviews of each project. If more information for a specific project is required for a specific day, the user can access the raw-logs generated by the processing unit. Customised and detailed graphs of the raw data can be viewed in the web-application. The user can also generate PDF reports containing these graphs. The following sections give more detail about the processes involved during report generation and distribution.

Generating a report

All reports are generated with a similar set of steps. Figure 2.17 shows the basic reporting process. The process starts by receiving instructions to generate a report. The instructions include the type of report (i.e. daily, monthly or group), and the period or date. SQL queries are formulated in order to retrieve the data from the database.

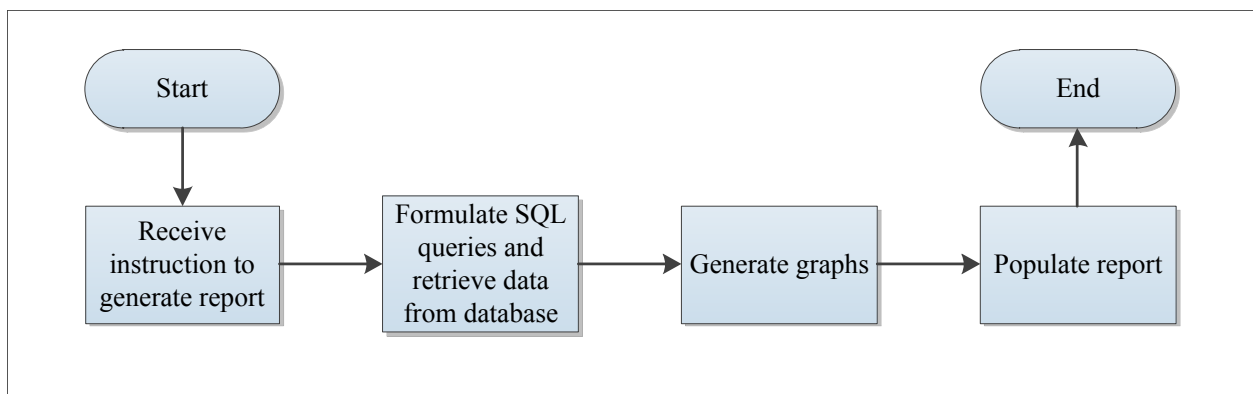


Figure 2.17: *Generating a report*

The SQL queries for the daily reports are relatively simple. Only the day savings and profiles of the project have to be retrieved from the database. Monthly reports use the SUM and AVERAGE SQL functions to calculate the total energy and financial impacts, and the average energy profiles for the whole month. SQL queries for group reports are more complicated, because the impacts and profiles need to be calculated for each project.

When all the data are retrieved from the database, the graphs for the report are generated. These graphs include power profile graphs, time-of-use graphs and monthly performance tracking graphs. Figure 2.18 shows a typical power profile graph. This graph gives the user an indication of how much energy was saved during which part of the day.

From Figure 2.18, for example, it is clear that the actual power profile is higher than the baseline from 06:00 to 08:00, by approximately 1 900 kW. This indicates a negative energy saving of 3.8 MWh for the two hours. The average difference between the profiles from 10:00 to 18:00 is approximately 4 900 kW, indicating a positive energy saving of 39.3 MWh for the 8 hours. The total energy saving for the day is 64.8 MWh.

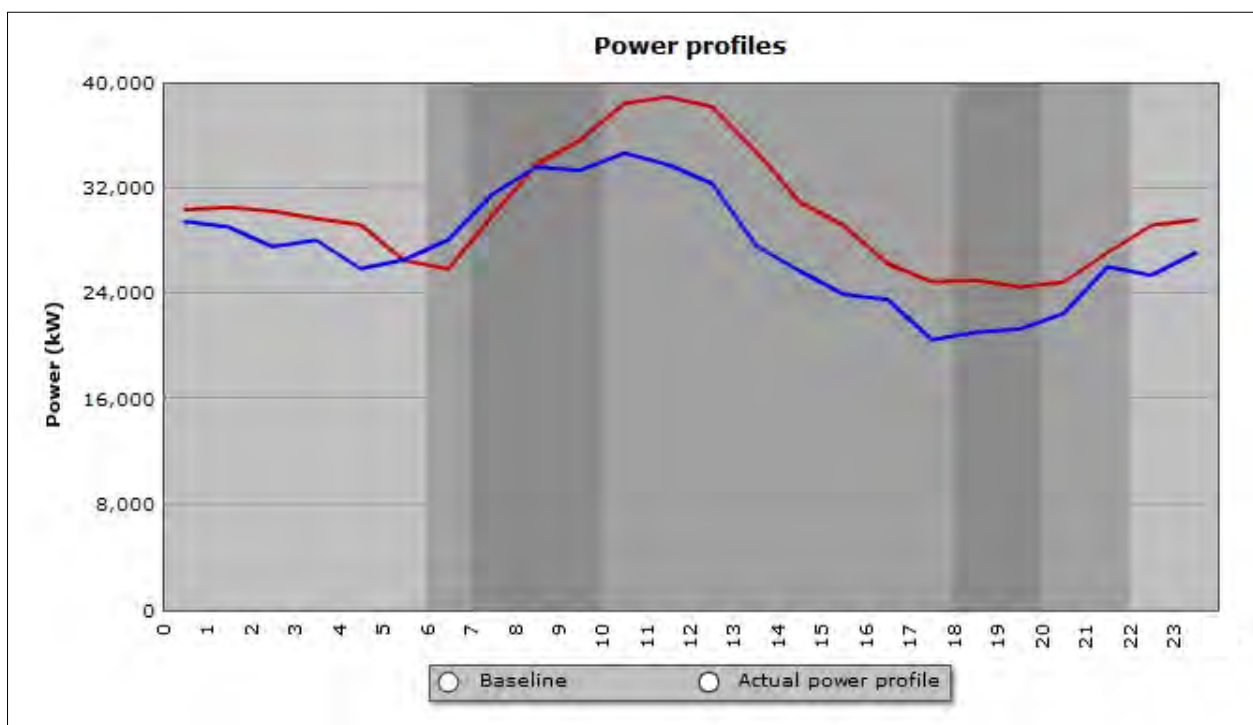


Figure 2.18: *Example of a power profile graph*

Figure 2.19 shows a typical time-of-use (TOU) comparison and consists of two pie charts. The first chart shows the percentage energy consumption for each Eskom billing period. The second chart shows cost of the energy consumed during each Eskom billing period. Comparing the two charts shows that although only 22% of the energy was consumed during the peak periods, the cost of the energy is 57% of the total cost.

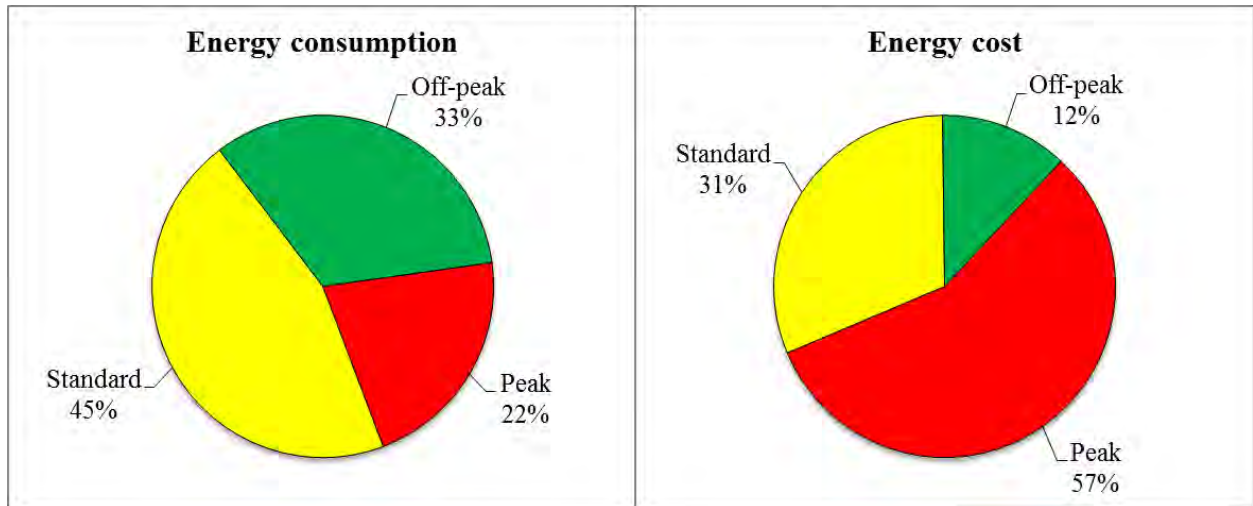


Figure 2.19: Example of a time-of-use graph for a winter weekday

Figure 2.20 and Figure 2.21 show typical performance tracking graphs for a whole month. Weekday and weekend data are shown in these graphs, although mines are only liable for weekday savings. Condonable days are not shown in the graphs. A day is marked as a condonable day if it disrupts normal mining activities, for example, public holidays, maintenance and system failures.

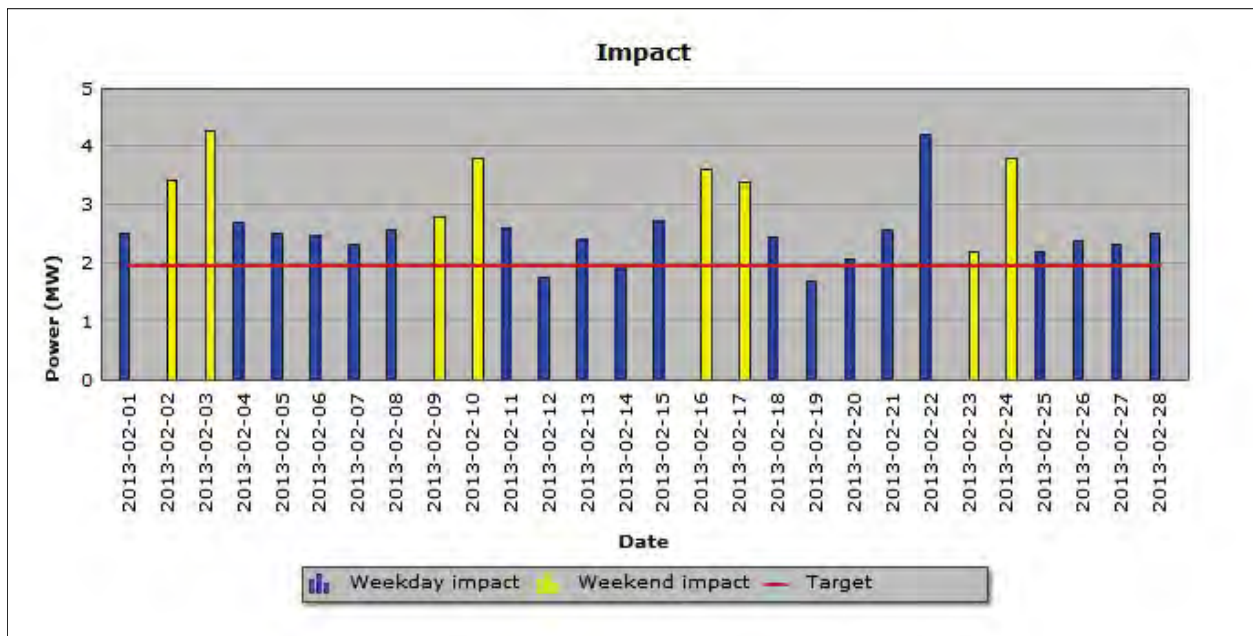


Figure 2.20: Example of a impact performance tracking graph

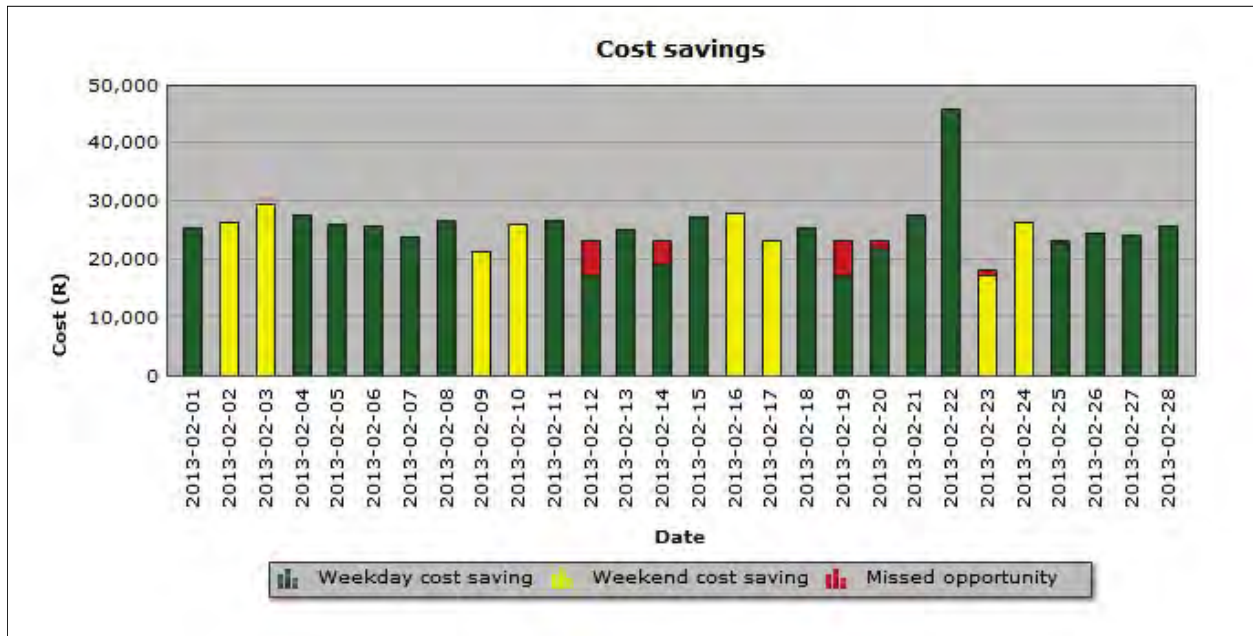


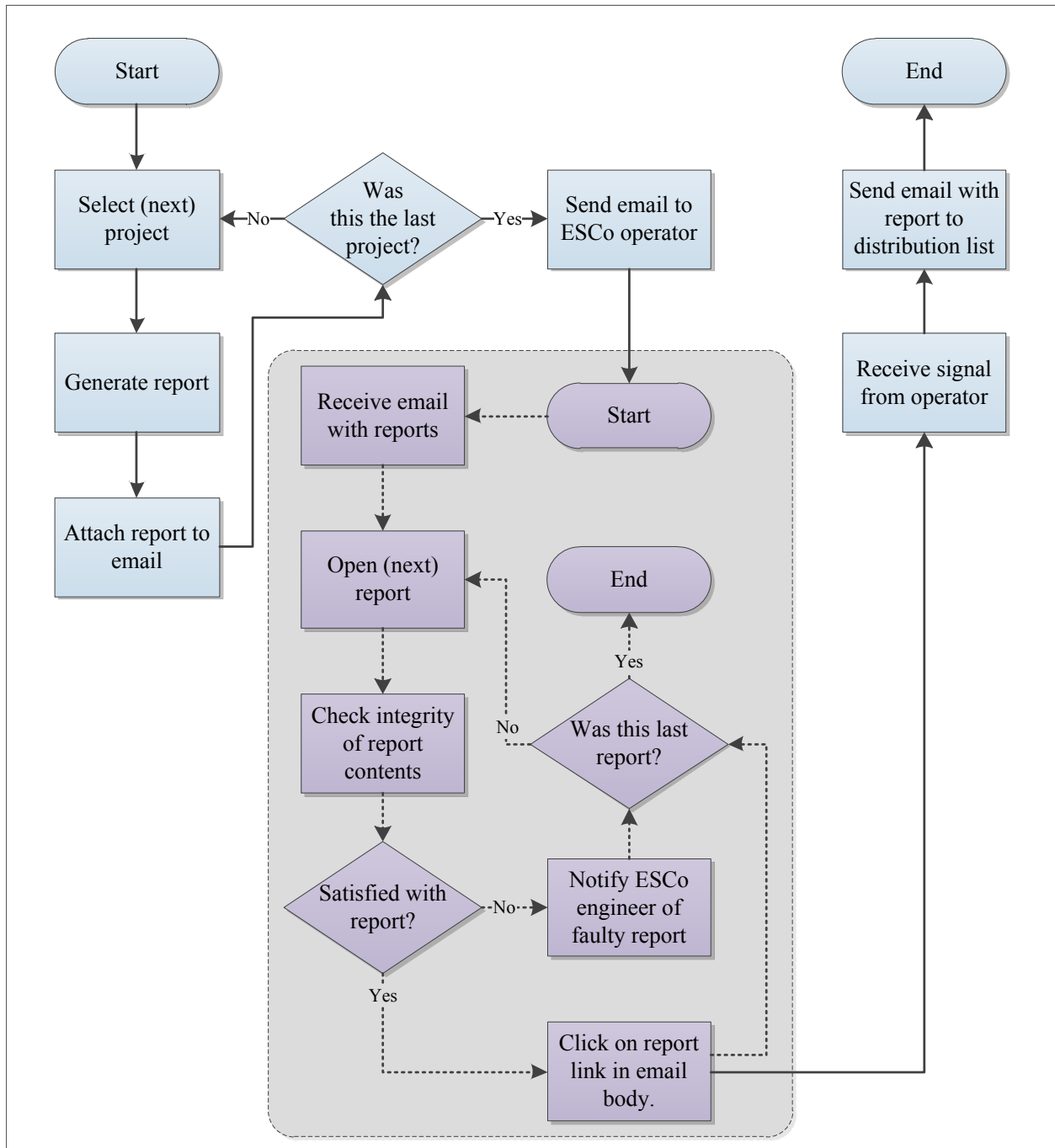
Figure 2.21: *Example of a financial performance tracking graph*

Figure 2.20 shows the actual energy impact of each day compared with the target saving of the project. This makes it easy to identify the over- and under-performing days. Figure 2.21 shows the cost savings and missed opportunities of each day. Missed opportunities are cost savings the project could have achieved if it did not under perform.

Distributing reports

All the reports should be checked before distributing them to mine personnel. Figure 2.22 shows the report distribution process. The report of each project is generated and attached to an email. The email is then sent to the an operator at the ESCo offices. The ESCo operator opens each PDF report and checks the integrity of the contents. When the operator is satisfied with the contents of the report, he/she clicks on the project's link in the body of the email. If the operator is not satisfied with the report, the relevant ESCo project engineer is notified.

When the report distribution unit receives the signal to distribute the report, the report is attached to an email and sent to the distribution list of the project. If the project did not achieve its target for the day, a message in the body of the email notifies the recipients that the project is under-performing.

Figure 2.22: *Distributing reports***Web-application**

The web-application makes it possible for authorised users to access the data of a DSM project. Users can also recreate day reports, month reports and group reports. Mine personnel must have maintenance contracts in order to access their DSM projects online. User rights are customisable for individual users. An instrumentation technician on a specific

mining shaft, may only have access to one project, for example. The energy manager of mining group may, however, have access to all the DSM projects of the mining group.

Apart from the functionality to recreate reports, the web-application also offers a number of web pages to view the data. Figure 2.23 shows a monthly overview of all the DSM projects in a mining group. The monthly performance of each project is colour coded. Green indicates that the average weekday performance of the month was higher than the project target. Red indicates under performance and grey indicates that no verified data are available for that month.

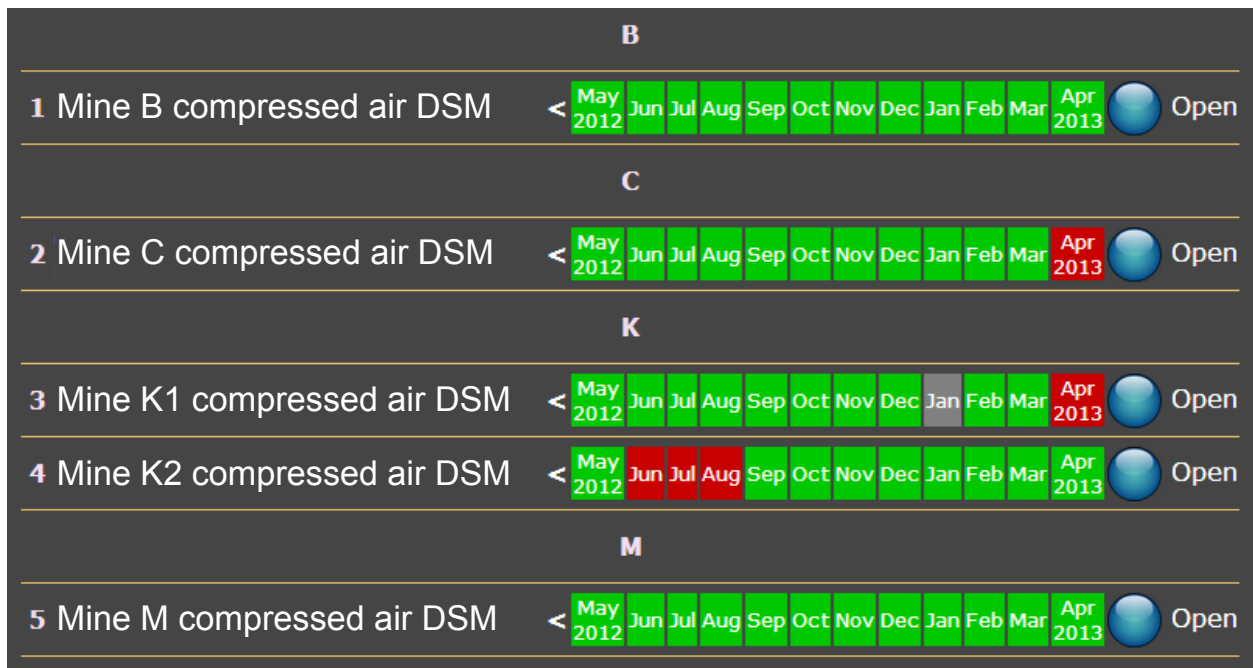


Figure 2.23: *Monthly overview of project savings*

The user can access more detail of a particular month by clicking on one of the coloured blocks. This opens a new page that shows the project performance, a power profile graph and a time-of-use graph. From this page the user can also generate the monthly report in PDF format. Figure 2.24 shows a daily overview of all the projects. The colours in this page is similar to the monthly overview, except for the orange colour which indicates a condonable day.

For more detail of a specific day, the user can click on the coloured block for that day. Similar to the monthly overview, this also opens a new page that shows the performance of the project, a power profile graph and a time-of-use graph. In addition to creating the report in PDF format, the user can also access the raw data of the project. The raw data of the project enable the user to create custom graphs for specific components in the compressed air system. Figure 2.25 shows an example of such a graph.

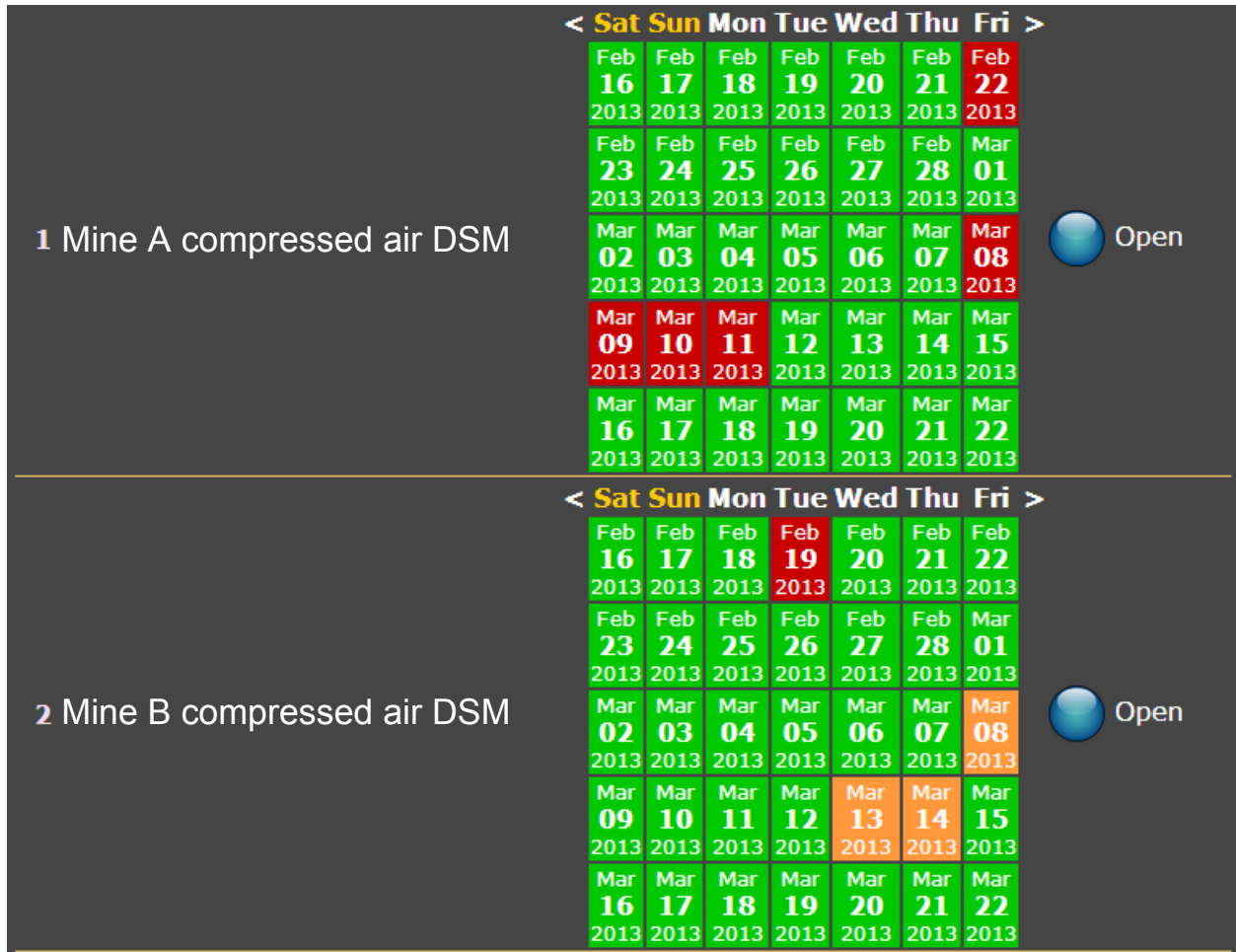
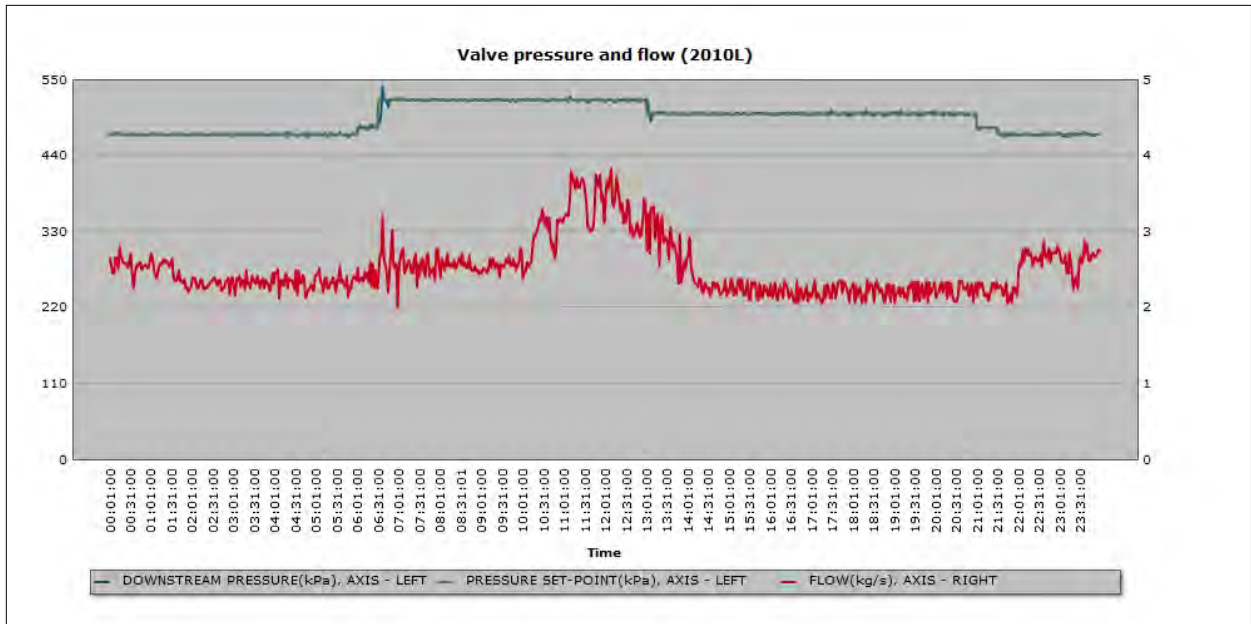


Figure 2.24: Weekly overview of project savings

The graph in Figure 2.25 compares the downstream pressure, the pressure set-point and the air flow of a valve in the compressed air system. In this particular scenario, an electronically actuated valve in the compressed air system is controlled according to a downstream pressure set-point. From the graph the user can see when the pressure set-point changed and how the valve controller responded. There is a large variety of different graphs the user can create. Appendix D shows screen shots of the web-application.

Figure 2.25: *Valve control graph*

2.6 Conclusion

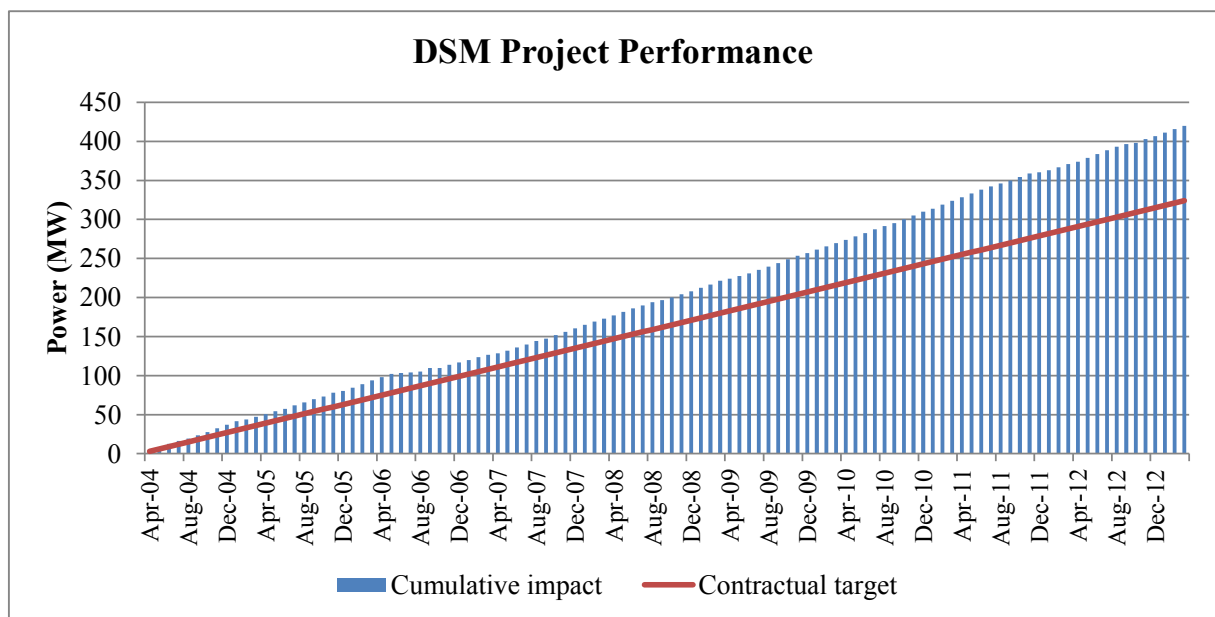
A new reporting system for compressed air DSM projects is developed. The needs for a new reporting system in the mining industry are investigated. User requirements and specifications are defined to ensure that all the needs are satisfied by the reporting system.

A typical mining environment is investigated to identify the hardware and software requirements to retrieve data of the compressed air system. Software requirements include modifications to the existing ESCo control system to log compressed air data. It also includes the implementation of a communication module to transmit the data. A router is required to send the data through a secure VPN, depending on the mine's network policies.

Data processing, storage and report generation are hosted on an off-site web server. This makes it accessible from anywhere. Reports are customisable in order to monitor compressed air projects with different layouts and circumstances. The reports are distributed on a frequent basis, which improves the efficient monitoring of mine compressed air systems.

Chapter 3

Results



Benefits of efficient monitoring of DSM savings

3.1 Preamble

In 2011 the ESCo implemented their control system on sixteen mine compressed air systems in South Africa. The aim of these control systems is to reduce the amount of compressed air used by the mines in order to reduce their electricity consumption. Automatic control valves were installed at each of the high compressed air demand sections in order to reduce the compressed air usage.

Two of the sixteen projects are selected as case studies. Both pressure and flow sensors had already been installed at various nodes in these compressed air networks. In each case study, one or two incidents are discussed to illustrate the efficiency of the reporting system. Due to confidentiality agreements the mines will be referred to as Mine A and Mine B.

A third case study is done on two other mines, referred to as Mine C and Mine D. The performances of these projects are measured and discussed. Before these case studies are discussed, the new reporting system is subjected to a number of tests.

3.2 Testing the reporting system

Three different processes in the reporting system are tested. Each day the reporting system creates a log file that records every step during the data processing procedure. Figure 3.1 shows an example log file created during the data processing procedure. The data in this file make it possible to calculate the elapsed time between each step. Using all the log files created in one month, the amount of emails received for each project can also be calculated.

The first test assesses the reliability of receiving project data from the mines. Table 3.1 shows the amount of data emails received from five projects during September 2012. The maximum number of emails for each project is 30, one for each day in September. An average of 98% of the data emails were received and processed.

```

2012-09-25, 01:30:00, --- SCHEDULER PROCESSING BEGIN ---
2012-09-25, 01:30:00, Engine: Get Messages Begin
2012-09-25, 01:30:00, 1 messages found with 'Mine 1 - Data Task' in subject.
2012-09-25, 01:30:00, Message 8400 with 'Mine 1 - Data Task' in subject added to message download list.
2012-09-25, 01:30:00, Message 8400: Attachment 1: Mine1 2012-09-24.zip
2012-09-25, 01:30:01, Message 8400 was downloaded and attachments were extracted successfully.
2012-09-25, 01:30:01, Message 8400 was deleted from the mail server successfully.
2012-09-25, 01:30:19, Engine: Get Messages End
2012-09-25, 01:30:19, Engine::Compile RAWLOGS for Mine 1 begin
2012-09-25, 01:30:26, Compiled rawlogs for Mine 1 on 2012-09-24 successfully.
2012-09-25, 01:30:26, Engine::Compile RAWLOGS for Mine 1 end
2012-09-25, 01:30:26, Engine::Compile DATALOGS for Mine 1 begin
2012-09-25, 01:30:28, Compiled datalog for Mine 1 on 2012-09-24 successfully.
2012-09-25, 01:30:28, Engine::Compile DATALOGS for Mine 1 end
2012-09-25, 01:30:28, Engine::Compile CALCLOGS for Mine 1 begin
2012-09-25, 01:30:28, Compiled calclog for Mine 1 on 2012-09-24 successfully.
2012-09-25, 01:30:29, Updated database for Mine 1 on 2012-09-24 successfully.
2012-09-25, 01:30:29, Compile CALCLOGS for Mine 1 end
2012-09-25, 01:32:53, --- SCHEDULER PROCESSING END ---

```

Date
Time
Message

Figure 3.1: *Example of a log file created during processing*Table 3.1: *Emails of five projects received in September 2012*

	Number of emails received (max. 30)	Percentage of emails received
Project 1	30	100.0%
Project 2	28	93.3%
Project 3	30	100.0%
Project 4	29	96.7%
Project 5	30	100.0%
Average	29.4	98.0%

Project 2 did not receive data emails for two consecutive days during September 2012. The reason for this was a communication failure between the SCADA and ESCo control system. This caused the ESCo control system to stop controlling the compressed air system. The control system also stopped recording data. A similar incident occurred with Project 4 and the data of one day were lost. For both projects these days are marked as condonable and are not used for the calculation of project savings.

For the second test the time required to process the data of the five projects is measured. Table 3.2 shows the average processing times over five days in September for each of the projects. The average time required to process the data for one of the five projects is 8.44 s.

Table 3.2: *Processing time results for five projects over five days*

	Download email and extract data	Generate raw logs	Generate data logs	Calculate savings and store in database	Total time
Project 1	2.2 s	14.6 s	2.4 s	0.6 s	19.8 s
Project 2	1.0 s	3.2 s	0.8 s	0.2 s	5.2 s
Project 3	1.0 s	3.2 s	2.4 s	0.4 s	7.0 s
Project 4	0.8 s	2.2 s	1.6 s	0.4 s	5.0 s
Project 5	1.0 s	3.6 s	0.4 s	0.2 s	5.2 s
Average	1.2 s	5.4 s	1.5 s	0.4 s	8.4 s

The processing time of Project 1 is more than double the average processing time. The reason for this relatively long processing time is the amount of data that is logged for Project 1. Compressed air data from two mine shafts are monitored for Project 1, increasing the amount of recorded data, which increases the processing time.

For the third and final test, the times required to generate the three different savings reports are measured. Log files similar to the example in Figure 3.1 are created when the reports are generated. Day and month reports have the same amount of information independent of the project. Generating a day or month report will, therefore, require approximately the same amount of time for all the projects. Examples of daily and monthly reports are shown in Appendix A and B, respectively. Table 3.3 shows the result of processing ten reports of each type.

Table 3.3: *Processing time for report generation*

	Day report	Month report	Group report
	3.7 s	5.3 s	22.0 s
	3.0 s	6.6 s	22.1 s
	3.5 s	5.4 s	23.9 s
	3.5 s	6.0 s	22.3 s
	3.1 s	5.5 s	21.0 s
	3.5 s	6.0 s	21.0 s
	4.1 s	5.5 s	21.6 s
	3.6 s	6.0 s	20.2 s
	3.7 s	5.2 s	22.7 s
	3.5 s	6.1 s	23.2 s
Average:	3.52 s	5.75 s	21.98 s

Group reports contain data for various different projects. For the purpose of this test, ten reports were generated for a group of nine projects. The average time required to generate the group report is 21.98 s. Day and month reports require average times of 3.52 s and 5.75 s to generate, respectively. Appendix C shows an example of a group report.

3.3 Case study A: Mine A

3.3.1 Background

At this mine, twelve underground levels were identified as large compressed air demand areas. Figure 3.3 is a schematic layout of this particular case study. The valves are electrically actuated and electronically controlled according to a downstream pressure set-point. Each valve set-point is assigned by the ESCo control system, depending on the particular pressure set-point schedule. A typical schedule used at Mine A, where drilling and cleaning operations require the highest pressures, is shown in Figure 3.2.

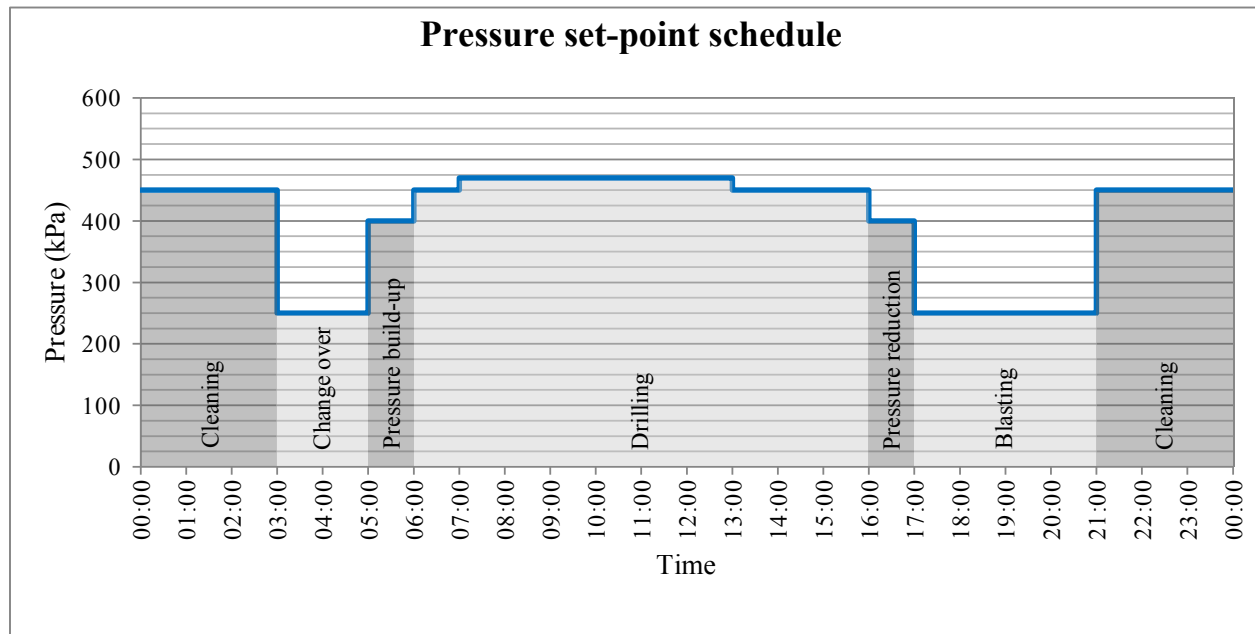


Figure 3.2: Weekday pressure set-point schedule for underground levels on Mine A

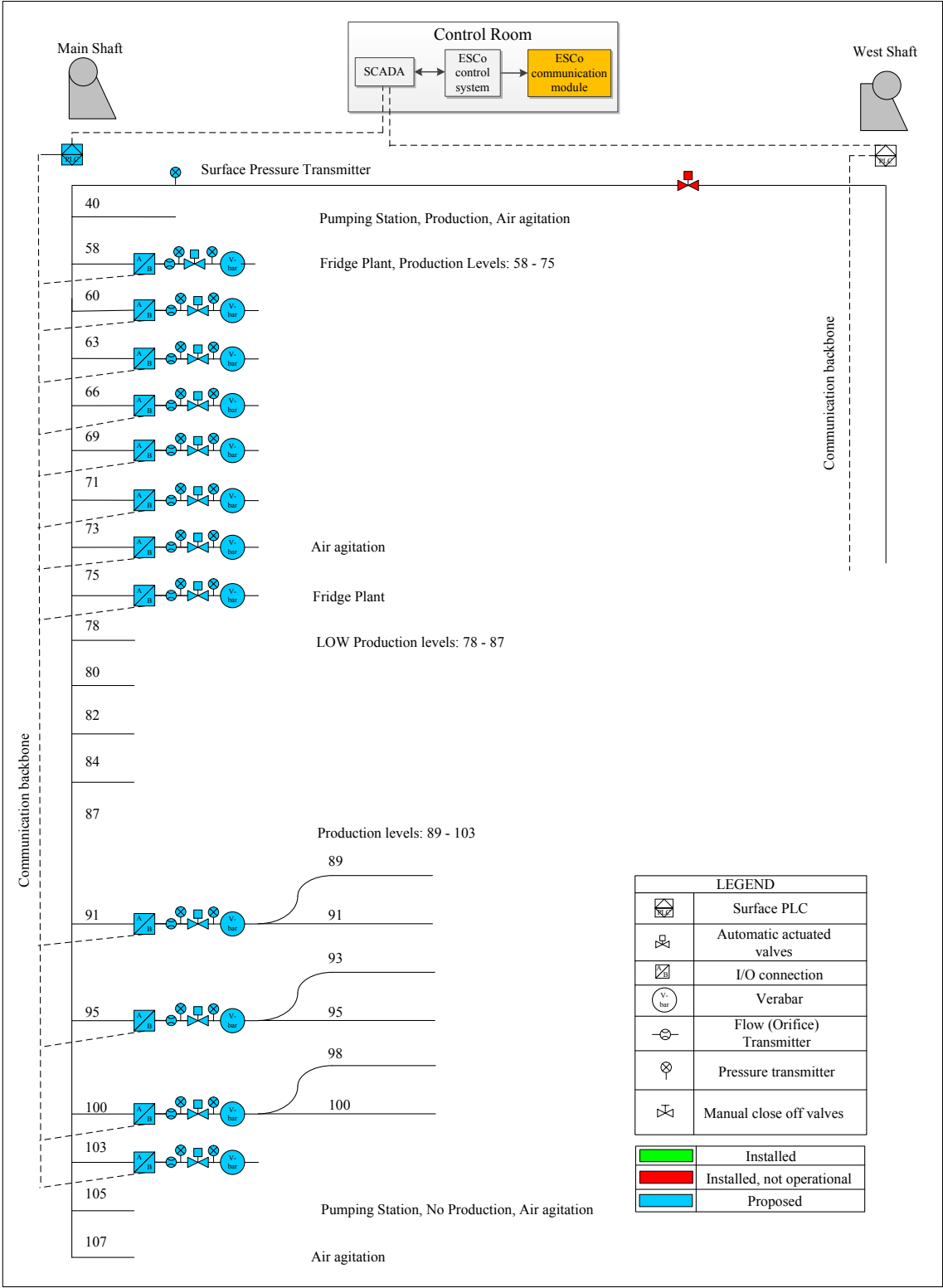


Figure 3.3: *Compressed air reticulation of Mine A*

3.3.2 Incident

On 13 May 2011 the airflow on 91 level increased by more than 500%. This increase in airflow is shown in Figure 3.4, which is the pressure and flow graph for 91 level. Figure 3.4 was generated through the web-site by the ESCo project engineer. The bar graph shown in Figure 3.5 emphasises the sudden increase in compressed airflow that occurred on 13 May. On this particular day, air usage of 466.8 tons was recorded, which is 451% more than the average weekday air consumption for the first twelve days of May.

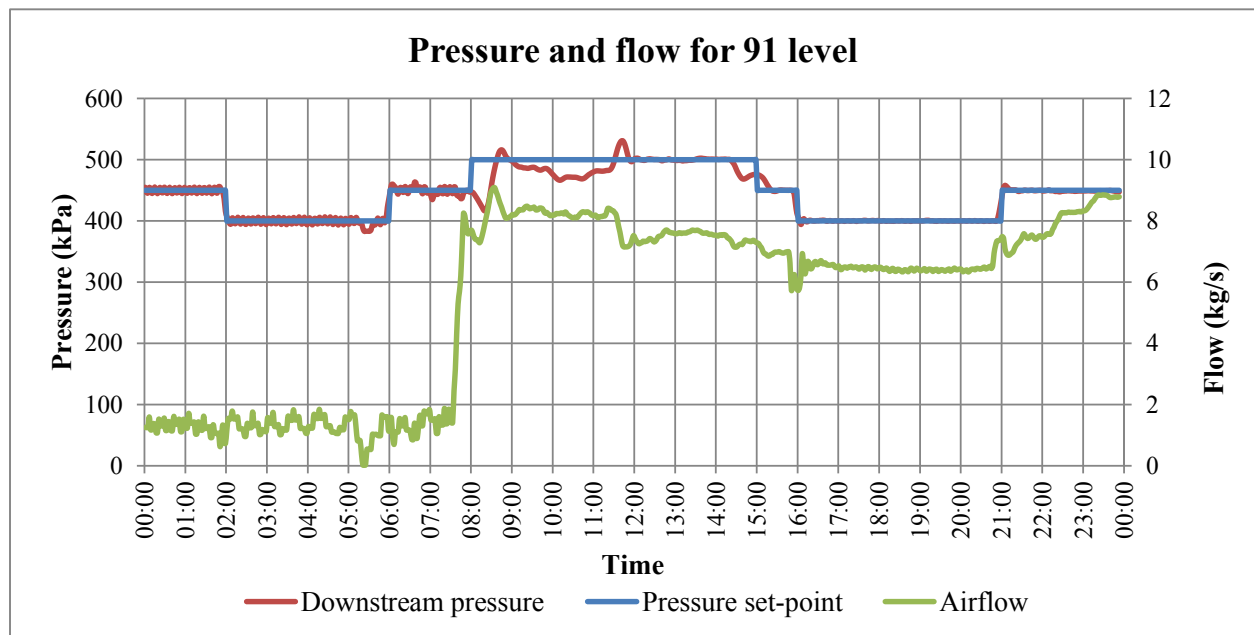


Figure 3.4: *Pressure and flow profiles for 91 level (13 May 2011)*

One possible cause for the increased airflow could have been a malfunctioning valve that remained fully open and did not respond to the pressure set-point control. However, when referring to the pressure profile of Figure 3.4, the actual pressure and pressure set-point appear to correlate well. This indicates correct valve control.

The small fluctuations between 08:00 and 12:00 are a result of the high airflow demand required during the drilling period. An increase in the airflow during the drilling period means that the compressed air demand is higher than the supply. Without starting additional compressors the system cannot supply the high airflow at the pressure set-point, causing the system pressure to drop. This pressure deviation will, therefore, be present throughout the whole compressed air network until more compressors are started.

It is unlikely for an increase in production on one mining level to abruptly require more than four times the usual compressed airflow. If increased production were the cause for the

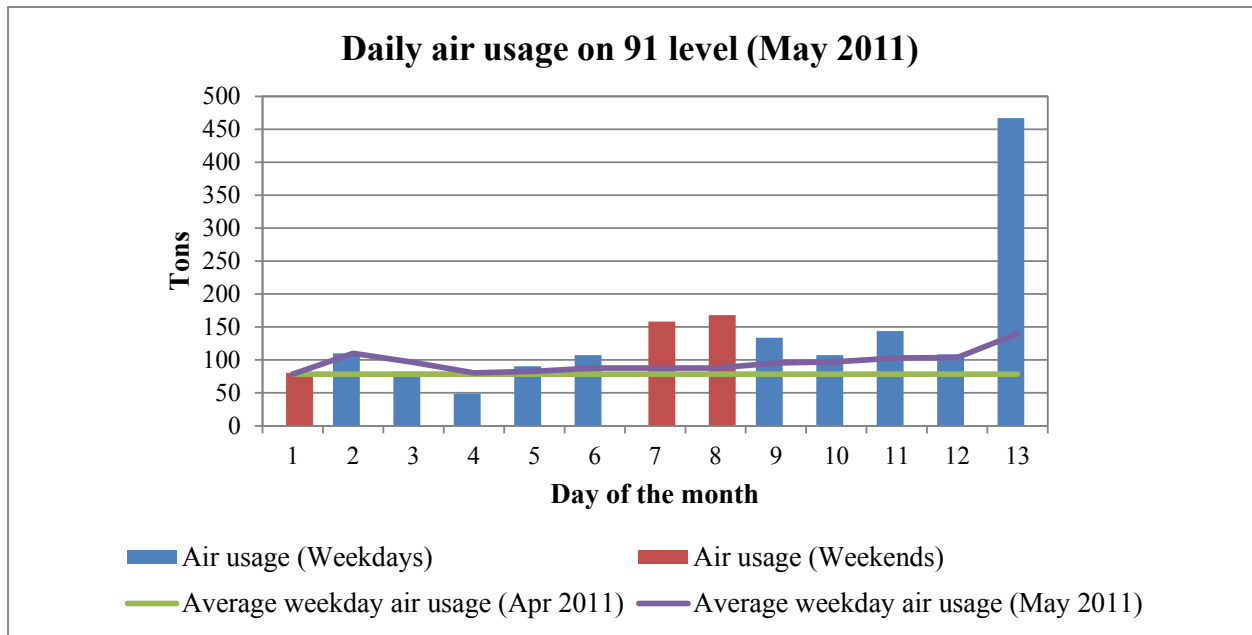


Figure 3.5: *Daily air usage on 91 level (13 May 2011)*

increased airflow, the airflow should then significantly decrease during the blasting period. However, this is not the case. An air leak is, therefore, a more likely explanation because of the sharp increase of more than 500%.

The sudden increase in airflow occurred on a Friday and was only reported the following Monday. A few days later an inspection was made to determine the cause and an air leak was found on 91 level. Figure 3.6 shows the daily air usage on 91 level for the entire month of May 2011. The leak was only repaired 13 days after it was found.

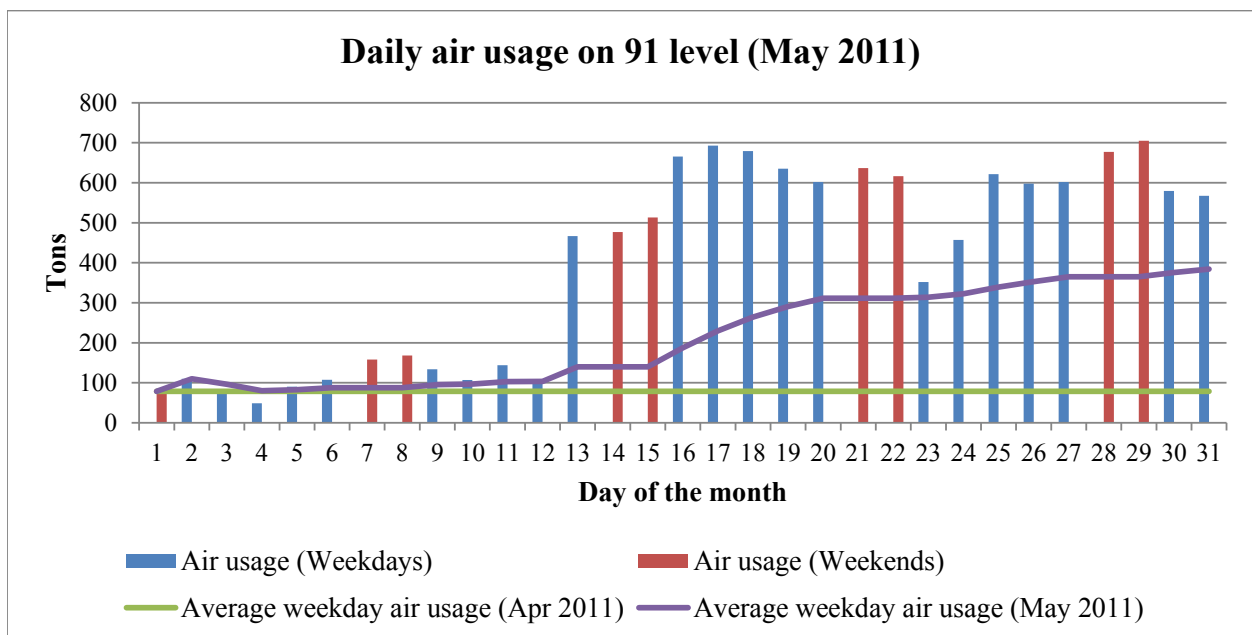


Figure 3.6: *Daily air usage on 91 level (31 May 2011)*

The effect of this leak is also evident in the energy savings data. An average weekday energy saving of 26.6 MWh per day was achieved until 12 May 2011. Thereafter, the average weekday energy savings dropped by 9.1 MWh per day to 17.5 MWh per day. Using an average of 31 c/kWh (summer tariffs), the loss in cost savings is calculated as R 2 821 per day. The total loss for the month is then R 36 673 for the thirteen workdays until the leak was repaired.

With the help of the reporting system it was possible to detect the leak in a short period of time. The leak was fixed at the beginning of the Eskom winter period, on 1 June 2011. During this period, electricity is substantially more expensive than the summer period. If the leak was not fixed this early in the winter period, the daily loss in cost savings would have been 112% higher. Figure 3.7 shows the daily air usage on 91 level for June 2011.

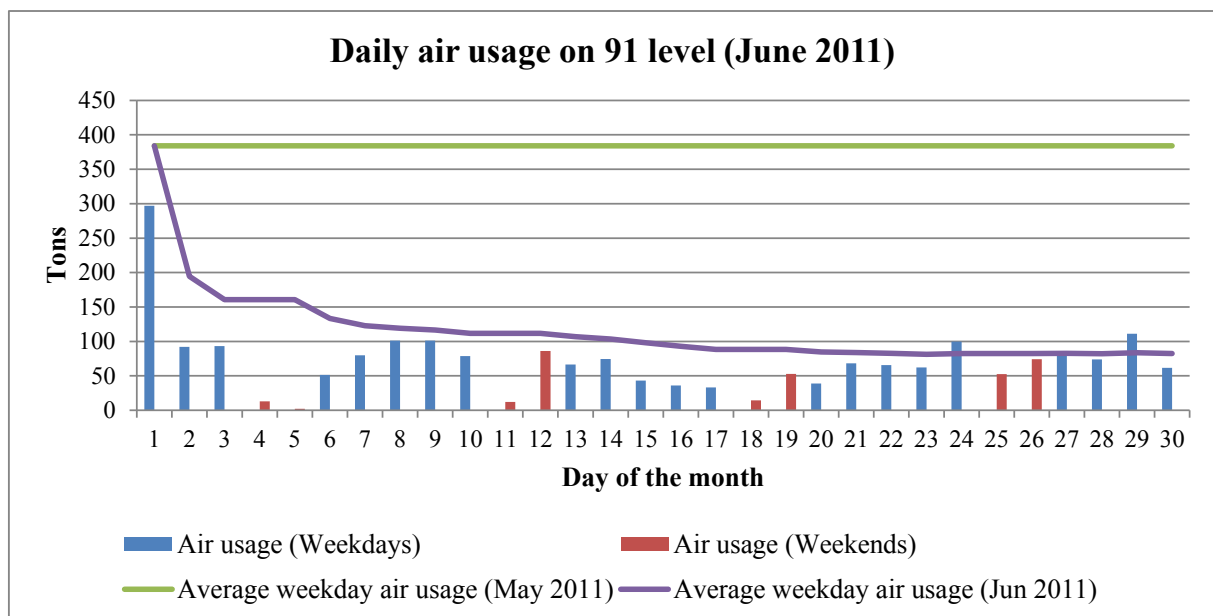


Figure 3.7: *Daily air usage on 91 level (30 June 2011)*

3.4 Case study B: Mine B

3.4.1 Background

On Mine B, eight levels were identified as large compressed air demand areas. Similar to Mine A, the valves are controlled according to a downstream pressure set-point assigned by ESCo control system. However, the valves on Mine B are electronically controlled and pneumatically actuated. Pneumatic actuators are less expensive than electric actuators, but require an upstream pressure to ensure proper control. Figure 3.8 is a schematic diagram of

the compressed air system at Mine B.

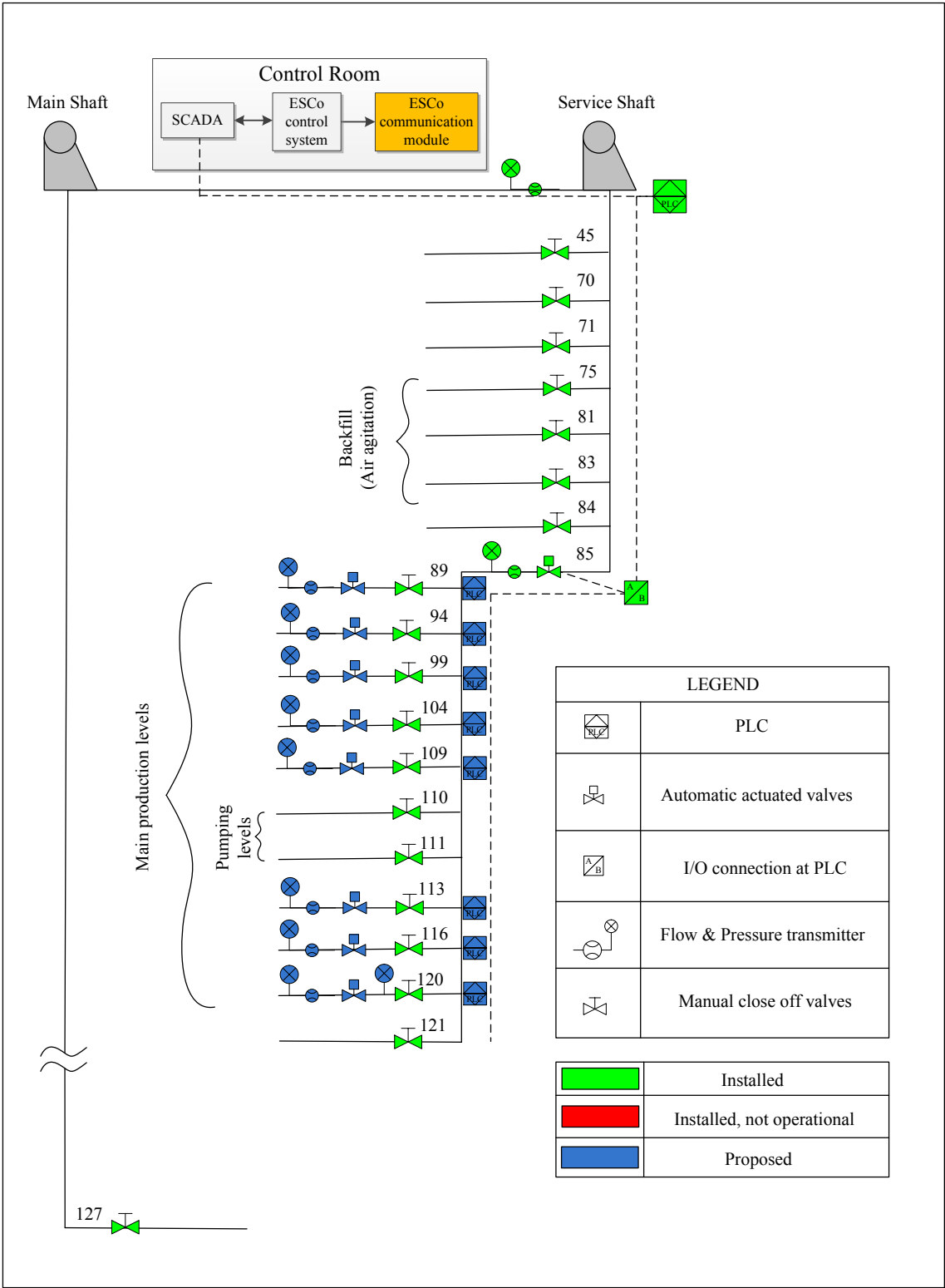


Figure 3.8: *Compressed air reticulation of Mine B*

3.4.2 Incident 1

Shortly after the implementation of the control valves on Mine B, some of the valves were not being correctly controlled. The valve on 104 level is used as an example. Figure 3.9 shows the pressure and flow profiles for 104 level. This graph was generated through the web-site by the ESCo project engineer.

During the first 14 hours of the day, the actual pressure and pressure set-point values correlate well. During the next eight hours, the pressure set-point for 104 level is 200 kPa. However, the actual pressure is only reduced to an average of 350 kPa. Note that the spike in the valve position at 23:00 is only the valve responding to the sudden increase of the pressure set-point value at that time.

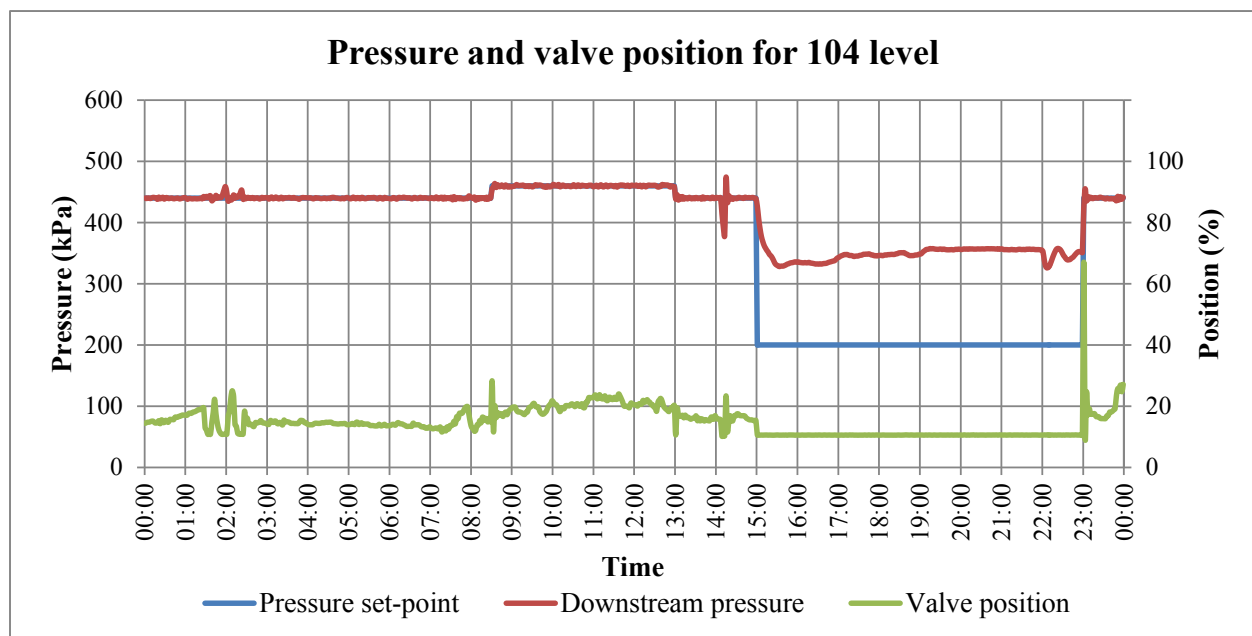


Figure 3.9: *Pressure and valve positions for 104 level (1 April 2011)*

After further investigation, it was found that a control limit for the valve position was set to a minimum opening of 10%. This is a necessary safety limit, implemented to maintain a minimum air pressure requirement for the refuge chambers. The chambers give refuge to miners during emergencies and require a minimum air pressure of 200 kPa, according to mining regulations of Mine B. However, on this particular level, the downstream air pressure is 350 kPa if the valve is 10% open.

Without the control limit on the minimum valve position, the valve could control closer to a 0% opening. This will allow the valve to control the downstream pressure closer to the 200 kPa pressure set-point, and still adhere to the mining regulations. However, if communication to the actuator fails when the valve is fully closed, it will stay in that position

until communication is re-established. The downstream pressure will then decrease regardless of the pressure set-point and the refuge chambers will not have sufficient air pressure.

In order to optimise the compressed air energy saving, the minimum limit of the valve was reduced. By changing the limit, the valve can control more closely to the pressure set-point. Figure 3.10 shows the control of the valve with a minimum opening restriction of 5%. The valve controls the downstream pressure at an average of 250 kPa, which is 100 kPa less than the original setup and 50 kPa more than the air pressure requirements for the refuge chambers. To quantify the additional savings, the two scenarios are compared in Table 3.4.

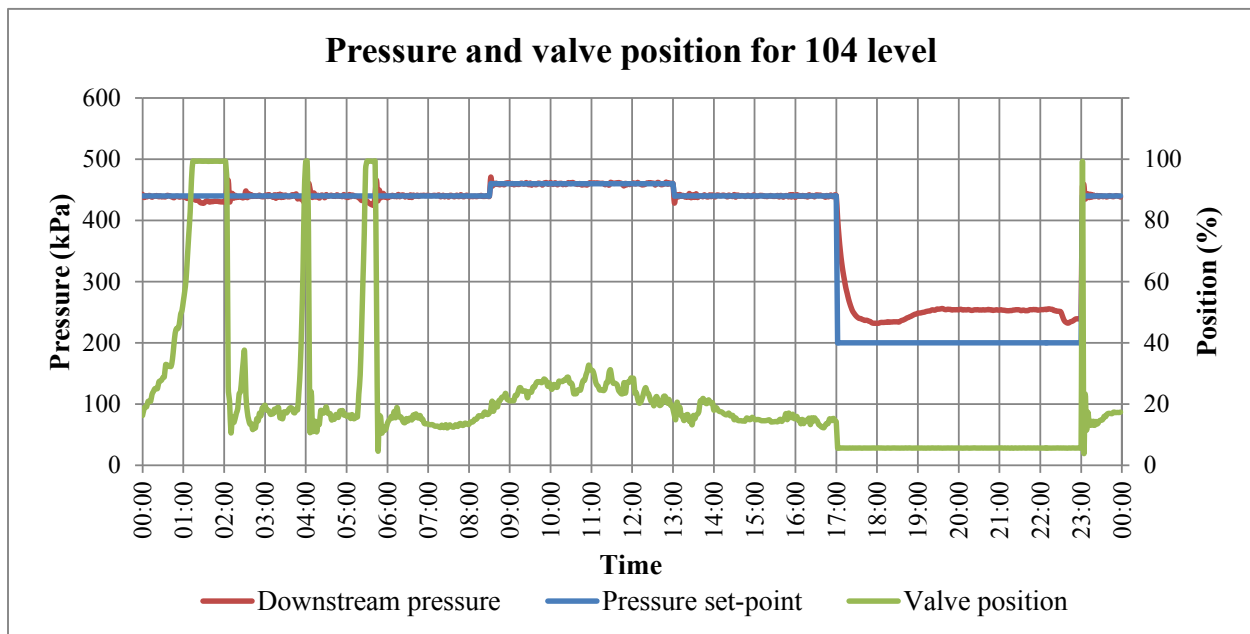


Figure 3.10: *Pressure and valve positions for 104 level (10 May 2011)*

Table 3.4: *Comparison between two different valve setups*

	Minimum valve position	Minimum actual pressure	Airflow	Energy usage per day	Energy cost per day (summer)	Energy cost per day (winter)
Original setup	10%	350 kPa	2.07 kg/s	11.41 MWh	R 3 537	R 7 530
Adjusted setup	5%	250 kPa	1.78 kg/s	7.44 MWh	R 2 306	R 4 910
Difference (saving)	-	100 kPa	0.29 kg/s	3.97 MWh	R 1 231	R 2 620

Note that the aggressive changes in valve position between 01:00 and 06:00 in Figure 3.10 is only the valve responding to the difference in the actual downstream pressure and the pressure set-point. Higher air demands cause the downstream pressure to decrease, which causes the valve to open in order to increase the air pressure to the selected pressure set-point.

3.4.3 Incident 2

On 6 March 2011 the valve on 109 level was controlling according to the pressure set-point. It was, however, restricted by the minimum valve position of 10% discussed in paragraph 3.4.2 (see Figure 3.11). This graph was generated through the web-site by the ESCo project engineer. At 22:00, the pressure set-point changed from 200 kPa to 440 kPa. The valve opened 100% in order to increase the downstream pressure. However, when the downstream pressure increased beyond the assigned set-point the valve did not respond.

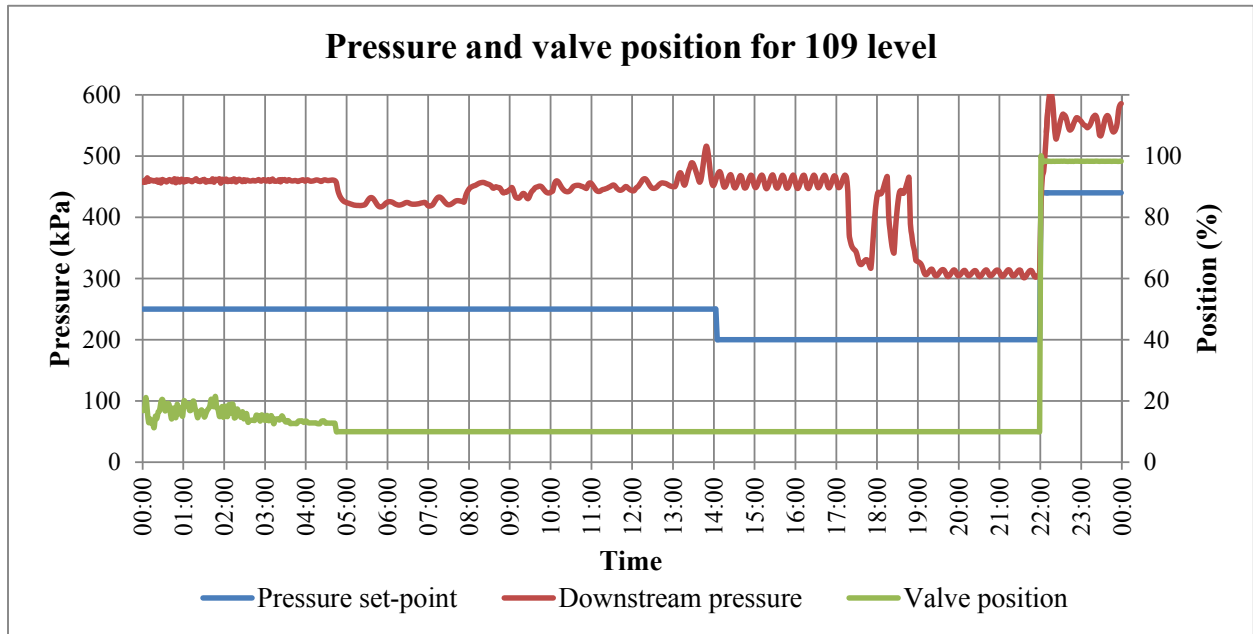


Figure 3.11: *Pressure and valve position for 109 level (6 March 2011)*

This valve continued to malfunction the following day as shown in Figure 3.12. The average downstream pressure for the day was 568 kPa which is 100 kPa higher than the set-point. After 20:00, the pressure peaked and reached a maximum of 658 kPa.

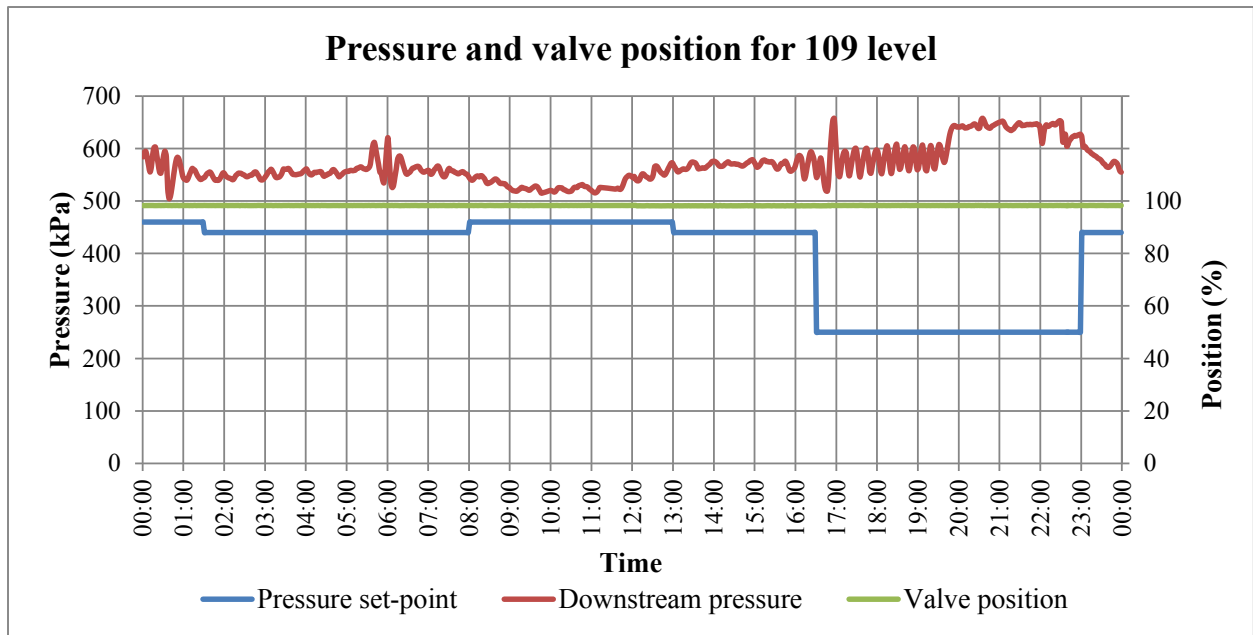


Figure 3.12: *Pressure and valve position for 109 level (7 March 2011)*

After further investigation on 11 May 2011, it was found that the position feedback sensor of the valve malfunctioned. This caused the valve to be positioned in default fail-safe position, which is the fully open position. Figure 3.13 shows that at 08:30, the valve actuator was reset and started to control the downstream pressure according to the set-point. However, at 23:00 when the pressure set-point increased from 250 kPa to 440 kPa, the position feedback sensor malfunctioned again and the valve returned to the fail-safe position.

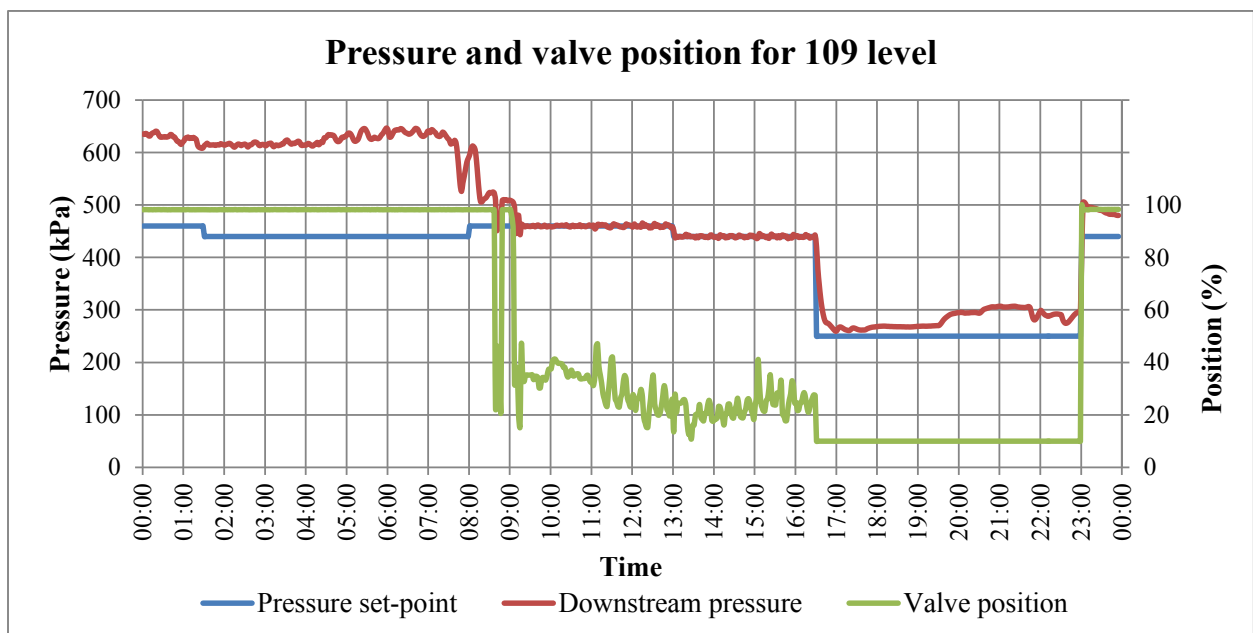


Figure 3.13: *Pressure and valve position for 109 level (11 March 2011)*

This incident repeated itself a few times before the valve was physically inspected. During the inspection it was found that water had entered the position feedback sensor. Whenever the pneumatic valve approached the fully open position, the electronic position feedback sensor transmitted a signal that appeared to be out-of-range. The specified range of the feedback signal is between 4 mA and 20 mA. If the signal is out-of-range, the valve enters the fail-safe-mode and remains in the fully open position.

The water vapour content in the compressed air was the cause of the moisture in the position feedback sensor. To mitigate this problem the mine installed additional air dryers. This not only enables the valve to control more reliably, but also protects other pneumatic equipment from potential water damage. Additional air dryers were also installed on other levels as a precautionary measure. Table 3.5 shows the estimated amount of energy and cost savings that were lost because of the malfunctioning valve.

Table 3.5: *Loss in savings due to malfunctioning valve*

	Average daily pressure	Average daily airflow	Energy usage per day	Energy cost per day (summer)	Energy cost per day (winter)
Non-controlling valve	568 kPa	5.31 kg/s	39.45 MWh	R 12 230	R 26 038
Controlling valve	435 kPa	4.52 kg/s	28.81 MWh	R 8 931	R 19 014
Difference (lost saving)	133 kPa	0.79 kg/s	10.64 MWh	R 3 299	R 7 023

3.5 Case study C: Mine C and Mine D

3.5.1 Background

In this case study the performance of two compressed air DSM projects are investigated. The projects are referred to as Mine C and Mine D. A group report is generated, which includes performance data of both Mine C and Mine D.

3.5.2 Mine C

The cumulative performance of Mine C for twelve months ending March 2013 is shown in Figure 3.14. It is clear from this graph that the project over-performed consistently each month. The average weekday energy impact for this period was 3.84 MW. This resulted

in a cumulative energy saving of 23.6 GWh per annum and a cumulative cost saving of R 16.6 million per annum.

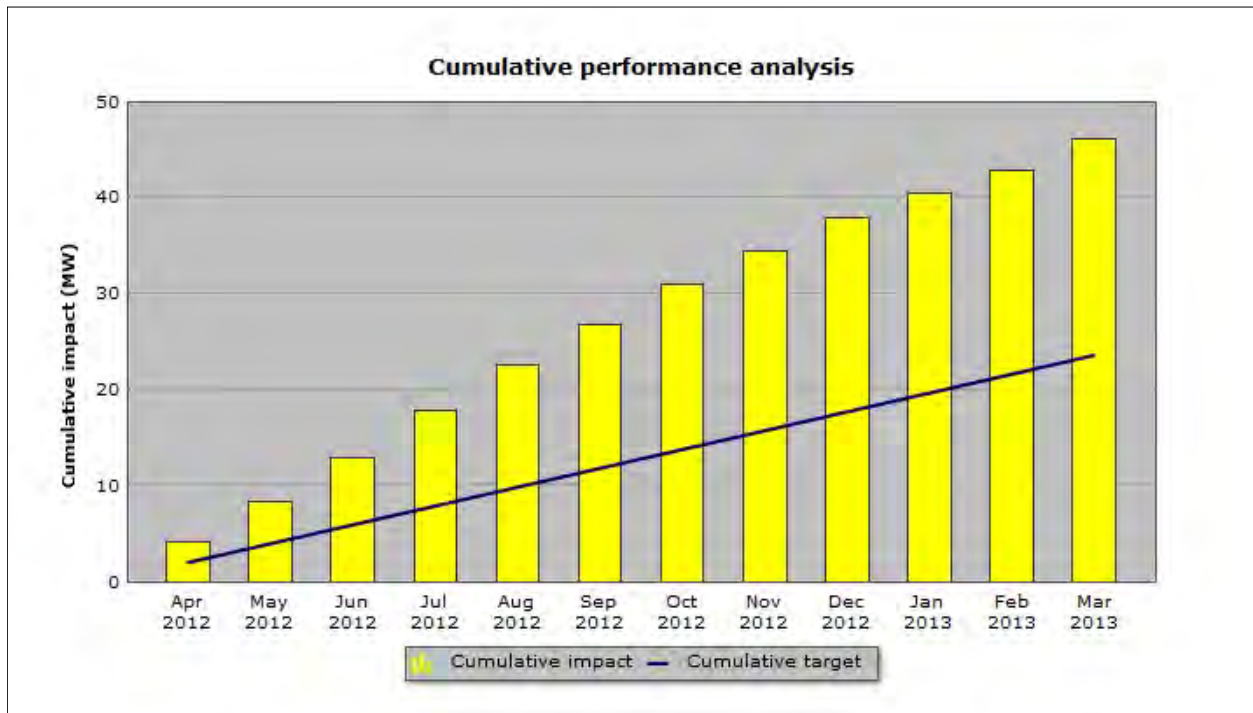


Figure 3.14: *Cumulative performance analysis of Mine C for the year ending March 2013*

3.5.3 Mine D

The cumulative performance of Mine D for fifteen months ending March 2013 is shown in Figure 3.15. It is clear from this graph that the project over-performed consistently for the first five months. From June to August 2012, however, the project only achieved 84% of its target savings. From September 2012 to March 2013 the project over-performed.

The average weekday energy impact for the fifteen months was 8.01 MW. A cumulative energy saving of 61.5 GWh and a cumulative cost saving of R 40.8 million was achieved during the fifteen month period. This is equivalent to a cumulative energy saving of 49.2 GWh per annum and a cumulative cost saving of R 32.6 million per annum.

From September to December 2012 the project did, however, achieve abnormally high savings. The average impact for this period was 15.28 MW, which is 358% higher than the target impact. This high energy saving can be attributed to strikes and not only the intervention. In 2012, South African mines were overwhelmed by striking mine workers demanding higher wages. This caused a lot of mines to reduce production or even close completely for this period.

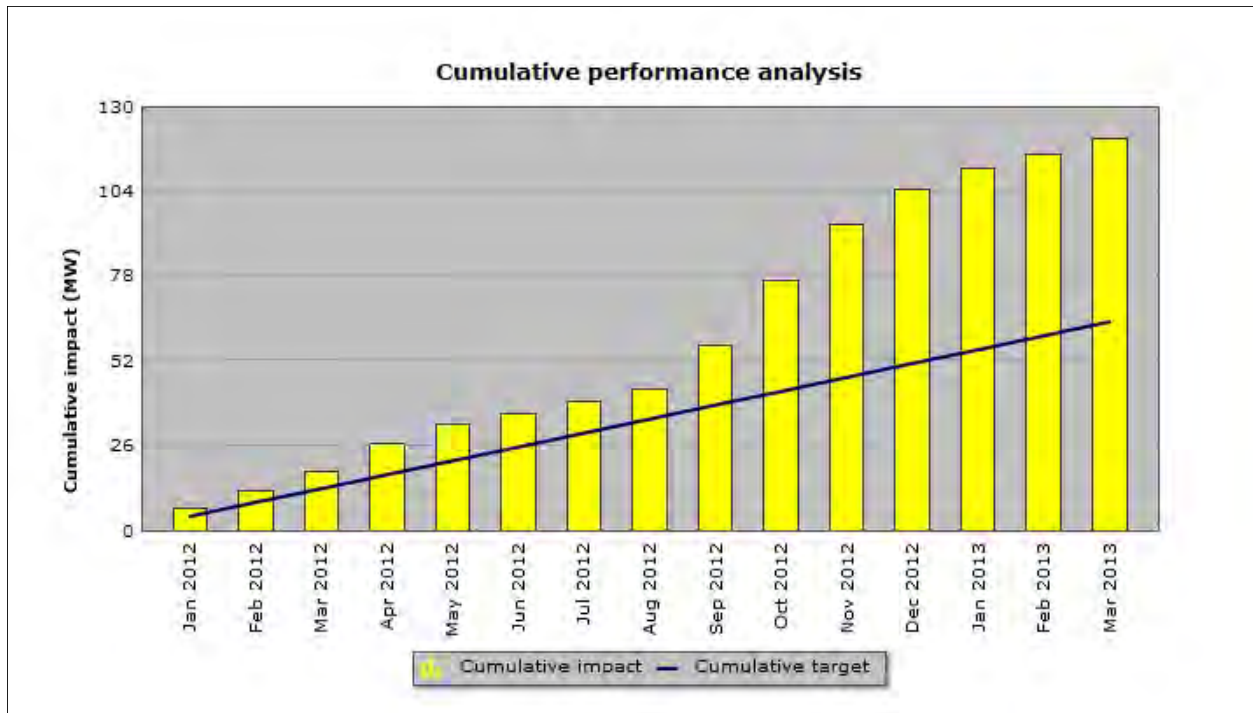


Figure 3.15: *Cumulative performance analysis of Mine D for the year ending March 2013*

3.6 Conclusion

In Section 2.4 the specifications for the new reporting system were stipulated. Table 3.6 shows the list of specifications. All the design specifications have been implemented in the new reporting system.

During September 2012, 98% of data emails were received for five projects. The average time required to process the data of a project is 8.44 s. Daily and monthly reports are generated in 3.52 s and 5.75 s respectively. A group report with nine projects requires an average of 21.98 s to process.

By making use of the reporting system, it was possible to:

- detect an air leak,
- identify the potential to optimise valve control, and
- become aware of a malfunctioning position feedback sensor.

Table 3.6: *Specification check-list of the new reporting system*

Specification	Accomplished
Raw compressed air data required by the system should be available on a daily basis.	Yes
The data should be processed automatically on a daily basis.	Yes
It should be able to report on several projects or groups of projects.	Yes
Reports should be sent out to the relevant persons on a daily and monthly basis.	Yes
It should be a centralised system that allows web access to clients.	Yes
Daily savings report for each project that includes:	Yes
an overview of the day's target savings	Yes
actual energy efficiency and cost savings for the day	Yes
a graph comparing the 24-hour energy consumption profile and the energy baseline	Yes
time-of-use (TOU) graph	Yes
Monthly savings report for each project that includes:	Yes
an overview of target savings for the project	Yes
a summary of the average daily impact for the period	Yes
a graph comparing the average 24-hour energy consumption profile and the energy baseline	Yes
time-of-use (TOU) graph	Yes
performance tracking table showing the energy and financial impact of each day	Yes
graphs visualising the performance tracking of the project	Yes
Group report that includes:	Yes
summary tables of each project type showing targets and actual impacts for each project	Yes
short summary of each project showing an average 24-hour profile graph as well as a cumulative performance analysis graph	Yes

In case studies A and B, the influence of the reporting system could be quantified in terms of energy and cost. Furthermore, the early detection of the air leak on Mine A realised additional cost savings because the leak was repaired before the commencement of the more expensive winter electricity tariffs. On Mine B, it was possible to take precautionary measures to prevent water damage to other pneumatic equipment and potentially reduce future maintenance cost.

In case study C, the performance of two mine compressed air DSM projects is analysed over a number of months. Mine C achieved a cumulative energy saving of 23.6 GWh per annum and a cumulative cost saving of R 16.6 million per annum. Mine D achieved a cumulative energy saving of 49.2 GWh per annum and a cumulative cost saving of R 32.6 million per annum.

Chapter 4

Conclusion



Tau Tona mine in South Africa. (Source: www.anglogoldashanti.co.za)

4.1 Summary

The objective of this study was to develop a new system that can efficiently monitor the performance of DSM projects on mine compressed air systems.

The need for such a system originated from the high electricity demands that South Africa's main electricity supplier, Eskom, was experiencing. To reduce this pressure, Eskom introduced Demand-Side Management (DSM) projects for major industries. Mine compressed air systems were identified as large and inefficient consumers of electricity. However, further investigations showed that the performance of DSM projects usually deteriorates shortly after the implementation phase.

A system was developed that records mine compressed air data from different mines on a daily basis. The data are then processed and the performance of the DSM projects is calculated. Reports regarding the performance of each project are sent to relevant mine and ESCo personnel. The reports enable people to monitor the performance and control of the DSM project and make suggestions and adjustments where necessary. This process creates a feedback loop which ensures the sustainability of the projects.

The system was implemented on sixteen mine compressed air DSM projects. Five projects were used to test the reliability and performance of the system. During a one month period, 98% of the data were received and the average daily processing time for one project was 8.44 s. Daily and monthly reports are generated in 3.52 s and 5.75 s, respectively. A group report with nine projects requires 21.98 s to generate. These results show that the system is very reliable and significantly reduces the time required to generate reports.

During September 2012, a total of 54 emails with daily reports were successfully sent to a number of mine personnel and ESCo engineers for the five projects. In order to further analyse the functionality and value of the reporting system, two of the sixteen projects were used as case studies. The case studies include three incidents where reports were used to detect anomalies with energy savings and identify opportunities to increase the energy savings.

The incident of case study A involves a sudden increase of airflow. By analysing the detailed airflow and pressure graphs in the reports and on the web-site, the mining level where increased airflow originated from could be identified. After further physical investigation, a leak was found and repairs were scheduled. Due to this leak, the project savings were reduced by R 2 821 per day. The report helped to identify and locate the air leak before the winter period with increased electricity costs, which is 112% higher than in summer.

In the first incident of case study B an anomaly with the control of certain air valves was identified. After further investigation it was found that due to mine safety regulations, the valves controlled within certain limits. These limits caused the valves to control above the scheduled air pressure set points. After reducing these control limits, the valve controlled closer to the set points and still within safety regulations. An additional daily cost saving of R 1 231 was achieved on each of the mining levels.

The second incident of case study B identified the malfunctioning of one of the control valves. Further investigations showed that water vapour in the position feedback sensor of the valve caused it to malfunction and stop controlling. An amount of R 3 299 was lost each day that the valve were not controlling. A water trap was installed to minimise the risk of water damage to the valve and other equipment. Because this was identified early with the reports, water traps were also installed on other levels before any damage to other pneumatic equipment was caused.

In the final case study, the performance of two mine compressed air DSM projects is analysed over a number of months. Mine C achieved a cumulative energy saving of 23.6 GWh per annum and a cumulative cost saving of R 16.6 million per annum. Mine D achieved a cumulative energy saving of 49.2 GWh per annum and a cumulative cost saving of R 32.6 million per annum.

Considering the above-mentioned results and case studies, the reporting system helped to efficiently monitor and analyse the performance of mine compressed air savings. It also helped to identify potential opportunities to increase the energy and cost savings of these mine compressed air systems.

4.2 Limitations and recommendations for further work

The reporting method described in Chapter 2 is primarily aimed at DSM projects on mine compressed air systems. Even though mine compressed air systems are major consumers of electricity, there is a number of other types of DSM projects that could also benefit from a product like this. These DSM projects include other energy efficiency and load shifting projects like the optimisation of water reticulation and cooling systems on mines.

The reporting system was developed in generic blocks in order to leave room for future expansion. Because of this generic design it will not be difficult to implement this system on other types of DSM projects on mines. It will, therefore, also be relatively simple to further expand the system for DSM systems in other industries like cement plants and other processing plants.

Due to the growing concerns of network vulnerability across the world, mines and other industries are continually upgrading their network security. Because of this it is becoming increasingly difficult to access the necessary data on the mines in the traditional ways. It is, therefore, necessary to develop a new protocol to establish communication between ESCo systems and client systems. This protocol should adhere to the networking standards of the client as well as the needs of the ESCo.

At the moment the frequency of feedback is 24 hours. By increasing the frequency, the response time to anomalies and malfunctions will decrease. Mine personnel and ESCo engineers will be able to optimise the performance of a DSM project faster and more efficiently. They will also be able achieve a more sustainable energy saving for the specific DSM project.

Finally, another possible feature that will enhance the effectiveness of the reporting system is self diagnostics. If the system can detect and diagnose certain anomalies in the data, it can also include suggestions for possible causes in the reports. This will make it easier to solve problems that affect DSM savings.

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Appendix A

Daily Report



Daily report for



28 February 2013

Generated on 25 March 2013

1 Project information

Project name: [REDACTED]
 Project number: [REDACTED]
 Tariff structure: MEGAFLEX
 Target impact: 1.96 MW
 Target energy saving: 47.04 MWh per day

2 Performance (Thursday 2013-02-28)

Performance of day:

Impact: 2.51 MW
 Energy saving: 60.33 MWh
 Cost saving: R 25,745
 Missed opportunities: -

Month-to-date performance:

Average impact: 2.48 MW
 Cumulative energy saving: 113.15 MWh
 Cumulative cost savings: R 703,138
 Cumulative missed opportunities: -

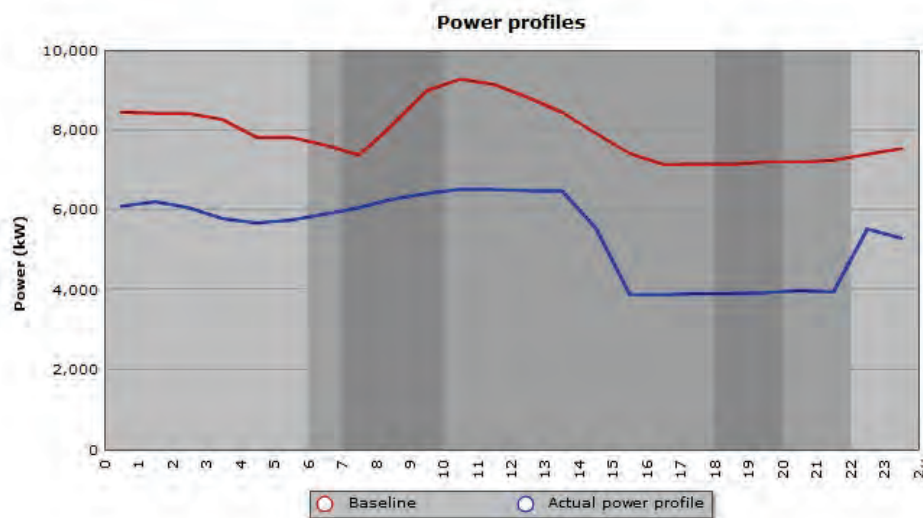


Figure 2-1: Power profile and baseline for 28 February 2013



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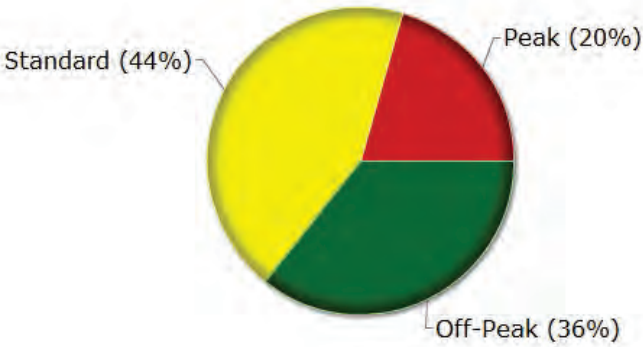


Figure 2-2: Weekday usage distribution - 28 February 2013

Appendix B

Monthly Report



report for

1 February 2013 - 28 February 2013

Generated on 23 March 2013

Table of Contents

1 Project information	1
2 Summary	1
3 Daily performance tracking	3



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1 Project information

Project type: [REDACTED]
 Energy type: Energy efficiency
 Project number: [REDACTED]
 M&V team: [REDACTED]
 Project stage: Completed
 Contract completion date: 2011-02-28
 Actual completion date: 2011-02-28
 Contractual impact target: 1.96 MW
 Performance assessment (PA) impact: 1.30 MW
 Post-PA impact target: 1.96 MW

2 Summary

Table 2-1: DSM summary for the period: 2013-02-01 to 2013-02-28

	Weekdays
Average daily impact	2.44 MW
Energy saving	1.17 GWh
Energy consumption	2.63 GWh
Cost savings	R 703,138
Missed opportunities	-

Table 2-2: Project lifetime summary (from 2012-02-01 to 2013-02-28)

	Weekdays
Average daily impact	3.90 MW
Cumulative energy saving	25.26 GWh
Cumulative cost saving	R 17,228,608

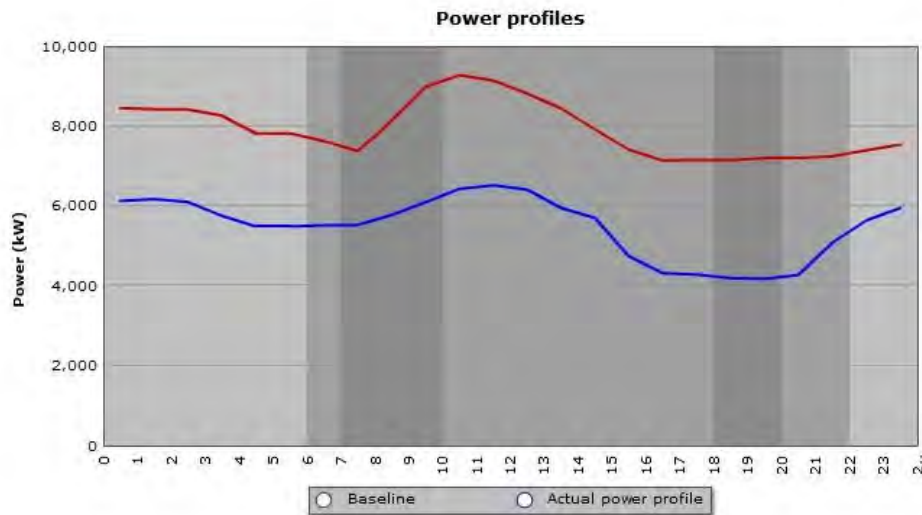


Figure 2-1: Weekday average power profile and baseline for 1 February 2013 to 28 February 2013



Figure 2-2: Weekday usage distribution - 1 February 2013 to 28 February 2013

3 Daily performance tracking

Table 3-1: DSM summary for the period: 2013-02-01 to 2013-02-28

Date	Impact (MW)	Cost saving (R)	
2013-02-01	2.50	25,210	
2013-02-02	3.41	26,248	
2013-02-03	4.28	29,463	
2013-02-04	2.69	27,569	
2013-02-05	2.50	25,851	
2013-02-06	2.48	25,690	
2013-02-07	2.31	23,930	
2013-02-08	2.57	26,469	
2013-02-09	2.79	21,359	
2013-02-10	3.78	26,010	
2013-02-11	2.61	26,756	
2013-02-12	1.75	17,283	
2013-02-13	2.41	25,189	
2013-02-14	1.90	19,114	
2013-02-15	2.73	27,404	
2013-02-16	3.62	28,018	
2013-02-17	3.38	23,240	
2013-02-18	2.43	25,413	
2013-02-19	1.68	17,170	
2013-02-20	2.08	21,932	
2013-02-21	2.56	27,433	
2013-02-22	4.20	45,864	
2013-02-23	2.19	17,159	
2013-02-24	3.80	26,191	
2013-02-25	2.18	22,904	
2013-02-26	2.38	24,528	
2013-02-27	2.32	23,998	
2013-02-28	2.51	25,745	
Total:		703,138	

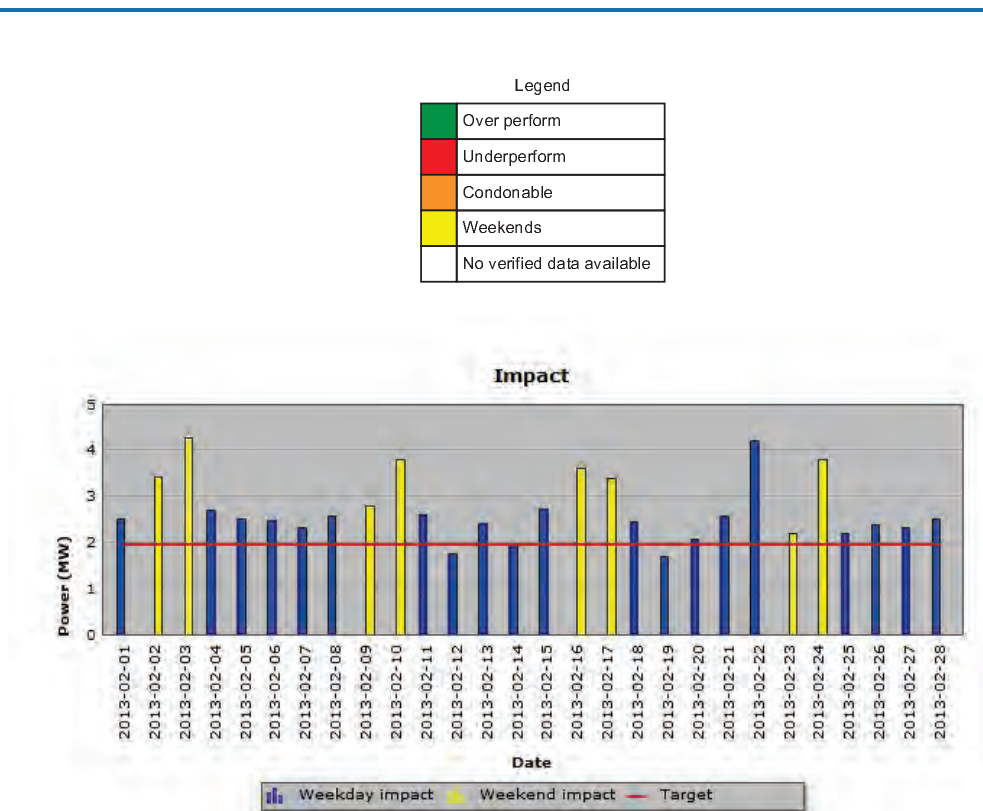


Figure 3-1: Daily impact - 1 February 2013 to 28 February 2013

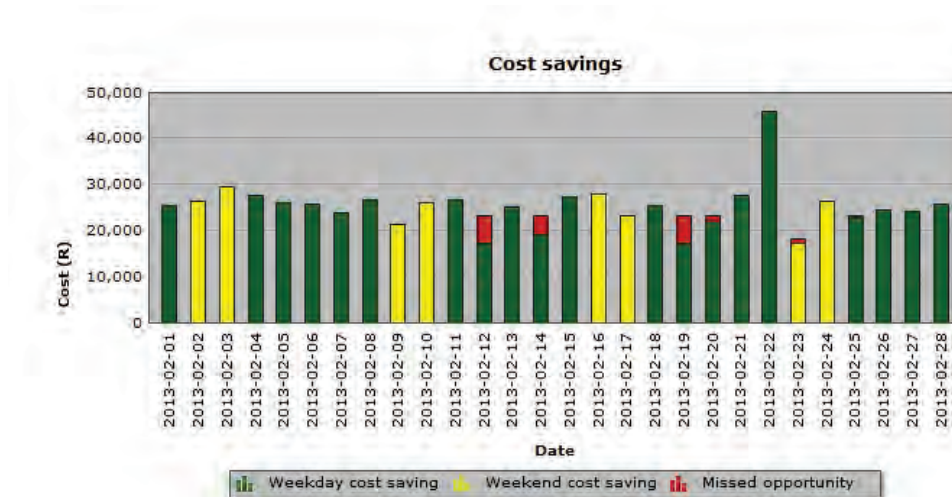


Figure 3-2: Daily cost savings - 1 February 2013 to 28 February 2013

Appendix C

Group Report



**Group report
for**



1 February 2013 - 28 February 2013

Generated on 25 March 2013

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1 Summary 1

2 Energy efficiency projects 2

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2.2 [redacted] 3

2.3 [redacted] 4

2.4 [redacted] 5

2.5 [redacted] 6

1 Summary

Table 1-1: Summary of energy efficiency projects

Project	Target	Impact	Baseline energy	Energy consumption	Energy saving	Cost saving
	1.96 MW	2.48 MW	3.61 GWh	2.49 GWh	1.13 GWh	R 703,138
	1.22 MW	2.35 MW	3.82 GWh	2.68 GWh	1.14 GWh	R 627,959
	1.50 MW	4.04 MW	3.10 GWh	1.26 GWh	1.84 GWh	R 1,213,680
	1.60 MW	8.49 MW	5.63 GWh	1.56 GWh	4.07 GWh	R 2,171,802
	1.50 MW	4.86 MW	5.09 GWh	2.73 GWh	2.36 GWh	R 1,235,232
Totals:	7.78 MW	22.22 MW	21.26 GWh	10.72 GWh	10.55 GWh	R 5,951,811

2 Energy efficiency projects

2.1 [Redacted]

Project type: [Redacted] (Energy efficiency)
Project number: [Redacted]
Actual completion date: 2011-02-28
Contractual impact target: 1.96 MW
Performance assessment (PA) impact: 1.30 MW
Impact target: 1.96 MW

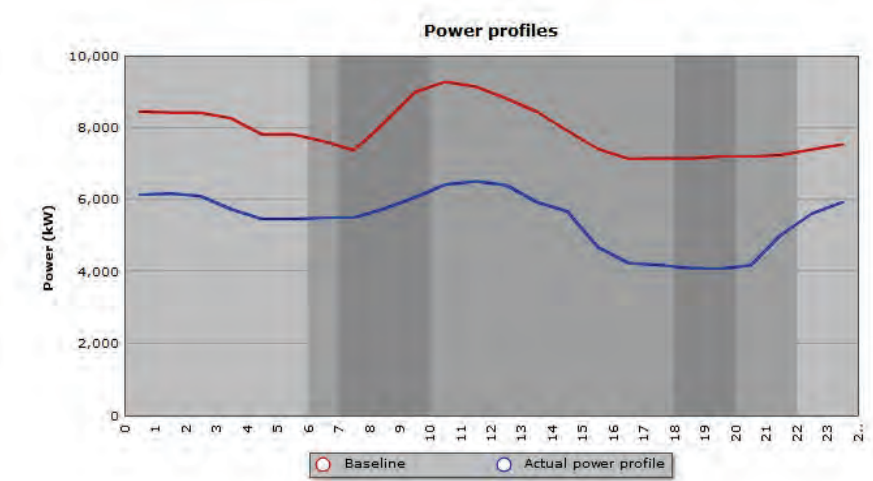


Figure 2-1: Weekday average power profile and baseline for 1 February 2013 to 28 February 2013

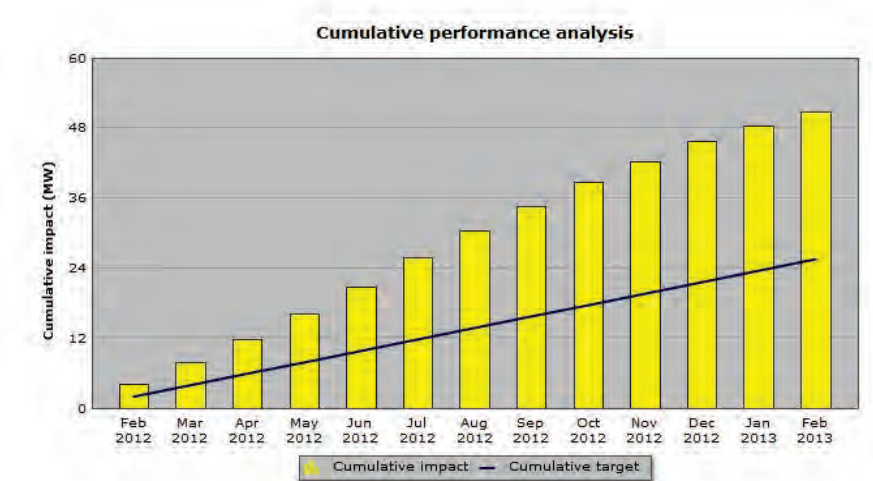


Figure 2-2: Cumulative performance graph

2.2 [Redacted]

Project type: [Redacted] (Energy efficiency)
Project number: [Redacted]
Actual completion date: 2010-11-30
Contractual impact target: 1.22 MW
Performance assessment (PA) impact: 1.68 MW
Impact target: 1.22 MW

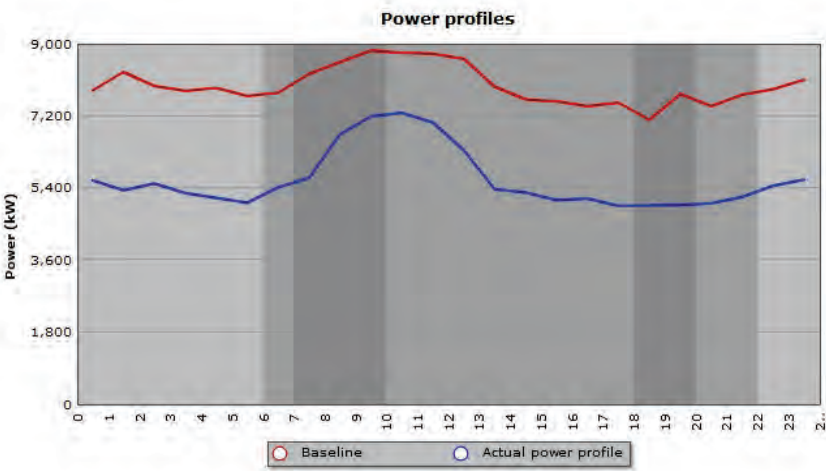


Figure 2-3: Weekday average power profile and baseline for 1 February 2013 to 28 February 2013

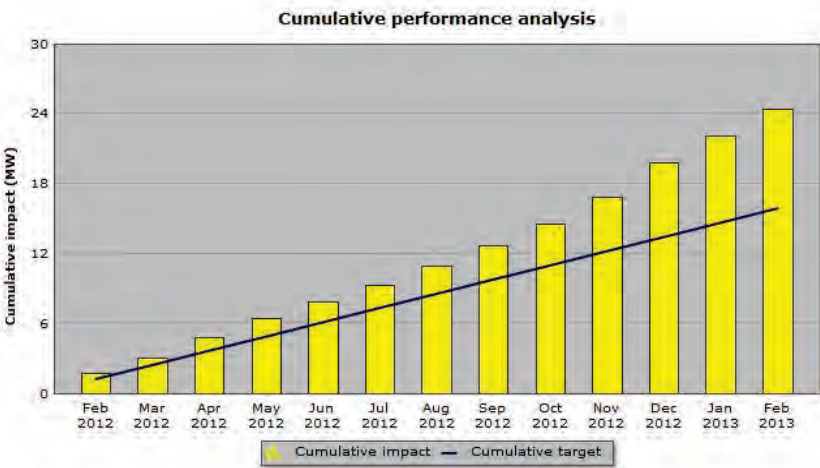


Figure 2-4: Cumulative performance graph

2.3 [REDACTED]

Project type: [REDACTED] (Energy efficiency)
Project number: [REDACTED]
Actual completion date: 2012-02-15
Contractual impact target: 1.50 MW
Performance assessment (PA) impact: 1.50 MW
Impact target: 1.50 MW

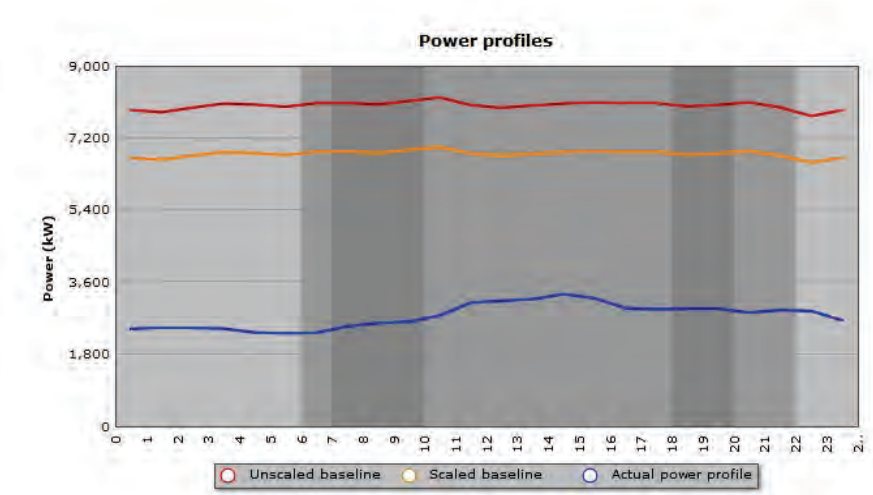


Figure 2-5: Weekday average power profile and baseline for 1 February 2013 to 28 February 2013

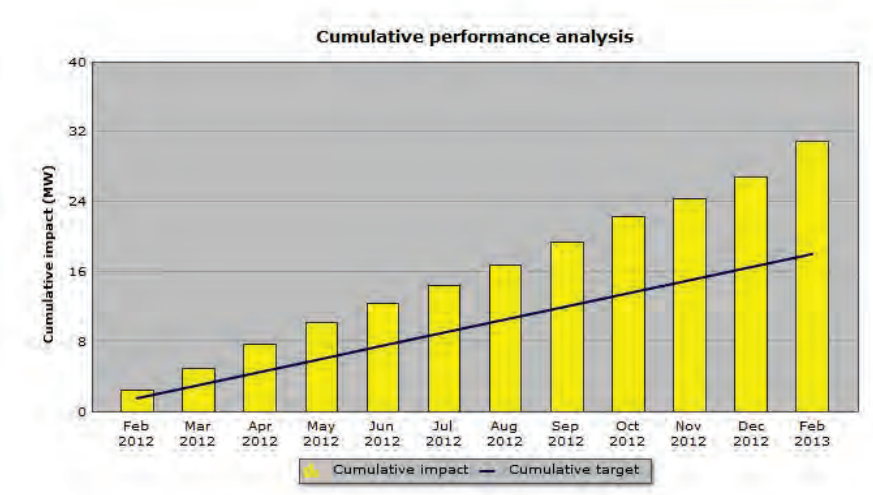


Figure 2-6: Cumulative performance graph

2.4 [Redacted]

Project type: [Redacted] (Energy efficiency)
Project number: [Redacted]
Actual completion date: 2011-02-28
Contractual impact target: 1.60 MW
Performance assessment (PA) impact: 3.15 MW
Impact target: 1.60 MW

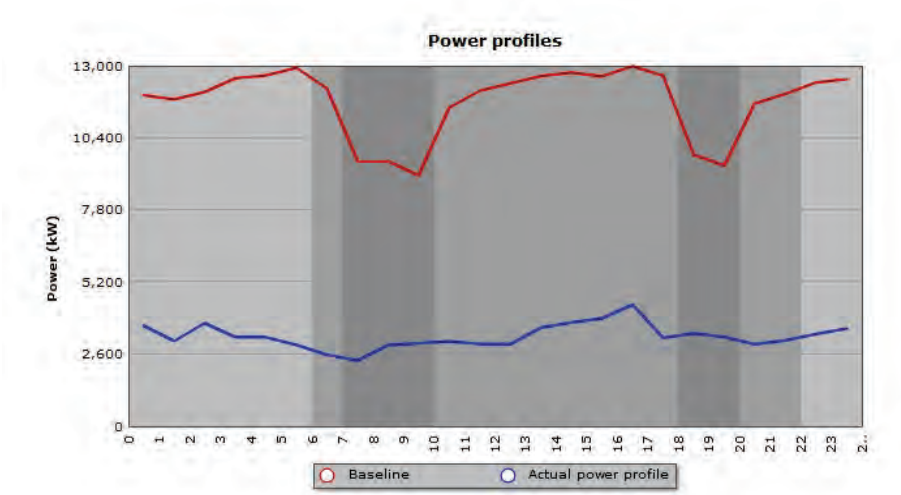


Figure 2-7: Weekday average power profile and baseline for 1 February 2013 to 28 February 2013

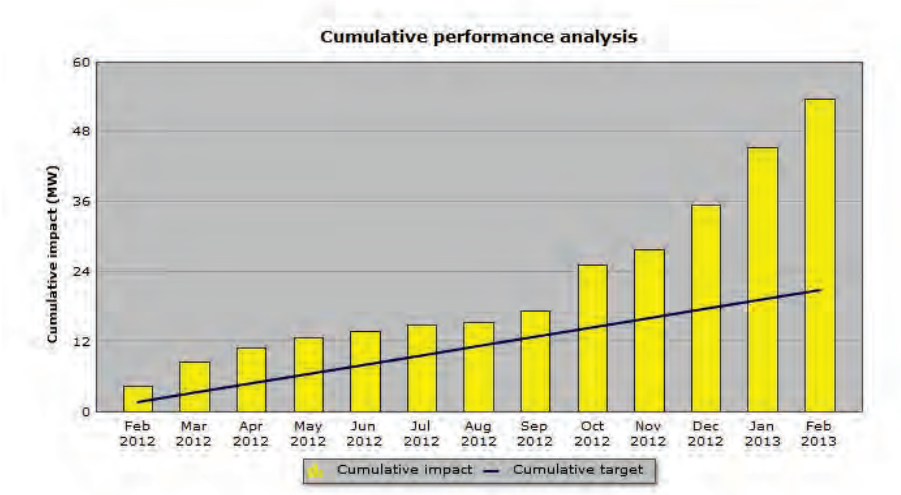


Figure 2-8: Cumulative performance graph

2.5 [Redacted]

Project type: [Redacted] (Energy efficiency)
Project number: [Redacted]
Actual completion date: 2012-05-31
Contractual impact target: 1.50 MW
Performance assessment (PA) impact: 0.00 MW
Impact target: 1.50 MW

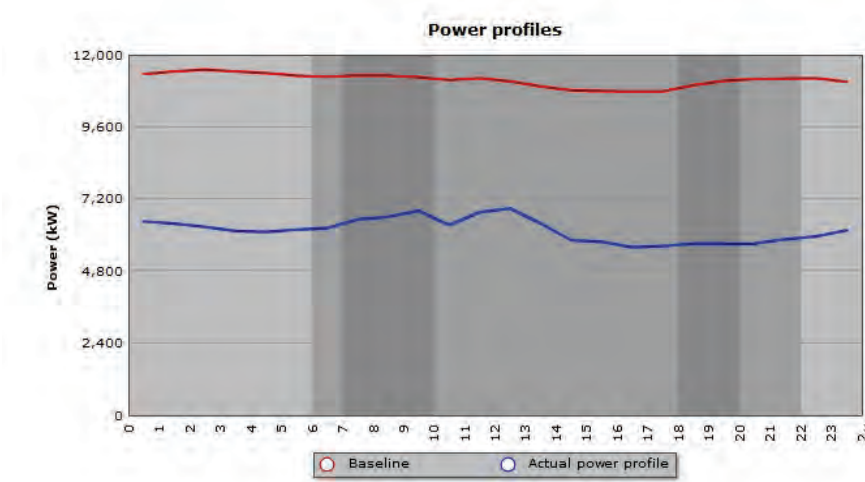


Figure 2-9: Weekday average power profile and baseline for 1 February 2013 to 28 February 2013

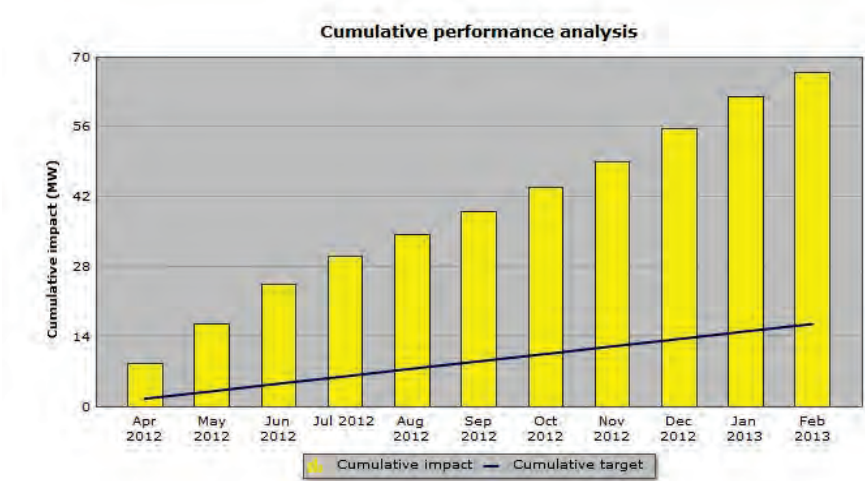


Figure 2-10: Cumulative performance graph

Appendix D

Web interface

Login

Figure D.1 shows the login screen of the web-application. Each user has his/her own user name and password. User access is strictly controlled by the ESCo administrator. A client user, for example, may only view the data of mining group he/she works for, while an ESCo user may view the data from all the mining groups.

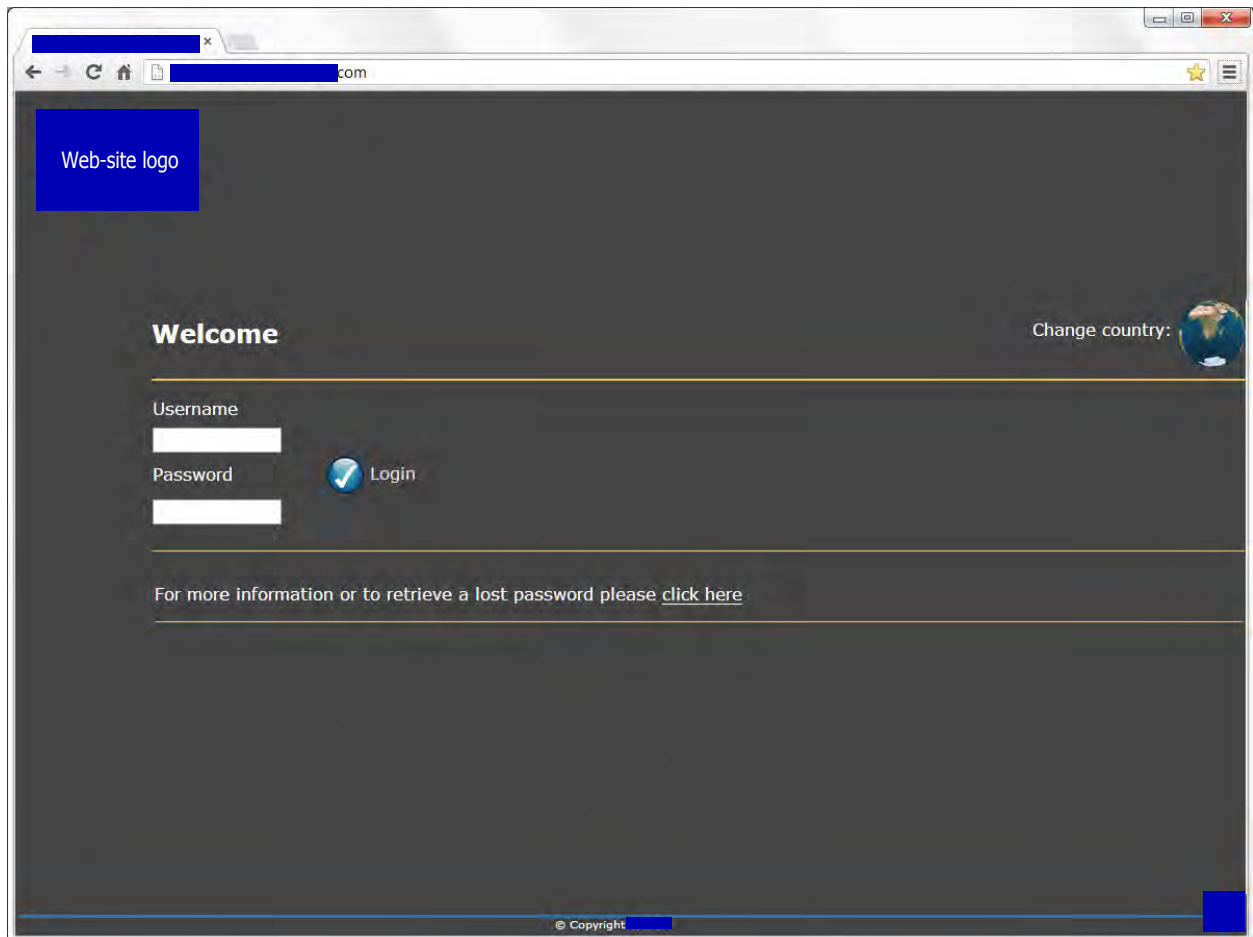


Figure D.1: *Login screen of the web-application*

Monthly overview

Figure D.2 shows the monthly overview of all the DSM projects in a mining group. The performance of each mine/project is shown for each month. Green indicates that the project achieved its target savings. Red indicates that the project underperformed and did not achieve its target savings. If there is no data available for a project, the colour is grey.

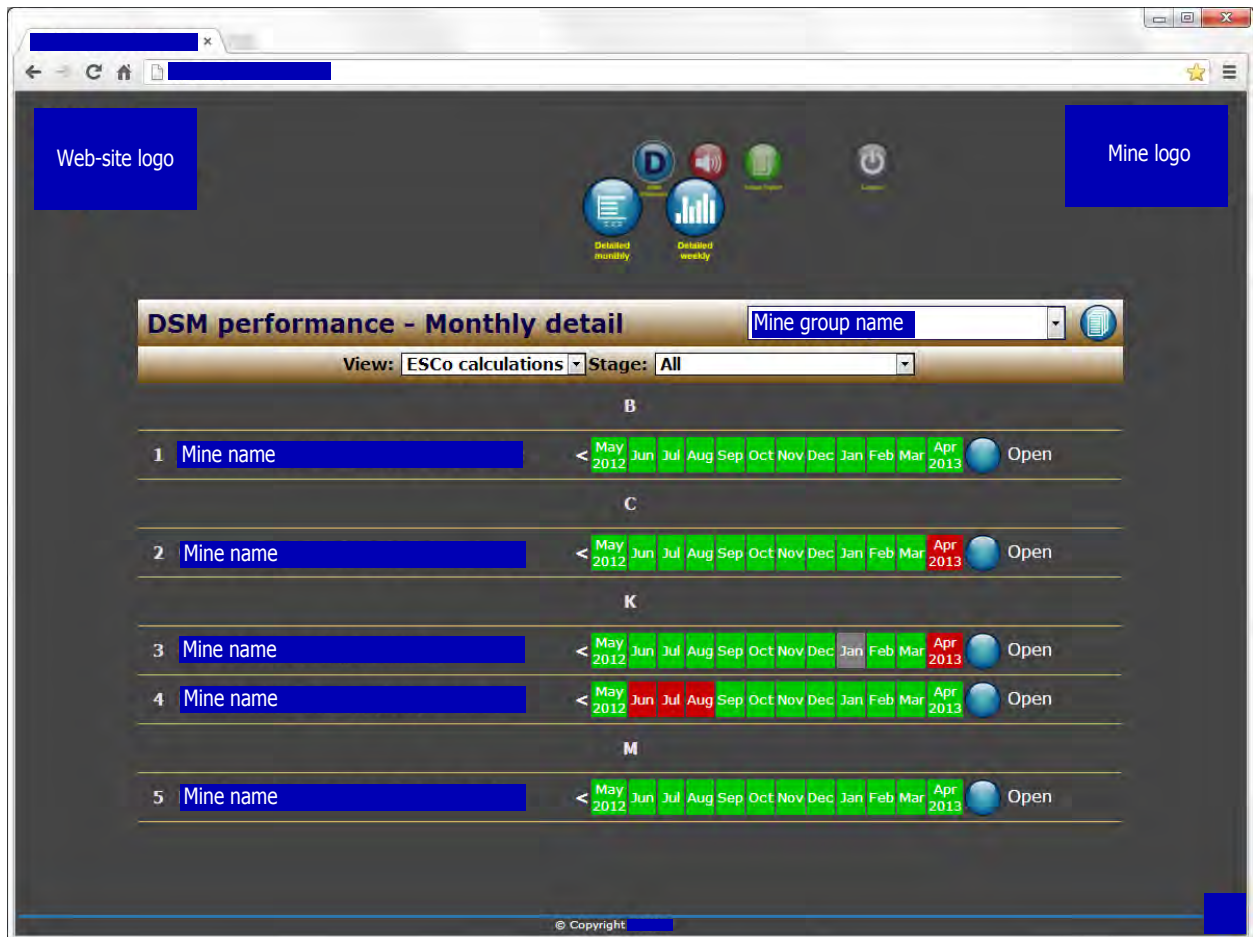


Figure D.2: Monthly overview of all projects in a mining group

Weekly overview

Figure D.3 shows the weekly overview of all the DSM projects in a mining group. The performance of each mine/project is shown for each day. Green indicates that the project achieved its target savings. Red indicates that the project underperformed and did not achieve its target savings. If there is no data available for a project, the colour is grey. Condonable days are marked in orange.

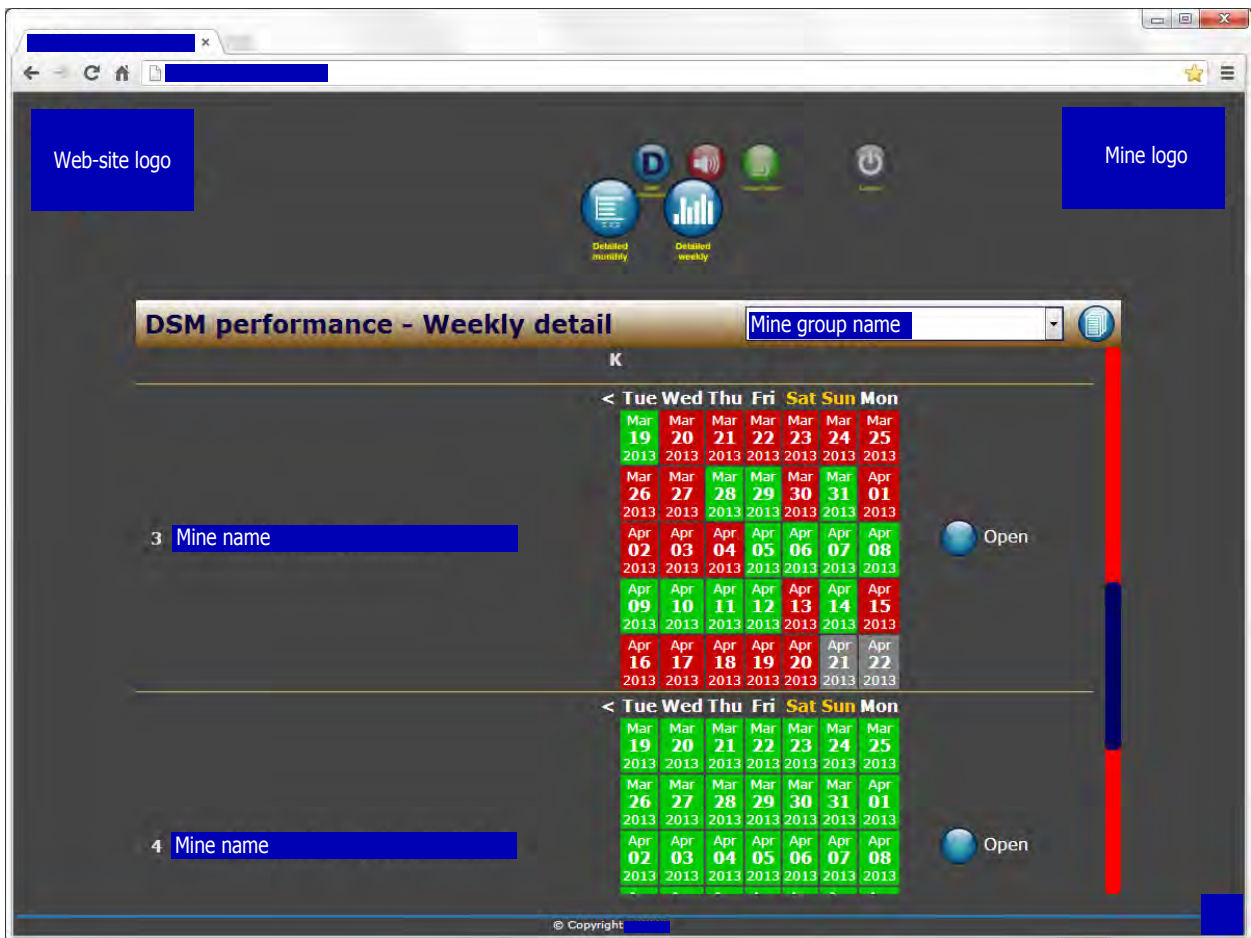


Figure D.3: Weekly overview of all projects in a mining group

Project information

The user can view more information about a project by clicking on the "Open" button of the project, shown in Figure D.2 and Figure D.3. This opens a page shown in Figure D.4. The "Report" button on this page allows the user to create daily or monthly reports for the project.

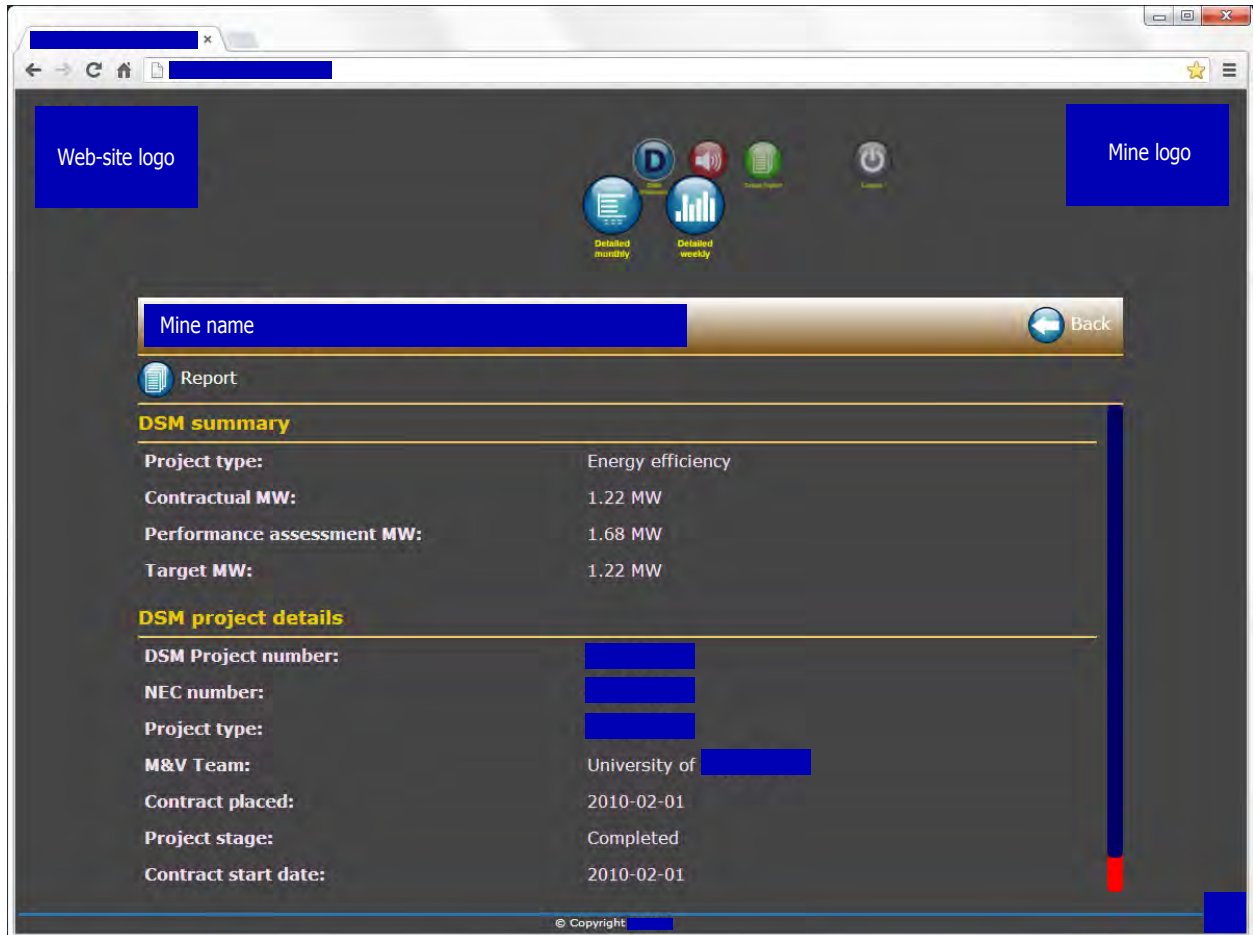


Figure D.4: *Detail information about a project*

Detail view for a month

The user can view more detail about a project's performance for a month by clicking on the coloured monthly blocks in Figure D.2. This opens a page shown in Figure D.5. Essential performance data for the month are shown as well as a power profile graph. The graph shows the average weekday power usage compared to the baseline. A monthly report can also be generated from this view by clicking on the "Report" button.



Figure D.5: *Detail information for a month*

Detail view for a day

The user can view more detail about a project's performance for a day by clicking on the coloured blocks in Figure D.3. This opens a page shown in Figure D.6. Essential performance data for the day are shown as well as a power profile graph. The graph shows the average power usage compared to the baseline. A day report can be generated from this page by clicking on the "Report" button. From this page the user can also mark the day as condonable if necessary. Only authorised ESCo users can mark condonable days.

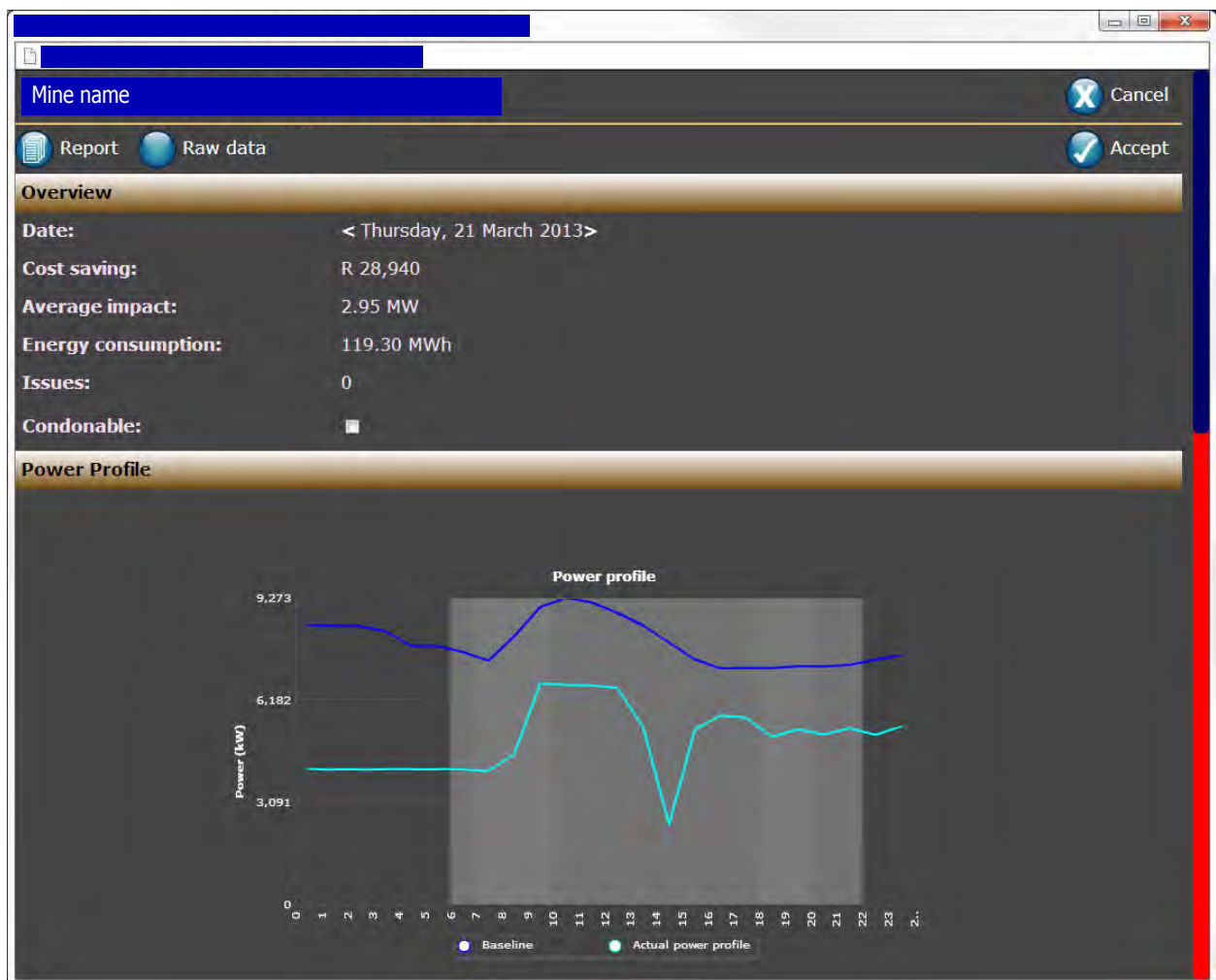


Figure D.6: *Detail information for a day*

Raw data view for a day

The user can view the raw data that were logged by the ESCo control system by clicking on the "Raw data" button shown in Figure D.6. This opens the page shown in Figure D.7. On this page the user can view various parameters of the compressed air system. The example in Figure D.7 shows the valve pressure and flow values of the valve at 2010-Level.

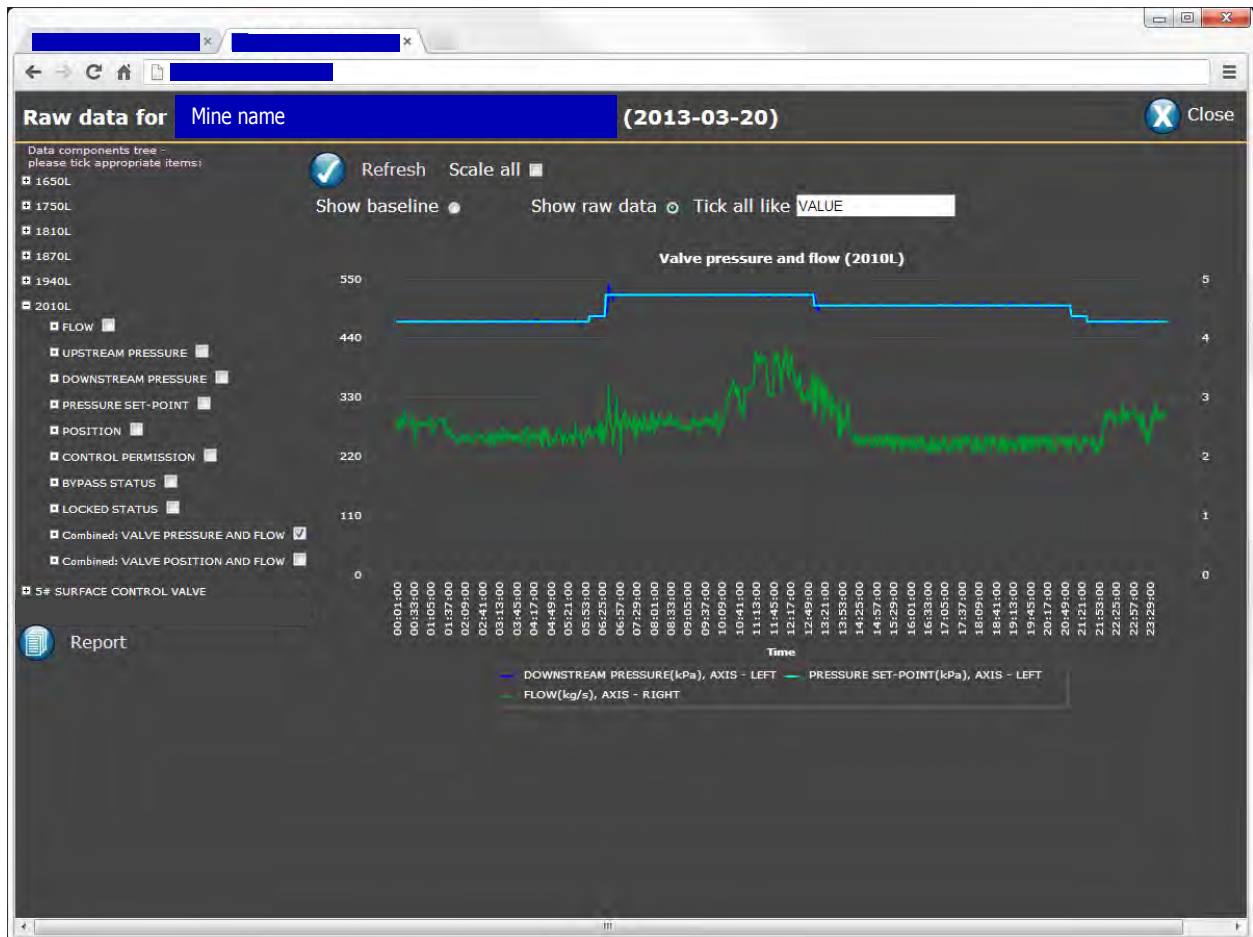


Figure D.7: *Raw data view for a day*

Generating a group report

From the page shown in Figure D.8 the user can generate group reports. The user can also send the report via email directly to himself or other recipients. The user can select different groups of mines to generate a report for. For example, the user can select only the northern or southern shafts of a mining group. This reduces the size of the report when the information of only a small number of projects is required.

Web-site logo

Mine logo

Data performance Issue Group report Logout

Group Report

Options	Select
1 Select group	Mine group name
2 Create report for the following period?	Current month-to-date From: 2013-04-01 to: 2013-04-22
3 Send report to my e-mail address?	☐
4 Send report to other e-mail addresses?	☐

Generate Report

© Copyright

Figure D.8: *Generating a group report*

Issue page

If there is a problem with a project or with the web-application, a user can report this issue on the page shown in Figure D.9. An ESCo operator will then receive an email with the issue information that was reported by the user. Thereafter, the ESCo operator will inform the person responsible to rectify the problem.

Figure D.9: *Issue reporting page*