DSM opportunities in underground refrigeration systems

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ABSTRACT

Title: Demand Side Management opportunities on an underground refrigeration system.
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School: Electrical and Electronic Engineering
Faculty: Engineering
Degree: Masters of Engineering (Electrical)

This study will focus on the feasibility of demand side electricity management on underground refrigeration systems. It will include a relevant literature study, the investigation process, a simulation model, expected simulated results, implementation of DSM on an underground refrigeration system, actual results, recommendations of further study, and a conclusion.

Eskom is presently struggling to adhere to the electricity demand in South Africa, specifically in the peak consuming periods. It was proposed that Demand Side Management possibilities must be investigated and evaluated on South-African gold mines.

The gold mining industry consumes approximately 26% of the electricity supplied by Eskom. Mines possess extensive machinery which consume much power in their mining activities. One of the most energy intensive machines is the refrigeration system machines.

Demand Side Management was previously successfully implemented on surface refrigeration systems and on cascade refrigeration systems. Mining depths increase continuously and surface refrigeration systems become inadequate. An underground refrigeration system is a viable option to aid this problem.

The possibility of Demand Side Management in underground refrigeration systems will be investigated. A simulation model will be created of the system and various control strategies will be applied and evaluated. These strategies will endeavour to reduce loads during the Eskom peak consumption periods.

The control strategy was implemented on the refrigeration system and load reduction results were obtained. The average load reduction for the evening peak, excluding condonable days, for the month of August 2009 was 6.60 MW. The average morning load reduction, excluding condonable days, was 6.06 MW. Load profiles from 1 October 2009 until 15 October 2009 show that the reduction for the evening peak, excluding condonable days, was 5.24 MW.

SAMEVATTING

Titel:	Demand Side Management opportunities on an underground refrigeration system.
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Skool:	Elektriese and Elektroniese Ingenieurswese
Fakulteit:	Ingenieurswese
Graad:	Meesters in Ingenieurswese (Elektries)

Hierdie studie konsentreer op die op die moontlikheid van n elektriese lasvermindering projek op ondergrondse verkoelings aanlegte. Dit bevat toepaslike literatuur studie, die ondersoekproses, 'n simulasie model, verwagte resultate, DSM implementering op n ondergrondse verkoelingsaanleg, werklike resultate en aanbevelings vir verdere studie.

Huidiglik kan Eskom nie die behoefte aan elektrisiteit in Suid-Afrika bevredig nie veral in die maksimum gebruik area. Eskom het n program geloots naamlik "Demand Side Management" om die moontlikheid van effektiewe elektrisiteitsgebruik na te strewe.

Die goudmyn bedryf gebruik omtrent 26% van die elektrisiteit wat Eskom genereer. Goudmyne besit vele geleë elektrisiteitsverbruikende apparate wat aangewend word vir mynbou aktiwiteite. Een van hierdie apparate is die masjienerie wat gebruik word in die verkoelingsaanleg.

"Demand Side Management" was in die velede suksesvol aangewend op verkoelings aanlegte wat bogronds gelee is. Die diepte van goudmyne neem konstant toe en bogrondse verkoelingsaanlegte is nie meer in staat om voldoende verkoeling te bied nie. Ondergrondse aanlegte bied 'n praktiese oplossing.

Die moontlikheid van "Demand Side Management" op ondergrondse verkoelingsaanlegte gaan ondersoek word. 'n Simulasie model gaan geskep word en verskeie beheerstrategiee gaan getoets word. Hierdie strategiee gaan poog om die elektrisiteitsverbruik gedurende piektye te verminder.

'n Suksesvolle beheerstrategie was toegepas op die verkoelingsaanleg op Elandsrand Goudmyn. Die gemiddelde lasvermindering in die aandpiektyd gedurende Augstus 2009 was 6.60 MW en die gemiddelde lasvermindering gedurende die oggendpiektye was 6.06 MW. Die gemiddelde lasvermindering vir Oktober 2009 tot en met 15 Oktober 2009 was 5.24 MW.

ACKNOWLEDGEMENTS

This dissertation represents my own research. I would like to thank everyone that contributed in this research. Information was obtained from various sources.

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Finally, I thank God for my talents and giving me the opportunity to glorify His name.

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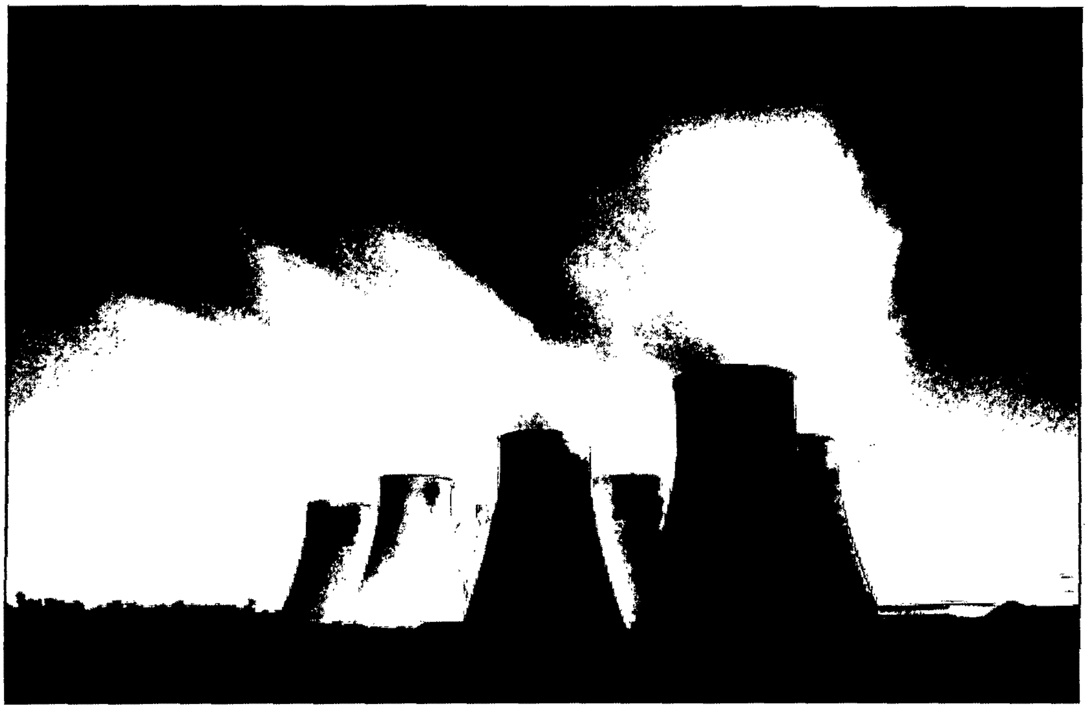
NOMENCLATURE

A	Amps
BAC	Bulk Air Cooler
COP	Coefficient of performance
DSM	Demand Side Management
ESCO	Energy Service Company
GW	Gigawatt
h, hr	Hour
m	Metre
m^2	Metres squared
m^3	Cubic metres
MW	Megawatt
M&V	Measurement and verification
NERSA	National Energy Regulator of South Africa
Q	Thermal Energy
s	second
SA	South Africa
SCADA	Supervisory Control and Data Acquisition
T, Temp, temp.	Temperature
U/G	Underground
USA	United Sates of America
V	Volts
W	Watt
°C	Degrees Celsius
°	Degree
Δ	Delta
%	Percentage

1

INTRODUCTION



This chapter will discuss the electricity crisis in South Africa and some of the energy intensive machines that cause this problem.

1. INTRODUCTION

1.1. The energy demand and resources in South-Africa

Energy is one of the most essential commodities in the world today [1]. The availability and affordability of energy is essential for global development [1]. The economic growth of a country is directly commensurate with the ability to adhere to the energy demands it is presented with.

South Africa ranks as one of the most economically efficient producers of electrical power in the world. Eskom is one of the top ten international electricity suppliers in terms of size and sales. It supplies 95.2% of South-Africa's and 60% of Africa's electrical energy [2].

The graph in Figure 1 developed by the Nus Consulting Group compares the electricity costs of South Africa to several other well developed countries [3]. It is apparent that in 2007 South Africa produced electricity much more cheaply than the other countries.

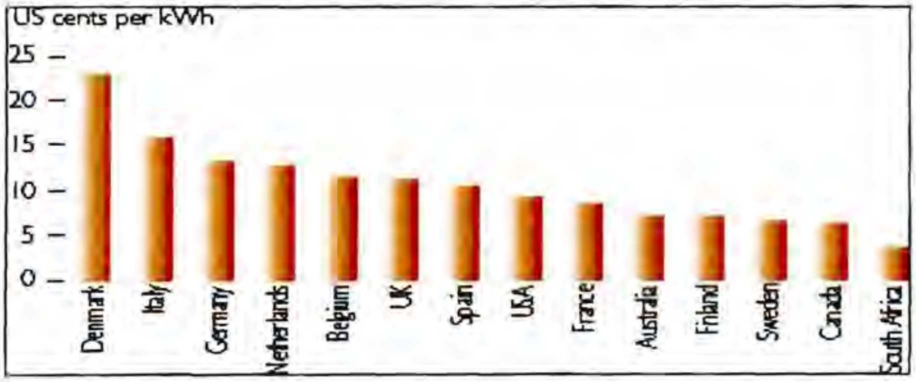


Figure 1: World industrial electricity prices from a representative consumer in each country [3]

More than 75% of South Africa's electricity is generated from coal fired power stations. The rest of the composition is shown in Figure 2 [4]. A small percentage of the electricity consumption mix is comprised of natural gas and nuclear power.

South Africa has the sixth largest recoverable coal reserves in the world [5]. Coal is preferred due to the low cost and availability.

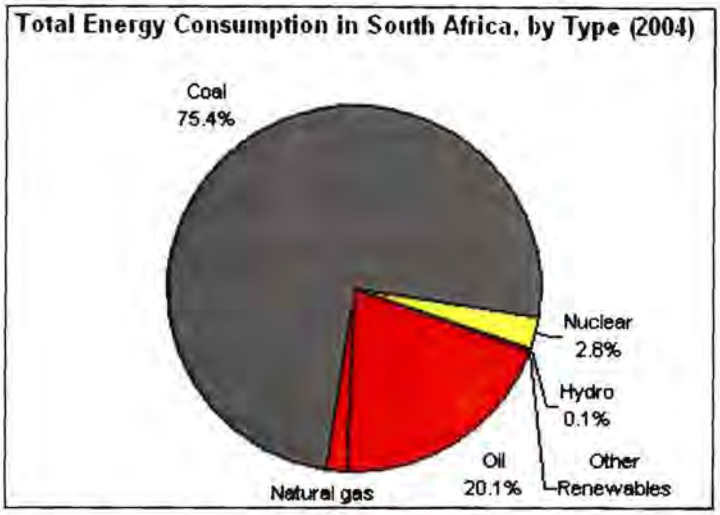
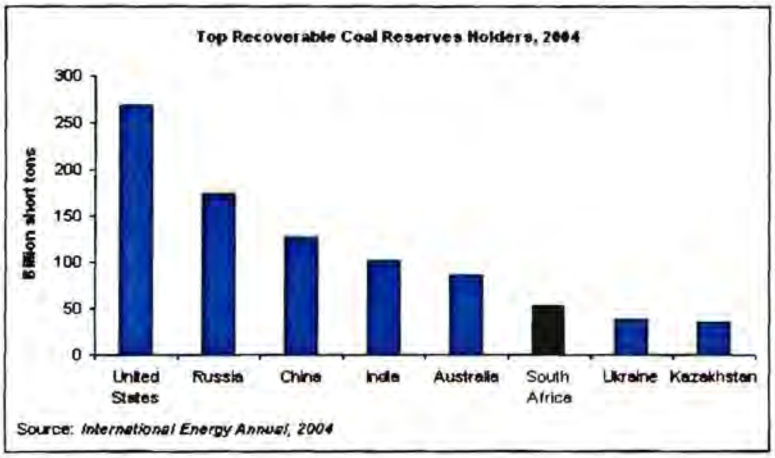


Figure 2: Energy consumption in South Africa as in 2004 [4]

Figure 3 indicates the countries which possess the largest coal reserves:



Source: *International Energy Annual, 2004*

Figure 3: Table indicating the major recoverable coal reserve holders [5]

There has been a continuous worldwide increase in electricity demand [6]. In South Africa it was estimated in 1990 that the electricity demand would increase by nearly 60% by the year 2020 [6]. Therefore Eskom had started to accelerate strategies to compensate for higher economic growth estimates. It is now estimated that the demand will increase by 6% annually [7].

South Africa's ability to provide electricity was above average, largely due to the historical structure of the economy [2]. Electricity saving technologies have not been applied due to historically relatively low electricity costs. South-Africa's coal dependency and lack of energy efficient methods of generating electricity are creating various problems [2].

South Africa produces an average 243 million tons and consumes 177 million tons of coal annually. The vast majority of consumed coal is used for electricity generation and in the synthetic fuel industry. Almost one-third of coal produced in South Africa is exported to the European Union and East Asia [5].

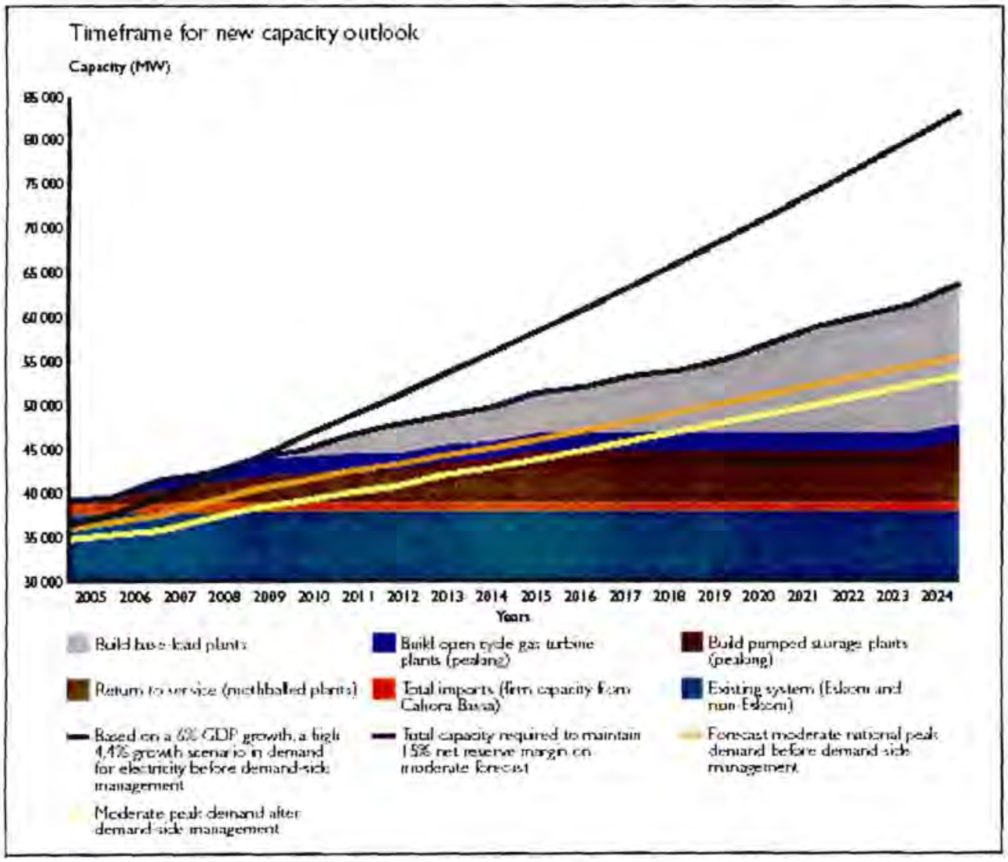


Figure 4: Eskom estimated capacity outlook [8]

Figure 4 indicates the estimated electricity demand growth. The frequent power outages in recent years exploited the vulnerability of the country's power system. Several factors occurred; higher than expected demand, unplanned outages, and more importantly, a diminishing reserve capacity [9].

The licensed capacity of Eskom was 38,900 MW in 2007. The demand for electricity exceeded the operational capacity of 35,000 MW on seven occasions. It climaxed with a peak of 36,500 MW [3]. Figure 5 indicates Eskom's power stations' generation capacity and the maximum demand of the country.

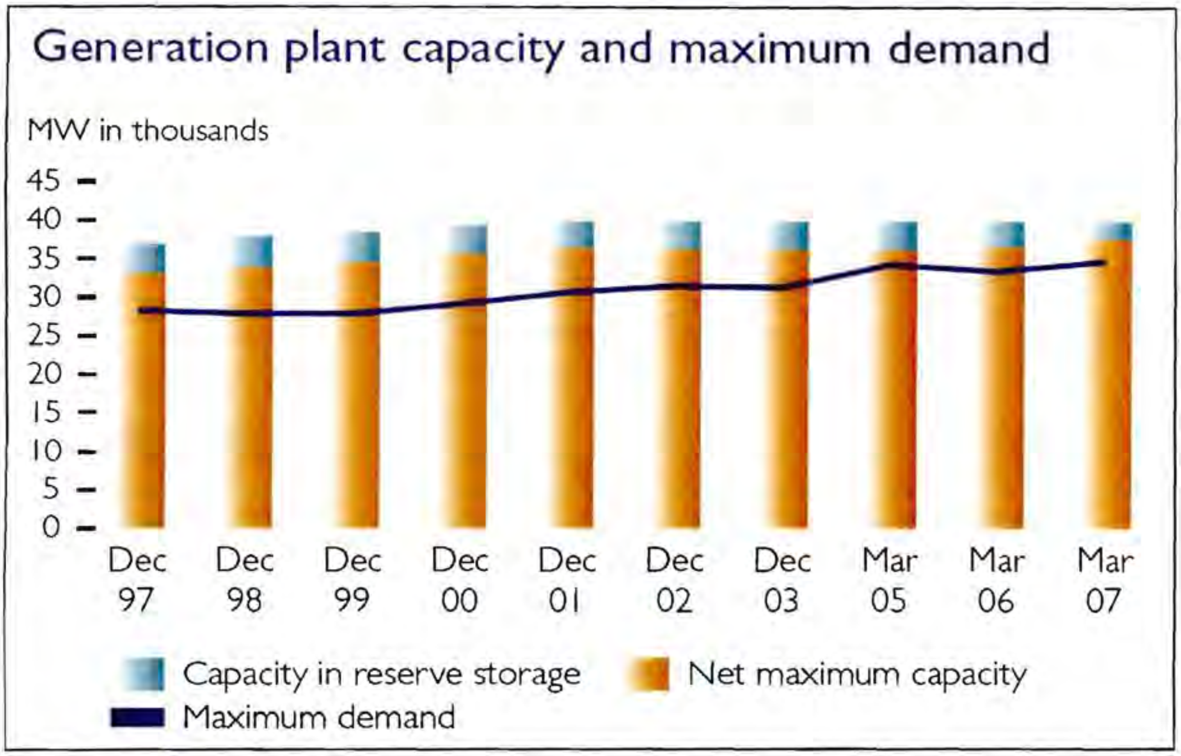


Figure 5: Eskom's generation capacity and maximum demand [3]

The retail price of electricity will increase due to coal prices and infrastructure improvements. Eskom applied for the retail price of electricity to increase by 18% in 2007 [11]. In 2008 Eskom planned an increase of 60% in retail price [12]. NERSA approved a 14.2% increase in December 2007 and a further 13.3% in June 2008 [13].

Eskom is planning to double its generating capacity within the next 20 years [7]. Frequently the demand often exceeds the safe supply margin. Load shedding occurs when the supply is suspended in certain areas [19]. In 1992 Eskom launched a programme called Demand Side Management (DSM) to prevent load shedding

1.2. Demand Side Management

Demand Side Management is the process whereby an electricity provider influences the way electricity is utilised by the consumers [15]. Eskom has launched a subdivision to promote and manage the consumption of electricity projects, viz. Eskom-DSM [15].

The reason for investigating the DSM potential is the extremely lengthy and expensive processes associated with constructing new generating facilities. Energy efficiency, load reduction, load shifting and negotiated interruptible supply have been DSM methods successfully applied in previous projects [15].

DSM is the planning to encourage consumers to utilise electricity more efficiently and sparingly [15]. This includes the timing and level of consumption. The objective of DSM is to effectively manage the demand. By the year 2012 the DSM programme of Eskom plans to save 3 000 MW daily [16].

Figure 6 is the average load curve of South Africa in 2006. It distinguishes between the summer and winter load curves.

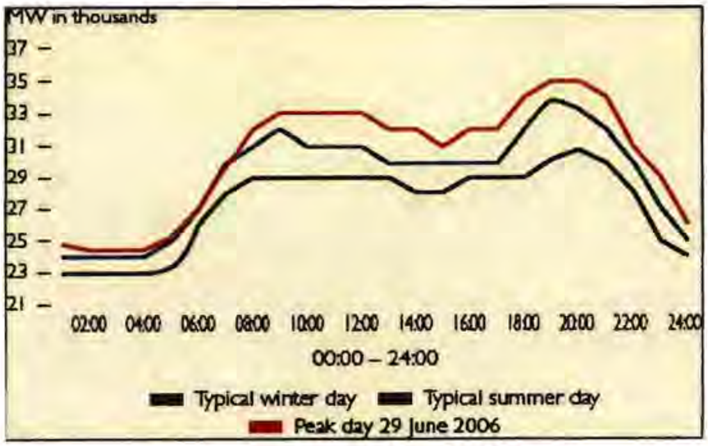


Figure 6: Eskom average load curves in 2006 [3]

From Figure 6 two distinct peak periods can be identified; the morning peak period (07:00 – 10:00) and the evening peak period (18:00 – 20:00). Industrial retail prices are calculated according to the time of the day. The peak periods are more costly due to high demand. Figure 7 indicates the three different periods:

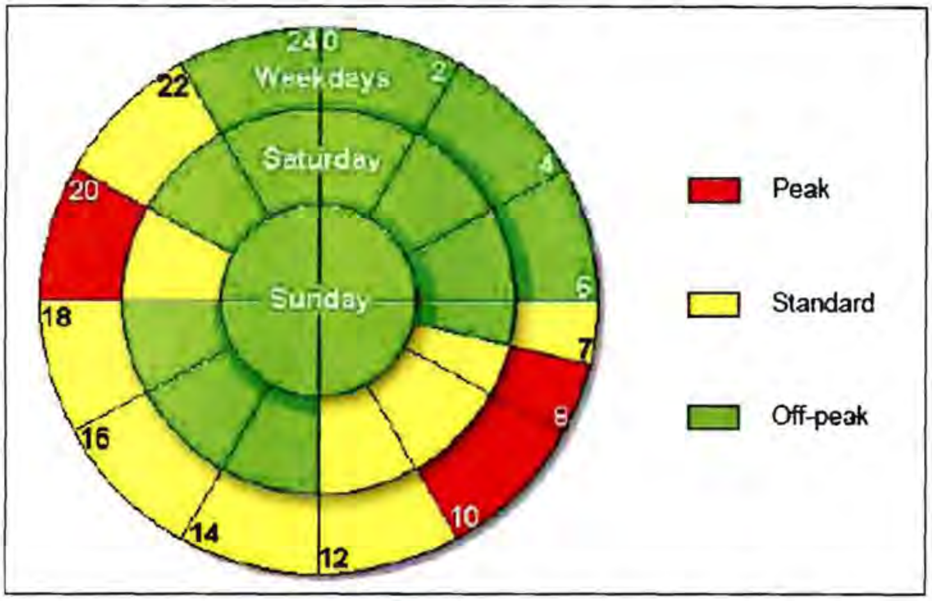
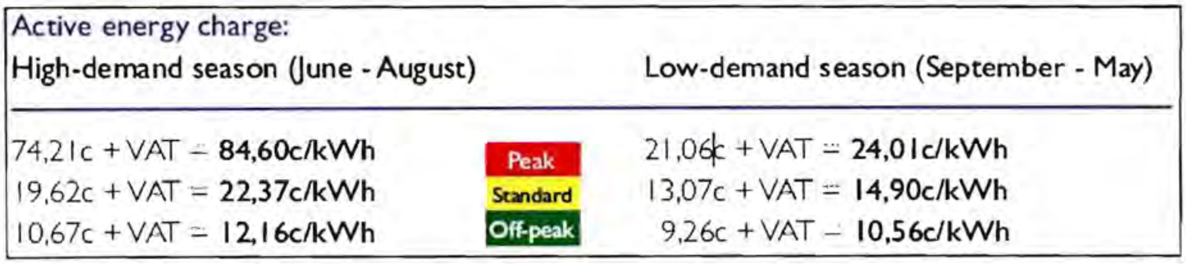


Figure 7: Eskom's consumption periods according to the level of demand [17]

Mines, large factories and other electricity intensive facilities are charged according to the Megaflex Tariff Structure of Eskom. The Megaflex tariff structure is applied to facilities that require more than 1 MW of electricity. Figure 8 indicates the retail prices of the three different periods of intensity of the Megaflex Tariff Structure [17].



Active energy charge:

High-demand season (June - August)		Low-demand season (September - May)
74,21c + VAT = **84,60c/kWh**	Peak	21,06c + VAT = **24,01c/kWh**
19,62c + VAT = **22,37c/kWh**	Standard	13,07c + VAT = **14,90c/kWh**
10,67c + VAT = **12,16c/kWh**	Off-peak	9,26c + VAT = **10,56c/kWh**

Figure 8: Mega flex retail price structure [17]

The planned electricity tariff increase will force consumers to utilise electricity more wisely. In 2008 the retail price increased by a combined 29.38%. Eskom requested a further increase of 53% in 2009 [18]. This will be a combined increase of 97.9% within two years.

Table 1 indicates the electricity consumption of a typical gold mine and its financial implications. It is clear that these hikes will have a drastic effect on the production costs of mines. A rise of 53% will increase the annual electricity bill of the mine by R27, 6 million. The production cost will increase by R2.3 million per month.

	Tariff		
	Winter	Summer	Unit
Peak	72.05	20.52	c/kWh
Standard	19.04	12.77	c/kWh
Off-peak	10.38	9.1	c/kWh
Total	652.73	315.87	c/kWh/day
kWh	1200000	1200000	kW/day
Total for period	21213725	30797325	R
Total for year		R 52,011,050	
53% Increase		R 79,576,906.50	

Table 1: A summary of typical gold mine annually electricity consumption and its financial implications.

1.3. Electricity demand in the mining sectors

The South African mining industry accounts for about 26% of the country's total electricity use [22]. Eskom is demanding a reduction in mining industry consumer demand of between 10% and 15% by 2015. This will create a national reduction of 2.6% [22].

A typical gold mine possesses major electricity consuming equipment. In 2005 the mining industry's electricity consumption was 40 557 GWh, at an average cost of 15.36 c/kWh. This amounts to an annual cost of R6.2 billion in electricity consumed by the mining industry.

The main electrical consuming equipment includes:

- Compressors
- Underground mining activities
- Underground pumping stations
- Winding systems
- Smelter plants and mineral processing equipment
- Cooling and ventilation
- Offices, hostels and other essential services

It is clear that the mining industry will be able to make a contribution in an attempt to stabilise the national power grid. The availability of the country's resources will also benefit, while maintaining a sustainable future for generations to come.

Savings in electrical energy are feasible on refrigeration systems. Previous studies conducted by Schutte (2007) and Calitz (2006) [25], have found that savings can be achieved by applying low cost methods such as the back-passing of cold water and compressor inlet guide vane control.

Refrigeration consumes an average 0.5 % of the total electricity supply in South Africa. It is essential to investigate the possibility of DSM on these systems. Previous studies successfully implemented DSM on surface refrigeration systems with little or no technical modifications.

1.4. Mine refrigeration systems

The electricity consumption per unit gold increases with the depth of a gold mine. The ambient temperature of the working environment also increases with depth. These factors force the mine to install additional refrigeration systems underground. Another problem is that the electricity consumption and the cost per ounce increase with reduced quality of the ore [23].

The introduction of underground refrigeration machines has resolved this problem. The cooling of the mine relies entirely on its refrigeration system and large part of the electrical energy is consumed by the refrigeration system due to the depth, size and temperature of the mine [24].

The mine water cycle is in a closed loop to reduce, or even eliminate, the environmental effects of mining process. The blasted ore is cooled by heat transfer to cold water and evaporative cooling. The mine ventilation air is cooled and dehumidified by a Bulk Air Cooler (BAC) which receives cold water from the refrigeration system [6].

The power consumption of the surface refrigeration system is dependent on the atmospheric conditions and will therefore change with the changing seasons [25]. The contribution of the refrigeration system to the total power consumption may be reduced from 25% to 13% when the seasons change from summer to winter.

Underground refrigeration machines are not subjected to ambient surface conditions. The underground environment is stable throughout the year. Therefore the electricity consumption of underground refrigeration machines is constant throughout the year.

1.5. Summary

This study continues to build on the following dissertations: Energy management of a multi-stage surface refrigeration plant, by Schutte (2007) and, Research and implementation of a load reduction system for a mine refrigeration system by Calitz (2006) [25].

This dissertation commences with familiarising the reader with the existing electricity crisis and the requirement for DSM. Clarifications will be made on the electricity usages on gold mines. The requirement for refrigeration on gold mines was explained in the previous sub-chapter.

Reasons for this study will be supplied and the nature of it will emerge throughout this dissertation. The literature analysis will include methods and revised methods of operation. A firm basis of relevant information regarding refrigeration and the electricity situation will also be included in the literature analysis.

A case study will be completed on a mine refrigeration system, including an underground refrigeration system at Elandsrand Gold Mine (EGM). A simulation model will be built of the refrigeration system and simulations of the various control strategies will be analysed.

A revised control strategy will be developed and implemented on the refrigeration system. The effect of the revised control strategy is verified, controlled and monitored. Data will be encapsulated and results will reveal the efficiency of the philosophy. In the conclusion the effect of the study is discussed.

1.6. Objectives of this study

The main objectives of this study include the following:

- Investigate the electricity demand of refrigeration systems used for cooling mines with the focus on underground refrigeration systems.
- Compile an electrical and thermal baseline of this refrigeration system in order to understand the electrical and thermal power requirements of the mine
- Develop an optimal equipment control strategy to reduce energy consumption during the evening peak period
- Apply this strategy in order to aid alleviating the national electricity supply problem.
- Compare predicted and actual results and evaluate effectiveness

2

UNDERGROUND REFRIGERATION SYSTEMS AND THE ASSOCIATED DSM OPPORTUNITIES

Background on mine refrigeration systems and DSM load shift potential

2. UNDERGROUND REFRIGERATION SYSTEMS AND THE ASSOCIATED DSM OPPORTUNITIES

2.1. Introduction to the thermal load of the mine

Mining activities at great depths develop immense thermal heat loads. These heat loads mainly originate from shafts, tunnels and stopes. The main shaft accounts for almost 50% of the heat load. Figure 9 illustrates the total thermal load of a typical gold mine [26].

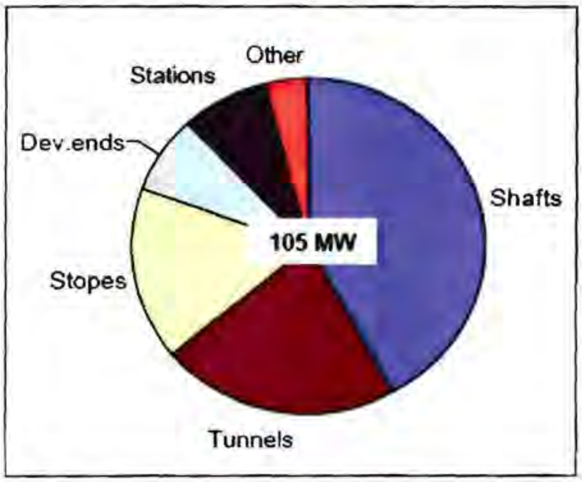


Figure 9: Breakdown of mine heat loads for a typical gold mine [26]

Figure 10 illustrates the thermal cooling requirements of a typical gold mine. The cooling requirements are greater than the thermal load shown. This is due to cooling losses that are caused by heat pick-up. It is essential that these losses are kept to an absolute minimum [26].

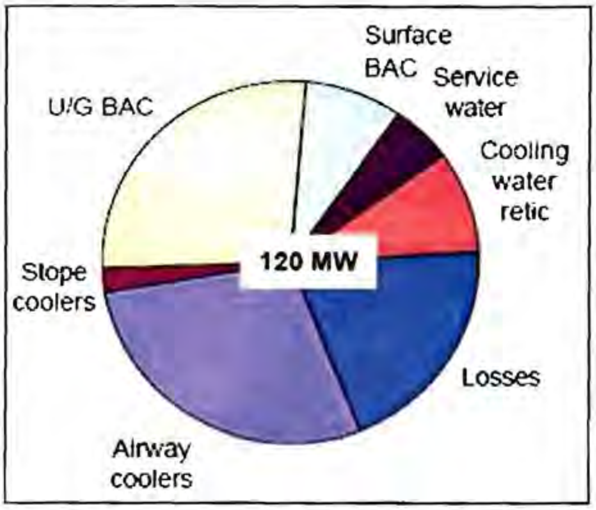


Figure 10: Mining cooling requirements [26]

From these graphs can be seen. Figure 11 illustrates the capital and running costs of a typical mine. From these graphs it can be seen that refrigeration and ventilation are responsible for more than half of the capital cost, which is nearly one third of the operating cost. The operating costs are given as present value costs during the life-of-mine [26]. Miscellaneous

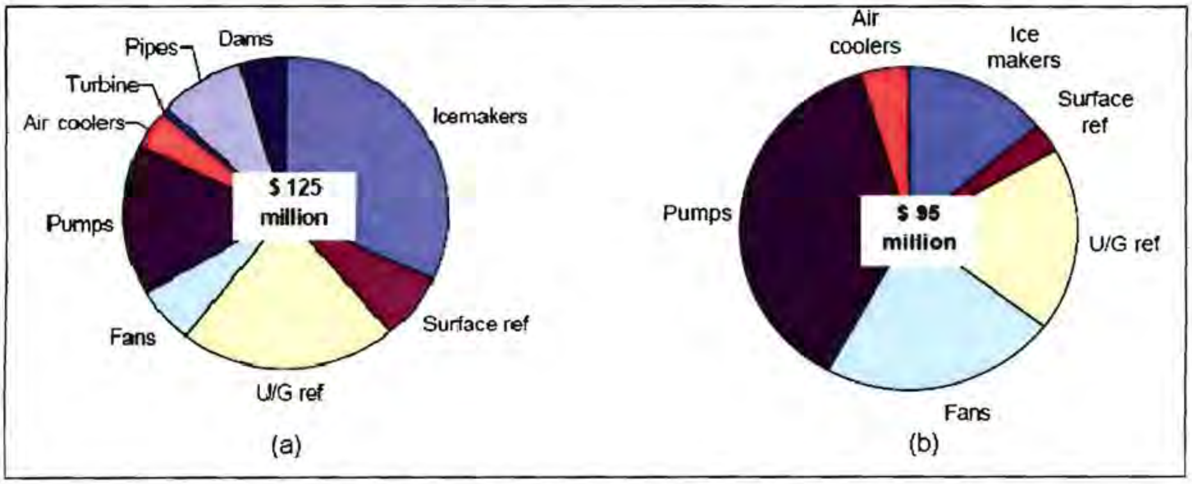


Figure 11: A model mine's capital cost (a) and operating cost (b) [26]

2.2. The process of refrigeration

Refrigeration is the process of removing heat from an enclosed space [27]. Cooling refers to any natural or artificial process by which heat is dissipated. The

Clausius statement of the Second Law of Thermodynamics states that some form of work must be performed in order to extract heat from an enclosed space [28].

The majority of refrigerators implement vapour-compression cycles. This same method is used in many large commercial and industrial refrigeration systems. Figure 12 provides a schematic diagram of the components of a typical single stage vapour-compression refrigeration system [29].

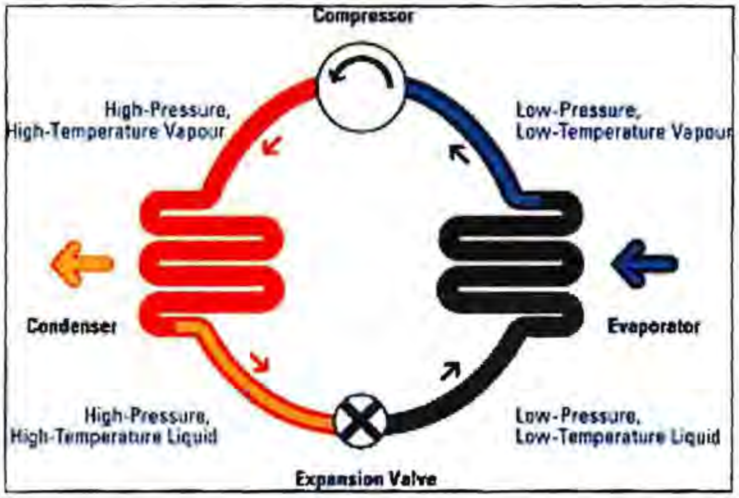


Figure 12: Graphical representation of vapour compression refrigeration [29]

All such systems have four similar components, namely:

- Compressor
- Condenser
- Expansion valve
- Evaporator

The sequence of the refrigeration cycle is shown in Figure 13. The process of vapour-compression commences by circulating refrigerant entering the compressor. This thermodynamic state of the refrigerant is known as a saturated vapour. The vapour is now compressed, i.e. 4 -1 in Figure 13, to a higher pressure resulting in a higher temperature [30].

The compressed vapour is now in the thermodynamic state of superheated vapour. The superheated vapour passes through the condenser coils, 1 - 2. Heat transfer at constant pressure takes place and the vapour will condense. The cooling agent in the condenser is typically cool water or air. The vapour is cooled to a saturated liquid state [31]. An adiabatic, irreversible expansion, 2 – 3, of the refrigerant takes place through an expansion valve. The liquid experiences a decrease in pressure to reach a liquid-vapour equilibrium state [31].

This cold liquid-vapour mixture then passes through the evaporator coil 3 - 4. A fan circulates the warm air across the coil containing the cold refrigerant liquid-vapour mixture. The warm air evaporates the liquid part of the cold refrigerant mixture and is cooled down to the desired temperature [30].

The circulating refrigerant removes heat from the air passing through the evaporator. The refrigerant vapour from the evaporator is saturated vapour once again and is returned to the compressor. This completes the refrigeration cycle.

The thermodynamics of a vapour compression cycle can be seen in the Temperature-Entropy diagram of Figure 13.

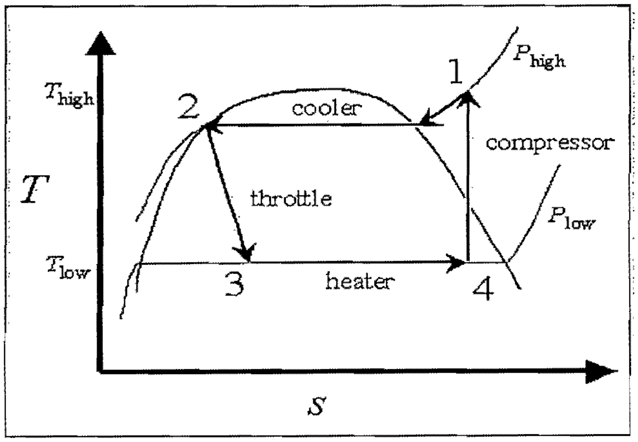


Figure 13: Temperature–Entropy diagram for a vapour compression cycle [32]

Entropy can be defined as the amount of energy in a physical system that is not available to do work. It is a key factor to thermodynamic relations and deals with the physical processes and whether they occur spontaneously [33].

Refrigeration on macro scale follows similar basic principles. It is mainly used to refrigerate water. The water is pumped through the evaporator and cooling takes place. The compressor motor is extremely electricity intensive, but the condenser and evaporator motors are less energy consuming.

Figure 14 indicates a refrigeration system used in industrial and mining environments. This figure represents the vapour absorption machine in the Hitachi refrigeration machine range. The models range from 80 TR to 1250 TR. It applies Hitachi Patented parallel flow cycle using medium pressure steam [34].

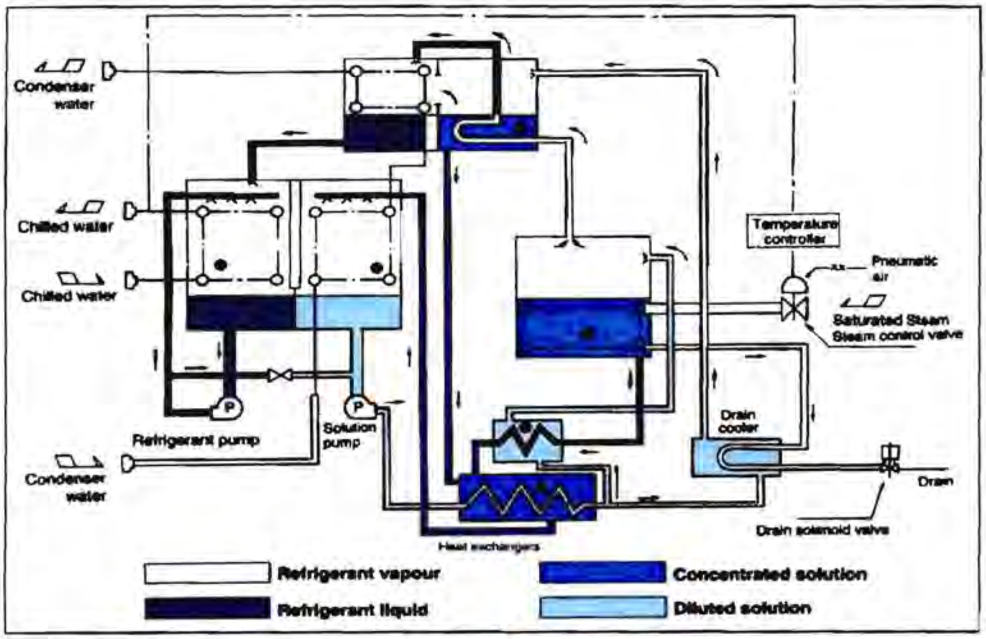


Figure 14: Refrigeration cycle of the parallel flow method that is used by certain mines [34]

2.3. An underground refrigeration system on a South African gold mine

The gold mining industry is presently mining at depths beyond 3500m. At these depths the rock temperature exceeds 70°C. Health and environmental issues arise when the average underground ambient temperature exceeds 28°C; this is known as the reject temperature. Figure 15 indicates the cooling required with increasing depth.

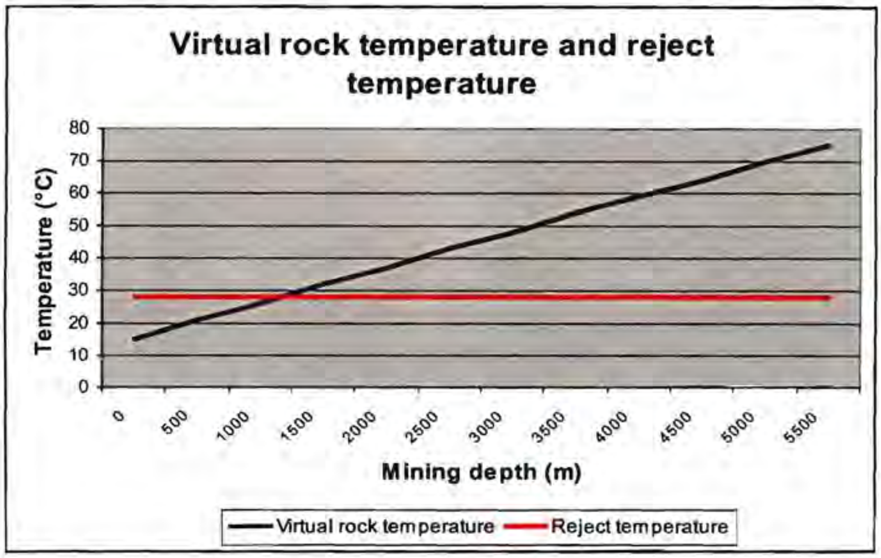


Figure 15: Virtual rock temperature and reject temperature

The factors that influence the virtual rock temperature include:

- Thermal rock conductivity and capacity
- Rock density
- Geothermal gradient
- Haulage depth
- Surface height above sea level [35]

The capability of surface refrigeration is unable to relieve the thermal load presented by these great depths. In order to reduce this thermal load, underground refrigeration presented a viable solution. The new environment of the machines possesses its own variables and constraints.

The more constant and predictable ambient conditions of an underground refrigeration system is its greatest advantage. However, there are also various disadvantages associated with the underground refrigeration machines. Studies have shown that the most significant of these disadvantages are the following:

- Limited air quantities due to restricted ventilation underground result in high condensing temperatures
- Underground air with relatively high wet-bulb temperatures has to be used for condenser heat rejection
- Reduced coefficient of performance results form these two conditions
- Water quality is inferior to surface utilised water
- Supervision and maintenance is difficult which shortens life span of equipment [35]

2.4. Integrating an underground and surface refrigeration system

The mine cooling philosophy plays an important role and characterises the positioning and type of refrigeration systems. As the depth of a mine increases, so also does the severity of geothermal and auto compressive heat problems. An integrated refrigeration system offers a viable solution [36].

The most general examples in which a surface and underground system is active will be discussed in this section. The essential role of the underground system is to concentrate the heat into a lower flow, higher temperature system for transmission to surface [36].

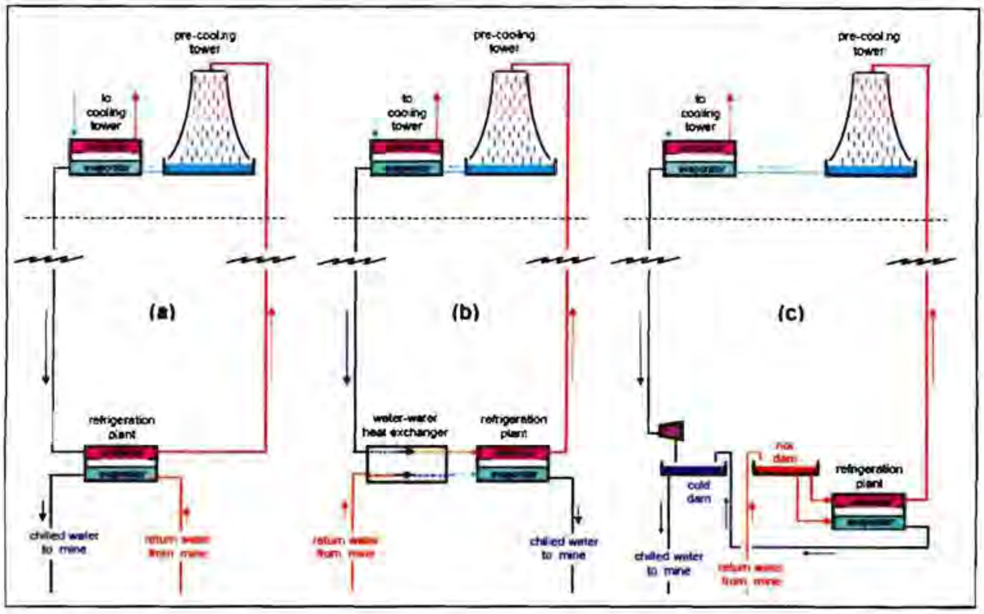


Figure 16: Examples of system configurations for combined surface and underground refrigeration plant [36]

System (a) in Figure 16 represents a system where the surface plant is used to cycle water and remove heat from the condensers situated underground. System (b) represents an energy efficient system. The water passes through a water-to-water heat exchanger before entering the condensers [36].

The return water will be pre-cooled in the exchanger before passing through the evaporators. System (c) the exchanger is replaced by a turbine. The cold water from the turbine is stored in a subsurface cold dam. In this example the hot dam water is split [36].

A portion of the hot dam water serves as the cooling agent in the condenser and returns it to the surface. The residue is chilled again and stored in a sub-surface cold dam. In all of the above examples surface produced cold water can be used for bulk air cooling. This cooled air is used to relieve the thermal load of the shaft [36].

A surface bulk air cooler (BAC) is used to cool the air that is sent to the subsurface sections. It is recommended that surface cooled air should be cooled to as low as practical a temperature. Heat accumulation and cooled air leakage are factors that contribute to inefficient cooling of surface air. An optimal temperature for surface cooled air is 10°C [26].

Underground bulk air cooling is also essential when mining at great depths. The wet bulb temperature of the cooled air increases at a rate of 4°C per 1000m below surface level. Hence in ultra deep mining areas it is vital to re-cool the air in order to sustain an acceptable ambient temperature [26].

It is optimal for the mine to install an underground refrigeration system at a depth ranging between 2000m and 3000m. Two BACs are required: one is used to cool the air sent down the mine, and the other to cool the circulated air. A favorable wet bulb air temperature underground is 20°C [26].

A refrigeration system is of great importance to the safety and security of a mine. Cooled air plays an essential part in establishing a comfortable working environment. This cooled air must be continuously supplied in order to sustain a level of comfort underground.

Load shifting must be applied in such a manner that it will not negatively influence the thermal relief supplied by the refrigeration system. During DSM peak clipping, a reduction in thermal relief will be experienced. It is essential that a safe margin of reduction is established.

2.5. The essential modifications required for DSM on an underground refrigeration system

The established system hardware determines the necessary modifications required for DSM. The hardware includes:

- Valves
- Pipe layout
- SCADA system capabilities
- Underground dam positioning

- Dam sizes
- Bulk air cooler capacities
- Level of automation

Refrigeration machine capabilities determine the feasibility of DSM. These capabilities include:

- Evaporator and condenser flow rate
- Cooling capacity
- COP

A cooling plant must be fully automated, remote viewed, and controlled. The machine must be continuously monitored by the SCADA system. All other system components must be easily accessible and remote viewed by the SCADA system. The SCADA system must be interlinked with the suitable Real-time Energy Management System (REMS) software.

On Site Information Management System (OSIMS) is a data management package. A baseline can be constructed by extracting data from this software package. It will also assist to accurately calculate the electrical and monetary savings of DSM.

Direct monitoring of such a system is also required. Hermes is a software package that enables the system to be monitored from any location using a General Packet Radio Service (GPRS) connection. All system details can be remotely viewed and the operator is able to manually override the system.

Hardware modifications of load shifting applications are fully funded by ESKOM whereas energy efficient applications are only partially funded. All implementations are subject to verification after completion. An independent verification group is appointed to audit the results.

REMS is a software package developed by HVAC International that assists with effective energy management. A stable communication network is needed for interaction between REMS and the existing SCADA network.

A new control strategy will be developed. This control strategy will be developed to promote energy neutrality. Electricity consumption will be shifted to periods of less demand. The strategy will result in little or no electricity usage during the evening peak periods.

Another control strategy is to reduce the energy to supply thermal relief. Tests must be conducted to establish a trend of temperature increase as a function of time. If this trend is manageable and enough thermal relief is provided during non-peak periods, peak clipping will be feasible.

2.6. Conclusion

It is apparent that refrigeration machines are very electricity intensive. All mines need refrigeration and ventilation to create a suitable working environment. Ultra deep mines have underground refrigeration machines to increase effectiveness of cooling and ventilation.

DSM is possible on mine surface refrigeration systems as shown by Schutte (2007) and Calitz (2005) [25]. The feasibility of underground refrigeration systems will be investigated, taking into consideration the mine water consumption, chill water storage capacity, and installed refrigeration capacity.

3

CREATING A SIMULATION MODEL

This chapter will discuss the investigation process, the simulation model created and the expected DSM results.

3. CREATING A SIMULATION MODEL

3.1. Acquiring data and identifying system constraints and variables

Prior to submitting a DSM proposal, an investigation must be conducted on the applicable mine. This investigation must entail the feasibility of electricity saving potential, an estimated monetary saving, and the date of savings commencement. This section will discuss the investigation process.

The present method of operation of the refrigeration system needs to be modelled. Data must be acquired and 24h-profiles of the key parameters must be created. These profiles will supply the system analyser with the fundamental information regarding the performance of the present system.

Figure 17 indicates the existing system layout at Elandsrand Gold Mine (EGM):

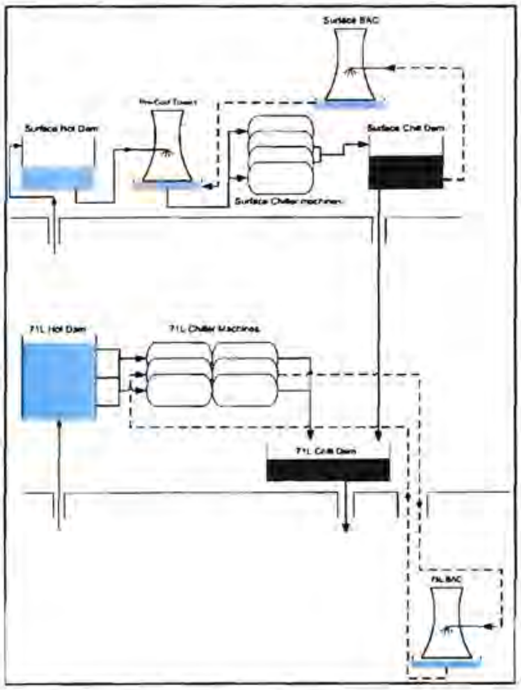


Figure 17: Refrigeration system on EGM

By law, mines are required to log critical information which must be stored in a data base. This database may be in electronic format or on paper log sheets. Usually the data is represented chronologically. The accuracy of the data is of paramount importance.

The critical variable data required at EGM at surface are:

- Levels of the hot, pre-cool and cold dams
- Water temperatures of the dams
- Water flow rate into and out of the dams
- Water flow rate through the refrigeration system
- Inlet and outlet temperature of each refrigeration machines
- Water flow rate to and from the BAC
- Power consumption of the compressor motors of the refrigeration machines
- Power consumption of evaporator water pumps, condenser water pumps and the condenser cooling fans

The critical variable data required at EGM on level 71 (71L) are:

- Levels of the hot and cold dams
- Water temperatures of the dams
- Water flow rate into and out of the dams
- Water flow rate through the refrigeration system
- Inlet and outlet temperature of each the refrigeration machines
- Water flow rate to and from the 75L BAC
- Power consumption of the compressor motors of the refrigeration machines
- Power consumption of the 71L evaporator water pumps, condenser water pumps and the condenser cooling fans

In order to successfully analyse a refrigeration system this data must be analysed and graphed. It is necessary to collect data for a typical summer and winter month. It is essential to ensure the collected data must be complete and accurate.

Days on which different standard operational procedures occur should be identified and excluded from the investigation.

Microsoft Excel (ME) is a powerful tool and will be used to assist the analyser in creating 24-hour profiles of data. Standard data files and log sheets need to be processed in order to create an accurate graph. All data points are recorded as a function of time.

Initially the data is documented electronically in a ME log file. Using the *hour*-function the data can be sorted as values that occurred during a specific hour. The integer hour value of the time of occurrence will be assigned to each of the data points.

Function 1 illustrates the application of this function:

$$\begin{aligned}&= hour(serial\_number)\\&= hour(22:34)\\&= 22\end{aligned}$$

Function 1

The data will now have various corresponding integer values according to the time of occurrence. An average hourly value must now be obtained. The sum of the data occurring in a specific hour must be obtained, as well as the number of data points during that specific hour.

The average hourly value can be calculated by dividing the sum value by the number of data points. Function 2 quantifies this method in ME:

$$Average\_hourly\_value = \frac{sumif(range, set\_value, data\_range)}{countif(range, set\_value)}$$

Function 2

A 24h-profile can now be constructed for all the crucial variable data. A table summarising the maximum and minimum values of the variable data range will serve as constraints of the system. These values are obtained by using the Function 3 in ME:

$$= \max(set\_point)$$
$$= \min(set\_point)$$

Function 3

Figure 18 indicates the existing surface refrigeration system at EGM. The present refrigeration configuration and water flow path are unchangeable. The evaporator pump of each refrigeration plant only influences the amount of water flow passing through the refrigeration machines. Infrastructure modifications can influence the water flow path.

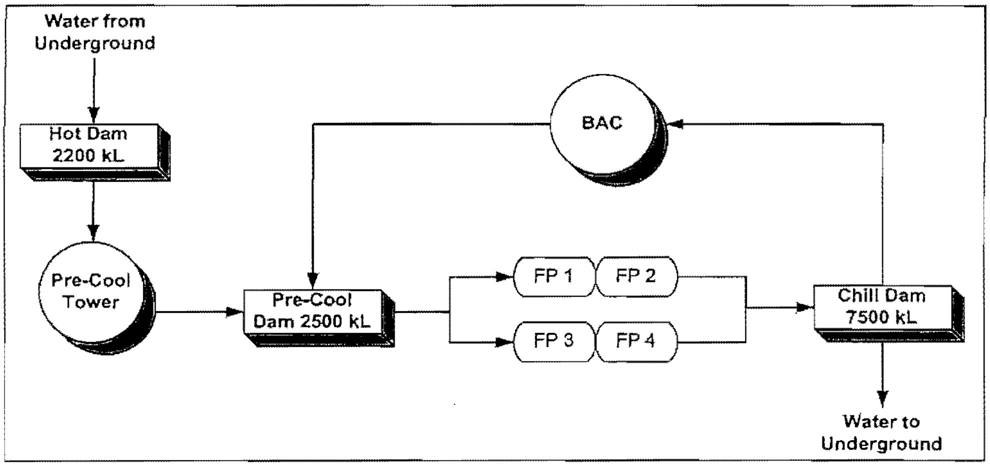


Figure 18: The surface refrigeration system layout and water flow path

Presently the surface refrigeration system at EGM satisfies the following parameters, which are stipulated below. These parameters were obtained from actual mine data. A simulated configuration must comply with these parameters:

- The hot water pumped from the underground mining levels has an average flow rate of 300 L/s with a maximum flow rate of 350L/s and a minimum flow rate of 240 L/s during a typical weekday. This water is stored in the surface pre-cool dam.

- The pre-cool tower cools the hot water down to an average temperature of 19 °C.

- The four surface refrigeration machines are connected into two lead-lag configurations. The first refrigeration machine (lead machine) of the pair reduces the temperature of the inlet water. The second machine (lag machine) will reduce this water to a desirable outlet temperature.

- The average weekday water flow rate through each refrigeration machine pair is 310 L/s during the summer. The chilled water is stored in the cold dam.

- The flow rate through each refrigeration machine pair decreases to approximately 220L/s throughout an average winter weekday.

- Each refrigeration machine pair has a maximum flow rate of 450 L/s.

- The inlet temperature of the two leading refrigeration machines may not be lower than 14 °C.

- The surface refrigeration machines cool water to an average outlet temperature of 4.5 °C.

- The surface refrigeration machines consume approximately 158,202 kWh per average summer day and 141,203 kWh per average winter day. These are the baseline values of the daily produced thermal energy.

- The 71L cold dam and mining levels receives cold water at an average of 280 L/s from the surface cold dam.

- The surface cold dam has a maximum consumption of 300 L/s and a minimum consumption of 250 L/s.

- There is one productive mining level between surface and 71L which accounts for a small fraction of this water.

- The surface BAC consumes between 180 – 220 L/s of cold water.

- The surface hot dam level capacities must be controlled between 40% and 95%, and the cold dam level must be controlled between 65% and 95%.

Figure 19 is a schematic of the existing layout and water flow path of the refrigeration system on 71L:

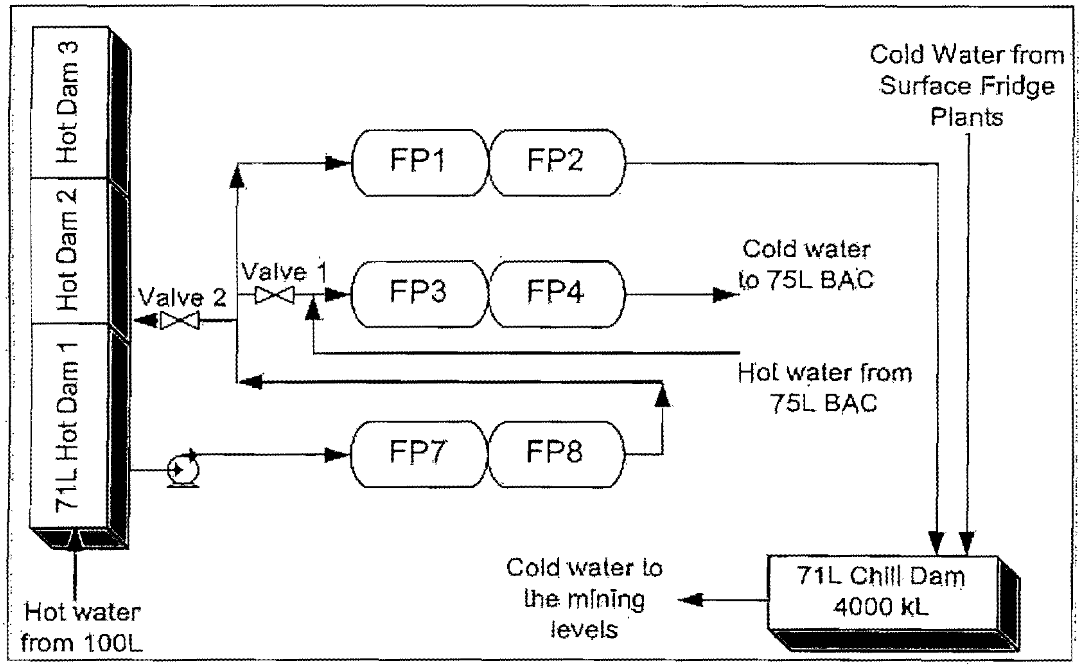


Figure 19: The present configuration used at 71L refrigeration

At 71L the parameters of the refrigeration system do not change significantly throughout the year. This is due to the very nearly constant ambient temperature underground. The parameters were verified from actual mine data. An optimised system must also comply with the following parameters:

- The used hot water returning from 100L has an average flow rate of 95 L/s and an average temperature of 26.5 °C during a typical weekday. The hot water is stored in the first hot dam.

- The 71L hot dam is cooled to approximately 22 °C by a small amount of cold water being returned to the dam.

- The hot dam level must be controlled between 50% and 99% and the chill dam must be controlled between 78% and 99%.
- The refrigeration machines 1 and 2 and 7 and 8 are situated in a lead-lag configuration. Water is distributed from refrigeration machine 8 to refrigeration machine 1.
- These four machines produce an average outlet temperature of 6°C. The cold water is directed to the 71L chill dam.
- Refrigeration machines 3 and 4 cool water to approximately 3.5°C. The average water flow rate through this refrigeration machine pair is 130 L/s.
- Refrigeration machines 3 and 4 are in a closed loop configuration with the BAC on 75L.
- The 75L BAC consumes between 120 – 150 L/s to cool the air sufficiently.
- The 71L refrigeration plant uses approximately 118,500 kWh during an average week day. This is the baseline value of the daily produced thermal energy.
- The 71L chill dam receives water from the surface cold dam at an average temperature of 8 °C. The average flow rate of this water is 275 L/s.
- Mining levels consume cold water from the 71L chill dam at a rate of 395 L/s.

3.2. Modelling and optimising a refrigeration system

The refrigeration system of EGM will now be analysed. Various system optimisation techniques are identified. These techniques will include infrastructure modifications in order to optimise the electrical savings potential and will also determine the optimum control strategy. The infrastructure modifications are attached in Appendix A.

Dam levels and temperatures

Figure 20 represents the average hourly surface dam level on EGM.

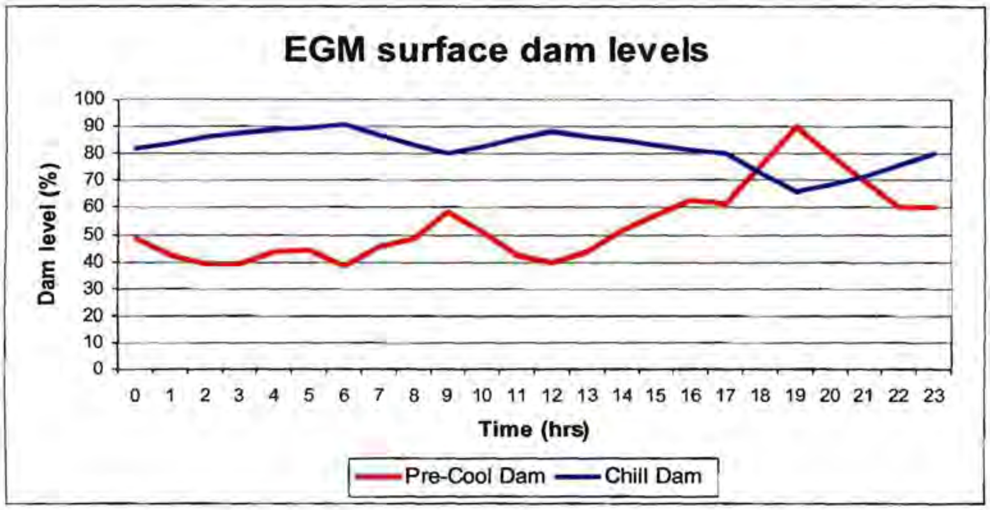


Figure 20: Surface dam level representation at EGM

Figure 20 shows that the mine's cold water demand reaches a peak between 18h00 and 20h00. The primary pumping into the warm dam occurs between 12h00 and 19h00 and between 06h00 and 09h00. The water of the cold dam is primarily routed to the chill dam on 71L.

Implementing an optimised load shifting technique the surface cold dam level needs to be at a maximum allowable and the pre-cool dam must be at a minimum allowable level just before the evening peak period. This can be achieved by integrating the control strategies of the pumping and refrigeration system in order to achieve the maximum saving.

Figure 21 indicates the average hourly water temperatures of the surface pre-cool and cold dam respectively:

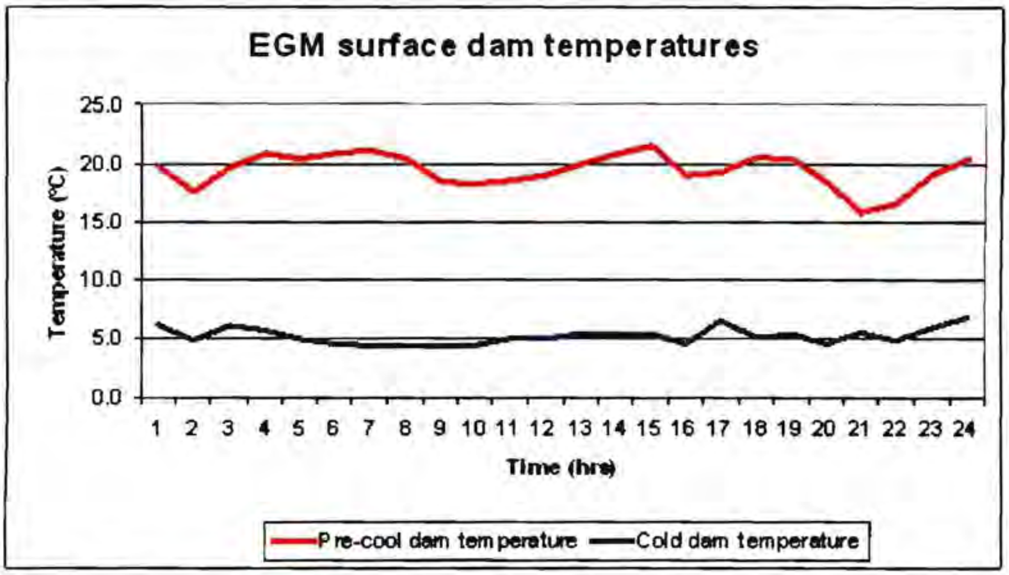


Figure 21: Surface dam temperatures of EGM.

Figure 21 shows the temperature of the surface pre-cool and cold dams as a function of time-of-day. The complete data series must be analysed in order to identify maximum allowable water temperatures of both dams. The minimum water temperature of the surface hot dam, below which machine surging could occur, must also be identified.

Figure 22 represents the average hourly 71L dam levels on EGM.

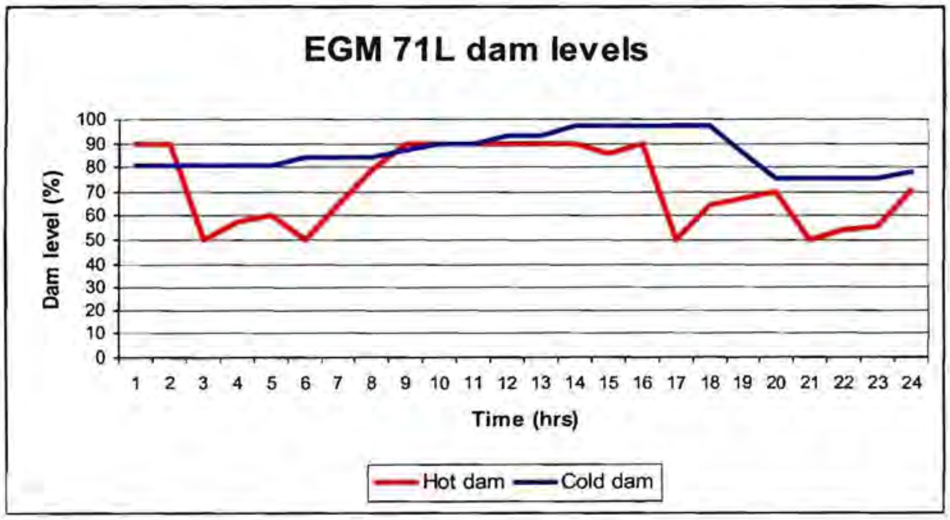


Figure 22: 71L dam levels on EGM

Dam water storage capacity is a major constraint on any refrigeration system. It is evident from Figure 22 that the mine's cold water consumption reaches a peak between 18h00 and 20h00. The primary pumping into the warm dam occurs between 22h00 and 01h00 and at 06h00 - 09h00. The pumping system will also be used to achieve the maximum saving as previously mentioned.

When investigating DSM it is essential to analyse these graphs and identify the factors that influence it. These factors vary from mine to mine. Production shifts play a significant role in cold water consumption. Ventilation and cooling of the working environment require a continuous supply of cold water.

Hence there will be a continuous consumption of cold water. Switching off refrigeration machines will prevent inflow into the cold dams and no outflow from the hot dams. However, there will still be a continuous outflow from the cold dam and inflow into the hot dam. Consequently the minimum level of the cold dam will be exceeded and the maximum level of the hot dam as well.

Figure 23 represents the average hourly water temperatures of the 71L hot and cold dams respectively:

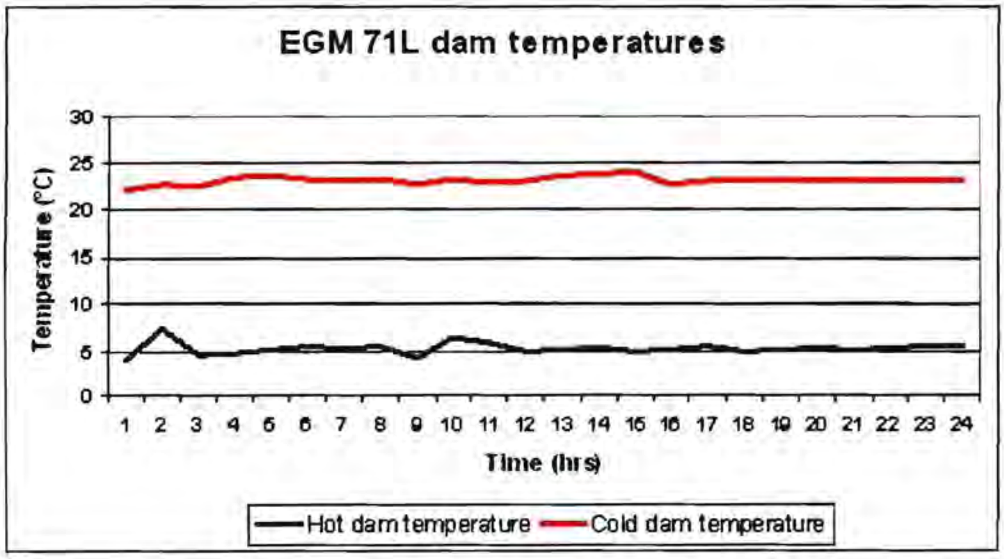


Figure 23: 71L dam temperatures of EGM

Figure 23 is the temperature curve of the 71L hot and cold dams. As in the case of the surface dams the complete data series must be analysed in order to identify maximum water temperatures of both dams. The minimum water temperature of the 71L hot dam must also be identified so as to prevent machine surging.

The wet bulb temperature of the cooled air must be analysed. The cooled air continuously relieves the thermal load of the shaft and therefore must be uninterrupted. Figure 24 represents the wet bulb temperatures of the cooled air from the BAC's on the surface and at 75L.

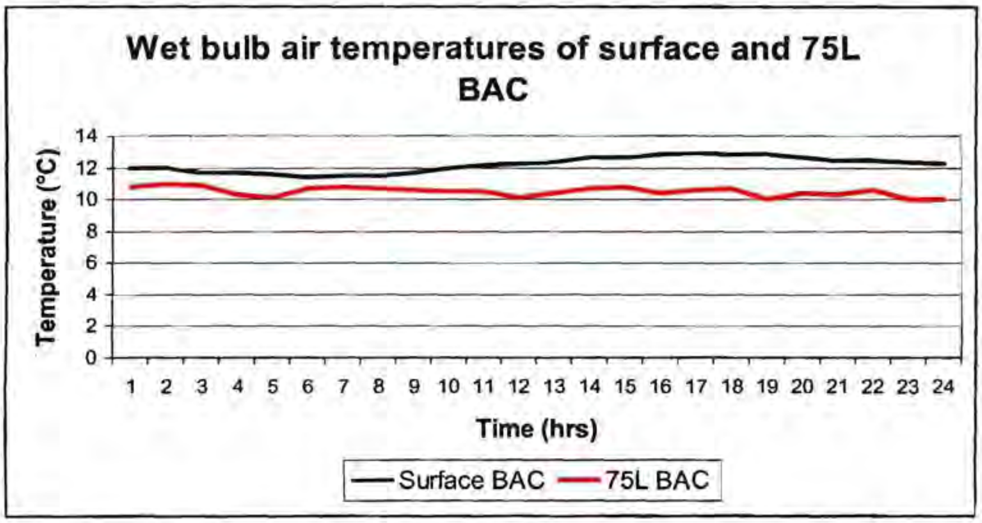


Figure 24: Wet bulb temperatures of cooled air from the BAC's

Infrastructure modifications

Preliminary investigations indicated that infrastructure modifications, on the surface system, must be made in order to maximise the electricity saving potential. A back-passing mechanism will be introduced to lower the inlet temperature to the machines. The cold back-passing water will act as an energy reducing mechanism.

Figure 25 illustrates the back-passing mechanism:

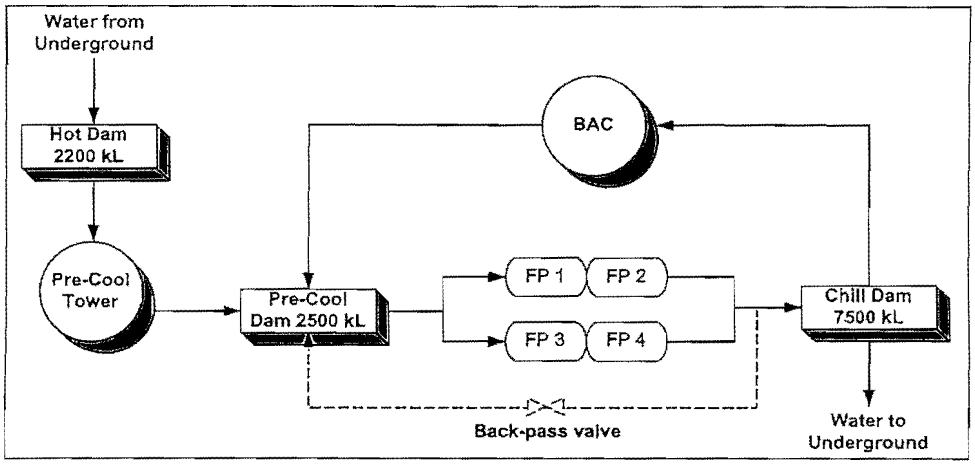


Figure 25: Needed infrastructure on the surface refrigeration system

Figure 25 indicates the required pipe work to redirect cold water to the pre-cool dam. The back-pass valve will control the amount of returning water into the pre-cool dam. The level and temperature of the pre-cool dam must still remain within the prescribed limits after this modification.

In Section 3.4 the following simulated results will be shown for the surface plant:

- Surface dam levels
- Surface temperatures
- Electrical power consumed

The existing infrastructure on 71L allows various water flow configurations. These different water flow configurations must not exceed water temperature constraints. The revised configuration must also ensure the optimal power saving potential during Eskom peak periods.

The first option is to divide the hot dam into three separate smaller dams. This is possible because the three dams are interlinked through an equalising pipe situated on the bottom of each dam. The dams can be separated by closing the interlinking valves. Figure 26 illustrates this configuration:

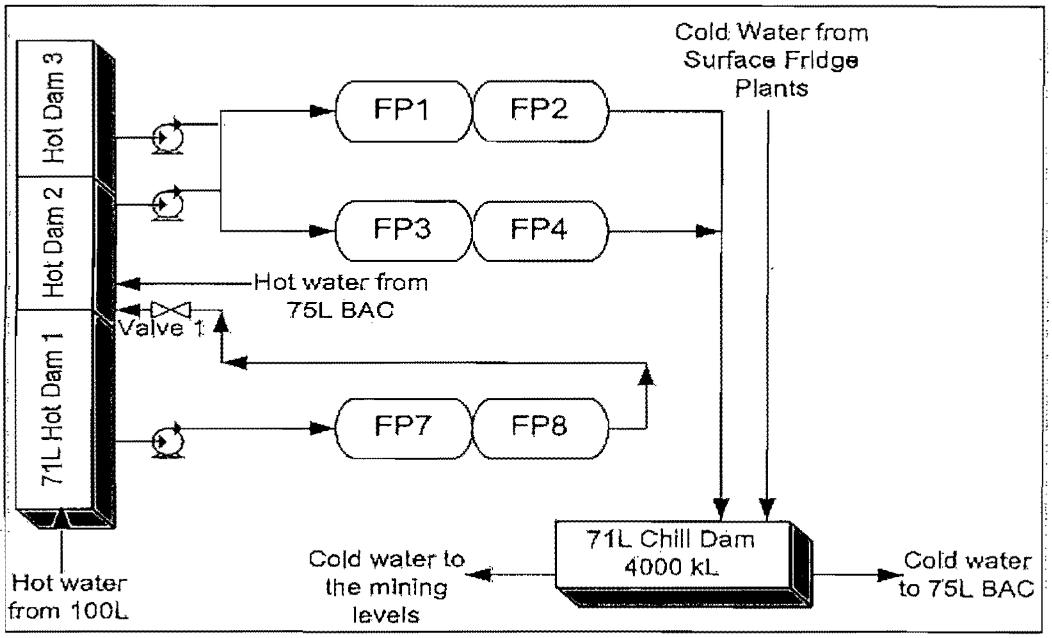


Figure 26: 71L flow configuration option 1

The hot water is pumped to 71L hot dam 1 from its sublevels. The water is cooled by underground refrigeration machines 7 and 8 and distributed to hot dam 2. Hot dams 2 and 3 will subsequently function as a pre-cool dam and will supply refrigeration machines 1, 2, 3 and 4.

Second stage cooled water will flow into 71L chill dam. The chill dam receives water from the second stage refrigeration machines as well as from the surface cold dam. The water flow path illustrated in Figure 26 will allow a considerable power saving potential.

The 75L BAC will not be in a closed loop with machines 3 and 4. The 71L chill dam will provide cold water to the BAC. This is possible during the entire day and during the peak periods when all the refrigeration machines will be inactive. Existing piping allows BAC return water to be returned to hot dams 2 and 3.

Maximum savings are feasible with this configuration due to energy efficiency by back passing colder water to the second pre-cool dam. The changes needed to the dams are extremely costly and modifications to the system will have a negative impact on mining production. Consequently this configuration cannot be implemented. This reduce the consumed electricity by almost 1 MW hourly outside the evening peak time period.

ESKOM allocates a budget for every DSM project. This will exceed the funds available for this potential saving. The underground cold dam temperature will rise to above the maximum allowable level and thus cooling of the sub levels will not be as efficient and will have a negative effect on the working environment and ultimately on productivity.

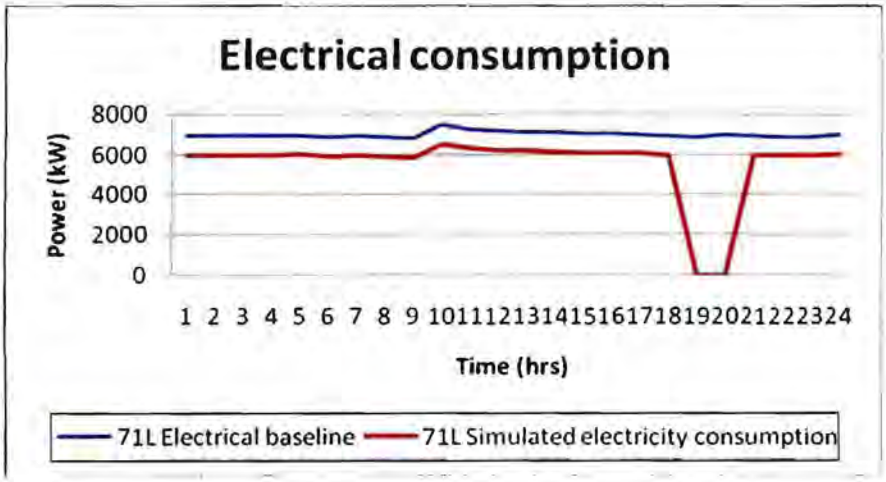


Figure 27: Simulated electrical consumption

Figure 27 indicates the simulated electrical consumption associated with the hardware modifications as discussed. However the cost implications associated with this modification will breech the allowed budget. Mining personnel raised a concern with total thermal relief produced.

The second option is to open the interlinking valves and view the 71L hot dams 1, 2 and 3 as a single unit. Figure 28 indicates this configuration:

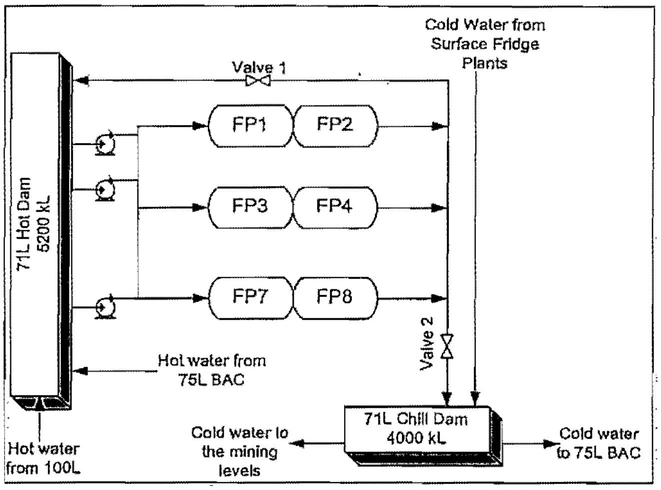


Figure 28: 71L water flow configuration option 2

The refrigeration machines are situated in a parallel configuration. Water is distributed from the hot dam to refrigeration machines 1, 2, 3, 4, 7 and 8. The cooled water from the refrigeration machines flows to the 71L chill dam. A small amount of chill water will be back-passed into the hot dam via Valve 1.

The back-passing is accomplished by a set of valves. In Figure 28, Valve 1 is an open/close valve, and Valve 2 is a modulating valve. The system will calculate the amount of back-passed water and will adjust Valve 2 accordingly. The water will then be returned through Valve 1 back to the hot dam.

Minimum infrastructure modifications are needed to the system for the flow configuration illustrated in Figure 28. Hot water from 100L is pumped to the 71L hot dam. The BAC return water is returned to the hot dam and will act as a further pre-cooling mechanism.

This will result in a reduction of electricity consumption of the cooling system and a lower temperature of the hot dam. This enables the secure shutdown of refrigeration machines 1, 2, 7, and 8 during the evening peak period. The flow through refrigeration machines 3 and 4 will also be reduced creating a further saving. The bill of materials of the infrastructure modifications is attached in Appendix 1.

Due to the minimum infrastructure modifications required and sustainable electricity saving this flow configuration will be applied when implementing DSM. In Section 3.4 the following simulated results will be shown:

- 71L dam levels
- 71L dam temperatures
- Electrical power consumed

Each mine possesses a unique method of operation. This control philosophy is applicable to EGM but other mines such as Target and Bambanani Gold Mines can be investigated and similar philosophies can be implemented.

Refrigeration machines

Definition 1 defines the thermal power produced by a refrigeration machine:

$$\boxed{Q_{Thermal} = \dot{m} * (T_{Inlet} - T_{Outlet}) * C_p = \dot{m} * \Delta T * C_p}$$

Definition 1

Thermal power is the product of water mass flow, the difference in water temperature and the coefficient of specific heat (at constant pressure) of water. This coefficient of heat transfer can be expressed in terms of the enthalpy change of water. Equation 2 defines this coefficient [28]:

$$\boxed{C_p = \frac{1}{m}\left(\frac{\delta Q}{\delta T}\right)_p = \frac{1}{m}\left(\frac{\partial H}{\partial T}\right)_p = \left(\frac{\partial h}{\partial T}\right)_p}$$

Equation 1 [28]

A study of the relevant refrigeration machines must be conducted. The most essential attribute of a machine is the thermal relief it produces. Figure 29 indicates the annual average hourly thermal power produced by the surface and the 71L refrigeration systems at EGM:

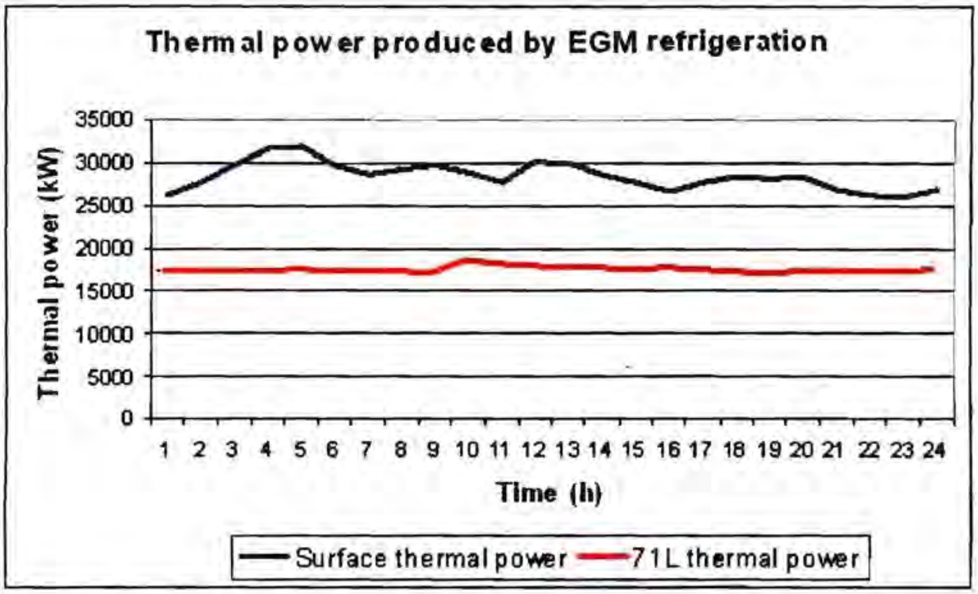


Figure 29: Thermal power produced by surface and 71L refrigeration plants as a function of time

It is important to calculate the maximum electrical power that the compressor motor consumes. A constant voltage is maintained thus the current and the instantaneous power factor are the variables. Equation 4 defines electrical power consumed by a three phase motor [39]:

$$\boxed{Q_E = \sqrt{3} * V * I * \cos\theta = \sqrt{3} * V * I * p.f.}$$

Equation 2

Q_e : Electrical three phase power
V : Voltage
I : Current
T : Phase Angle

Power factor is the ratio, P/VI, between apparent and real power represented by a dimensionless number between 0 and 1. A power factor of 0 will indicate a completely reactive energy flow. The stored energy in the load returns to the source on each cycle. A power factor of 1 will indicate that the load consumes all energy supplied by the source. [41]

Figure 30 indicates the annual average electrical power consumed by the compressor motors of the surface and 71L refrigeration systems at EGM:

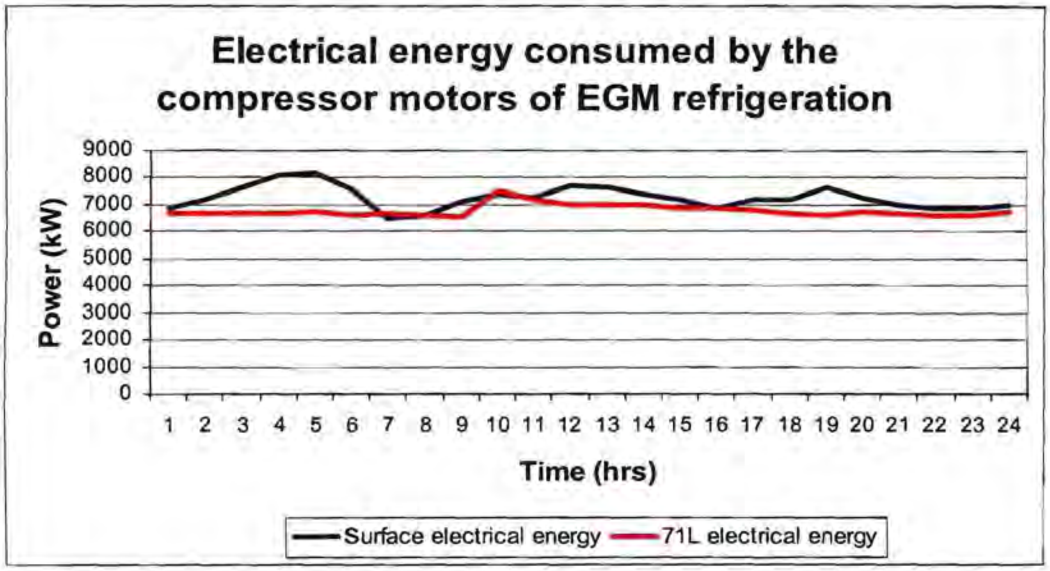


Figure 30: Electrical power consumed by the compressor motors of the surface and 71L refrigeration systems

For steady state AC circuits, electrical power has the three components:

- Average power, P = VI Cos Φ, measured in watts (W)
- Apparent power, S = VI, measured in volt-amperes (VA)
- Reactive power, Q = VI Sin Φ, measured in volt-amperes reactive (VAR) [37]

Where Φ = impedance phase angle.

P is the real component; Q is the complex, or imaginary component and S a complex value. This can graphically be represented by a power triangle as in Figure 31.

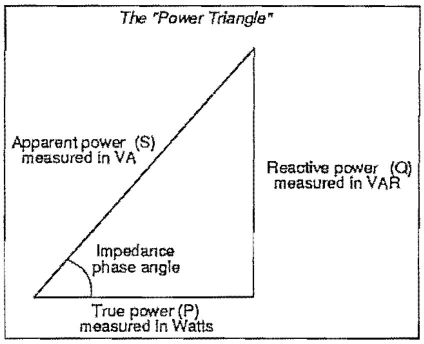


Figure 31: Power triangle [38]

The power factor is defined in Equation 5 as [40]:

$$\frac{P}{S} = \cos\phi \qquad \text{......Equation 3}$$

Equation 6 indicates that in the case of a perfectly sinusoidal waveform, P, Q and S can be expressed as vectors that form a vector triangle such that:

$$S^2 = P^2 + Q^2$$

Equation 4

Equation 7 indicates that if F is the phase angle between the current and voltage, then the power factor is equal to |cosF|.

$$P = S\cos\phi$$

Equation 5

$$S = \sqrt{3}VI$$

Equation 6

The electrical power consumption of the refrigeration system can be determined by this equation. The applied constant voltage is 6.6 kV, a medium voltage induction motor has a typical power factor of 0.85 and $\sqrt{3}$ is a constant. By obtaining the amps the power consumption of the refrigeration machine can be calculated.

An equally important parameter is the ratio of useful refrigeration effect to electrical energy consumed of the refrigeration system. This can be defined as the coefficient of performance (COP). Equation 8 defines the COP of the compressor motor of a refrigeration system.

$$\boxed{CoeffiecientOfPerformance = \frac{Q_{Thermal}}{Q_{Electrical}}} \quad \text{..........Equation 8}$$

Figure 32 indicates the COP of the surface and 71L refrigeration systems:

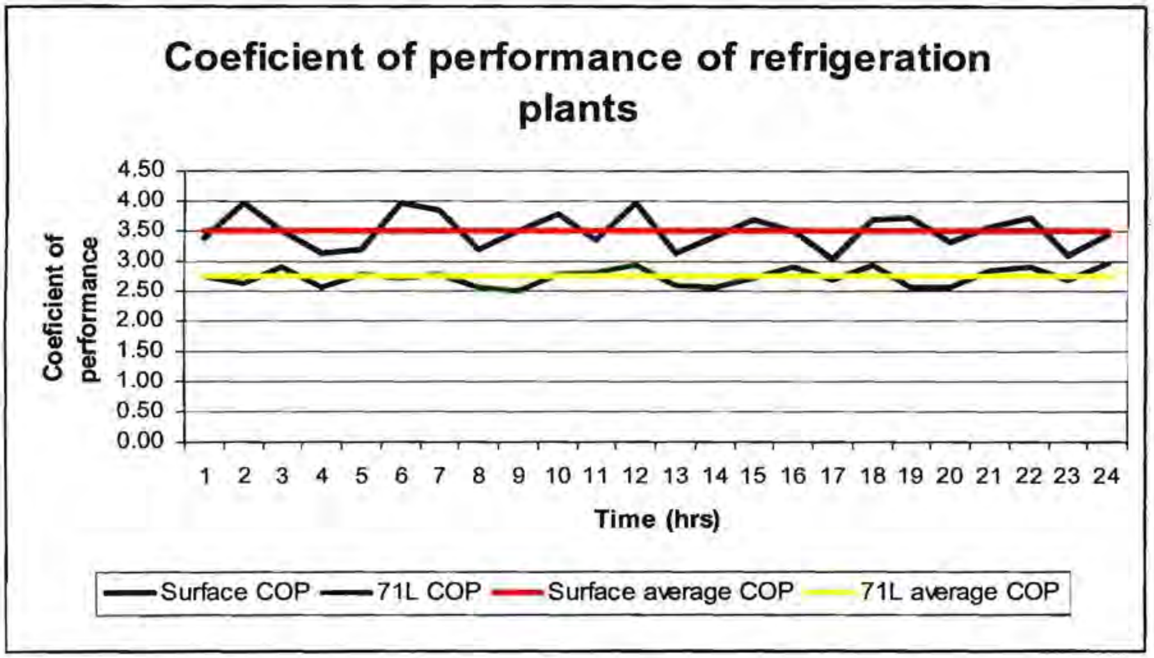


Figure 32: The COP of the surface and 71L refrigeration systems at EGM

The annual average hourly COP curve is shown in Figure 32. It varies due to the amount of cooling agent that passes through the evaporator. The daily average COP is also indicated. It is obviously desirable to maintain the COP as high as possible.

It is optimal to include low-voltage auxiliary power machines when determining the complete electrical load curve. These motors include the evaporator water pump, the condenser water pump and condenser cooling fans. These machines will always operate at close to their installed power rating.

Figure 33 indicates the auxiliary power associated with a refrigeration machine:

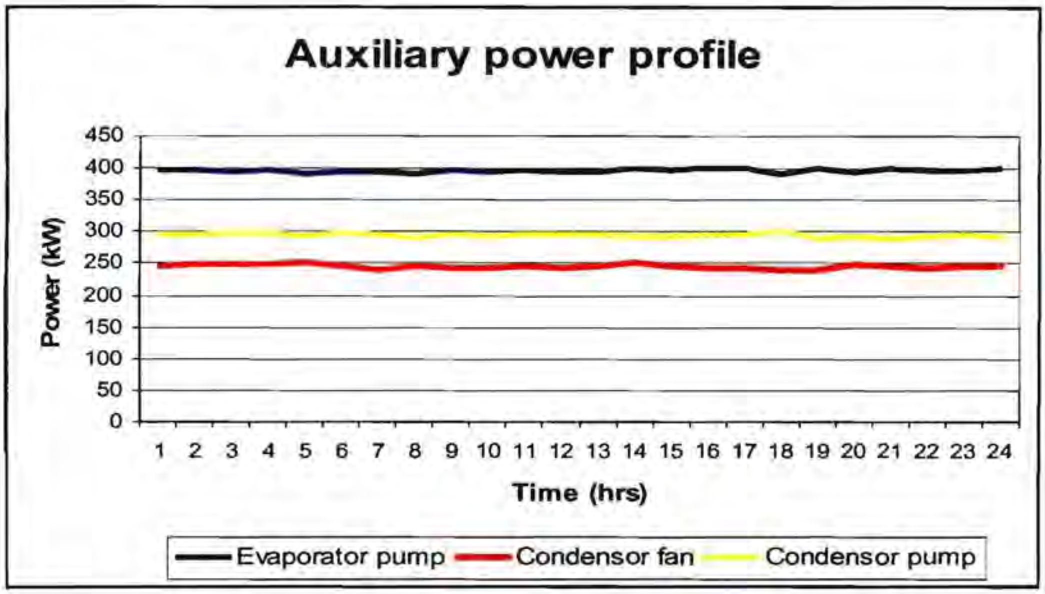


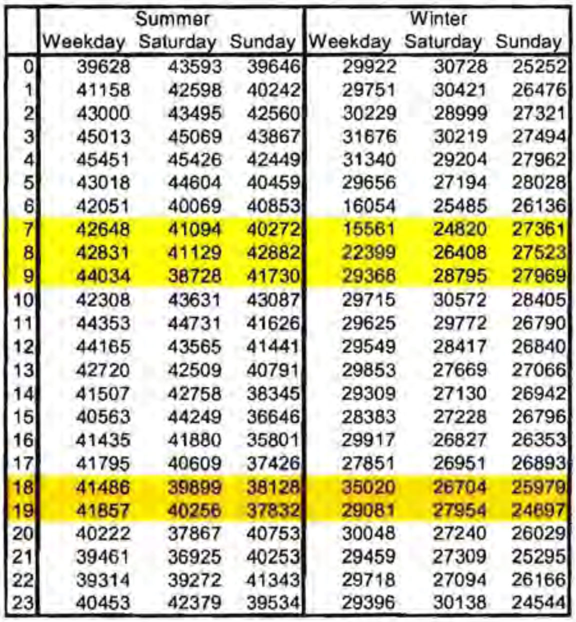
Figure 33: Auxiliary power of a refrigeration machine

An electrical baseline can be constructed comprising the electrical load profiles of the compressor motors of the refrigeration system and the auxiliary machines. The thermal baseline is the sum of the average thermal power each machine produces per hour.

These baselines can now be constructed using the different power curves of the different days. It is important to distinguish these load profiles into three subgroups. They are Weekday, Saturday and Sunday. An optional additional subgroup, Public Holiday, can also be considered if required.

Weather conditions play a significant role in thermal relief requirements of a mine. It is important to construct a baseline in order to accommodate the different seasons of the year. Therefore a baseline should be constructed for summer (September to May) and winter periods (June to August).

Figure 34 is the thermal power baseline of EGM (peak periods are highlighted):



	Summer			Winter		
	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
0	39628	43593	39646	29922	30728	25252
1	41158	42598	40242	29751	30421	26476
2	43000	43495	42560	30229	28999	27321
3	45013	45069	43867	31676	30219	27494
4	45451	45426	42449	31340	29204	27962
5	43018	44604	40459	29656	27194	28028
6	42051	40069	40853	16054	25485	26136
7	42648	41094	40272	15561	24820	27361
8	42831	41129	42882	22399	26408	27523
9	44034	38728	41730	29368	28795	27969
10	42308	43631	43087	29715	30572	28405
11	44353	44731	41626	29625	29772	26790
12	44165	43565	41441	29549	28417	26840
13	42720	42509	40791	29853	27669	27066
14	41507	42758	38345	29309	27130	26942
15	40563	44249	36646	28383	27228	26796
16	41435	41880	35801	29917	26827	26353
17	41795	40609	37426	27851	26951	26893
18	41486	39899	38128	35020	26704	25979
19	41857	40256	37832	29081	27954	24697
20	40222	37867	40753	30048	27240	26029
21	39461	36925	40253	29459	27309	25295
22	39314	39272	41343	29718	27094	26166
23	40453	42379	39534	29396	30138	24544

Figure 34: Thermal baseline for a refrigeration system in kW

The thermal power requirements are less during winter months. The mine benefits during these colder periods by the colder atmospheric conditions that result in greater thermal relief. The minimum allowable thermal energy produced per day is a major constraint when considering DSM.

Figure 35 is the baseline of the compressor motor of the refrigeration machines of EGM (peak periods are highlighted):

	Summer			Winter		
	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
0	13574	13128	11899	9534	9873	8163
1	13987	12857	12056	9486	9789	8493
2	14469	13105	12550	9605	9413	8544
3	15016	13556	13024	9999	9770	8752
4	15171	13650	12616	9930	9491	8847
5	14453	13481	12086	9438	9016	8877
6	14223	12114	12191	5770	8344	8360
7	14359	12399	12020	5627	8180	8668
8	14367	12426	12819	7457	8634	8831
9	15131	11732	12524	9590	9227	8978
10	14532	13061	13082	9619	9711	9351
11	15000	13363	12663	9537	9501	8879
12	14941	13077	12611	9513	9174	8891
13	14549	12729	12342	9597	8889	8830
14	14152	12772	11656	9407	8711	8758
15	13915	13175	11254	9167	8736	8804
16	14113	12527	10985	9562	8625	8634
17	14161	12184	11424	8974	8647	8768
18	14019	11995	11575	10872	8579	8461
19	14187	12113	11503	9304	8947	8125
20	13719	11416	12316	9551	8690	8514
21	13495	11178	12157	9390	8745	8295
22	13452	11808	12455	9457	8679	8541
23	13826	12794	11869	9407	9705	7975

Figure 35: Electrical baseline of the refrigeration machines in kW

The electrical baseline in Figure 35 represents the total electrical power consumed by the compressor motor which is required to provide the corresponding thermal energy. The ratio of electrical power that produces an amount of thermal power is not fixed and it is optimal to maximise this ratio. Figure 36 indicates the auxiliary motor electrical baseline (the peak periods are highlighted):

	Summer			Winter		
	Weekday	Saturday	Sunday	Weekday	Saturday	Sunday
0	926	935	924	626	619	621
1	940	928	950	622	636	630
2	923	929	922	623	618	618
3	937	947	922	635	618	628
4	933	949	935	636	626	625
5	923	944	948	633	635	618
6	931	923	927	618	621	624
7	949	945	943	633	632	636
8	936	939	943	629	632	627
9	941	942	939	631	629	631
10	949	950	924	636	619	636
11	940	944	930	633	623	630
12	927	923	950	618	636	621
13	950	927	922	621	617	636
14	935	931	921	624	617	627
15	939	935	934	627	626	629
16	922	937	928	628	622	618
17	938	948	947	635	635	628
18	928	934	927	626	621	622
19	943	926	920	620	617	632
20	928	920	929	616	622	622
21	945	945	943	633	632	633
22	936	925	940	620	630	627
23	948	932	929	624	622	635

Figure 36: Auxiliary machines electrical baseline in kW

The electrical baseline of the auxiliary machines has an important contribution in the electrical baseline of a refrigeration system. These machines are not as electricity intensive as the compressor motor but are included in the complete study. Motors which consume less than 5 kW are neglected.

It is optional to include a total annual baseline for the refrigeration system. Equations 6 and 7 are used to calculate an average baseline for the summer and winter periods:

$$\boxed{Summer\_Baseline = \frac{((Weekday * 5) + Saturday + Sunday)}{7}}$$

Equation 6

$$\boxed{Winter\_Baseline = \frac{((Weekday * 5) + Saturday + Sunday)}{7}}$$

Equation 7

Equation 8 is used to calculate the weighted annual baseline:

$$\boxed{Weighted\_Baseline = \frac{Summer * 9 + Winter * 3}{12}}$$

Equation 8

These baselines and 24-hour profiles form the basis of the model created for EGM. These variables need to be studied and the revised machine control strategy should not breech the limits of these baselines and profiles. Ideal profiles can now be derived in order to maximise the electrical savings possibility.

3.3. Analysis of various control strategies and techniques

Studies by Schutte and Calitz [25] have shown that DSM control strategies were successfully implemented on refrigeration systems. They are load-shifting, peak clipping and back passing of cold water. These methods have been verified at Kopanang Gold Mine and South Deep Gold Mine [6].

Load shifting enables the system to use less electricity during certain periods. Energy neutrality is when the same amount of energy is used daily by two different control strategies. Thus the area under the two power curves will be the same. The new and old load curves are energy neutral.

Figure 37 indicates a typical load shifting power curve:

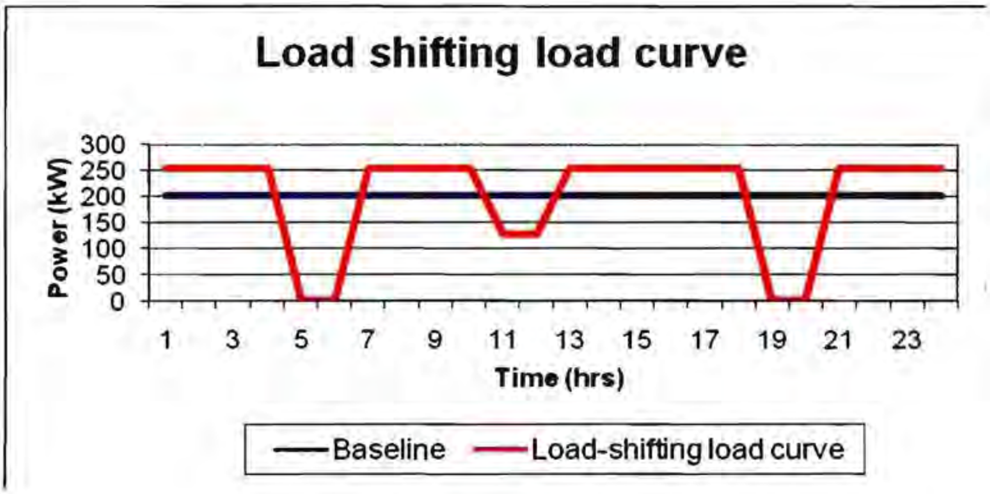


Figure 37: Typical power curve of load shifting

Peak clipping removes energy during specified periods of the day. Tests must be conducted in order to evaluate the impact it will have on the system. These curves are not energy neutral.

Figure 38 indicates a typical power curve of a system applying the peak clipping method.

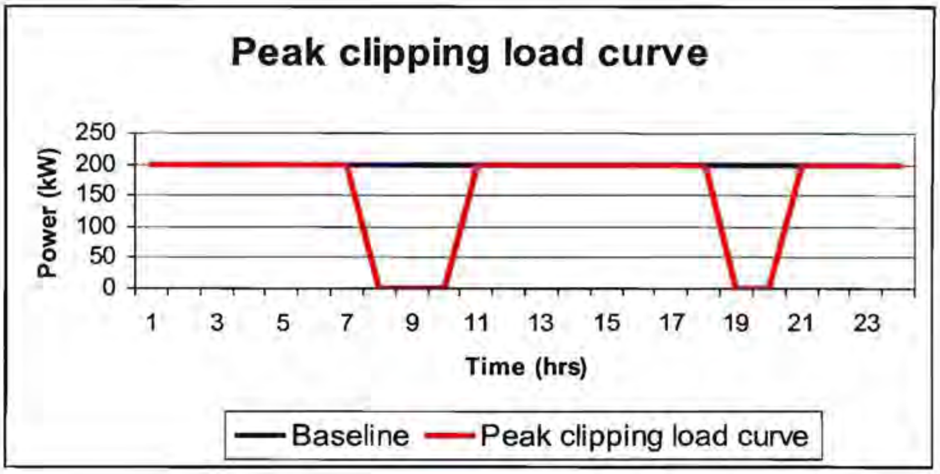


Figure 38: Typical power load curve of peak clipping

Back passing of cold water is an energy efficient method to reduce the total electricity consumed by a refrigeration system. It can be applied to mining refrigeration machines by reducing the inlet temperature of the machine. This reduces the thermal energy and hence the electrical energy consumed.

Figure 39 indicates a typical load curve associated with energy efficiency.

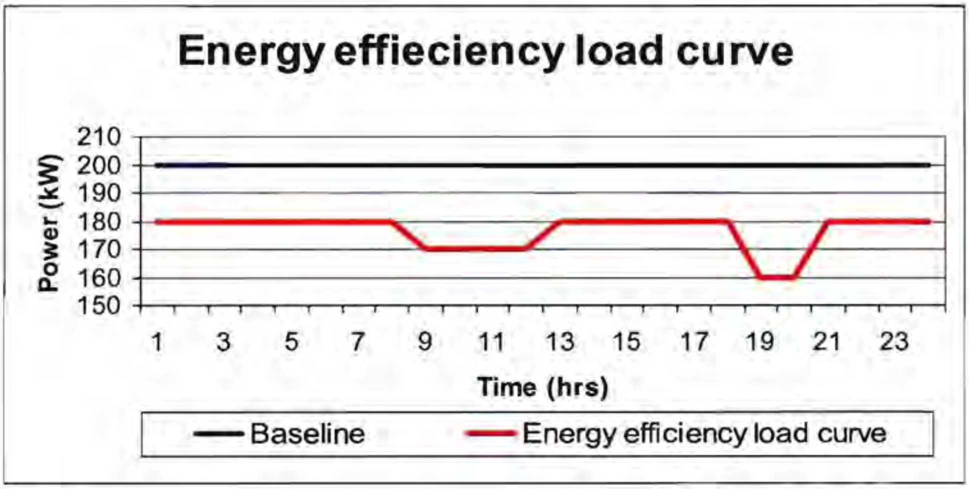


Figure 39: Typical power load curve of a system applying energy efficiency methods

3.4. New simulation model results

The refrigeration system must be studied before optimising the system. The next phase is to simulate the system behaviour and optimise all the elements of the system. This optimisation will focus on power reduction during the evening peak period on weekdays due to the greater demand during evening peak periods.

The simulated thermal relieving capability of refrigeration machines will be the average relieving capability of the baseline. The dam levels and temperatures will be simulated and the ideal curve will be established. It is ideal to establish a maximum level of all cold dams just before the evening peak period. The pumping system will need to aid in the preparation of these dams.

The average cold water consumption above and underground during the evening peak period was determined as 1210 kL and 2480 kL respectively. This amount of water is then taken as a percentage the cold dams' capacity. It is 24.3% on surface and 49.6% underground

Similarly the average inflow during the same period into the pre-cool dams was calculated and taken as a percentage of their capacity. Surface has a total inflow of 38.1% and underground has a total inflow of 43.8% of their respective total capacities.

The cold dams must be able to lose this amount of water without breeching the minimum level of the dams and the pre-cool dams must able to gain the average inflow mass of water without breeching the maximum dam level. This means that the refrigeration needn't be active during the evening peak period and a load shit strategy will be implemented.

A peak clipping strategy will only be feasible if the mine's cold water requirements decrease. The thermal power requirement will then be less and a percentage thermal power can be removed from the system. This will be done in the evening peak period.

The proposed back-pass valve will decrease the inlet temperature of the refrigeration machines. This will reduce the electricity consumed without impacting the thermal power produced by the machines

The components of the refrigeration system are essential in developing feasible control strategies and techniques. Control strategies are dependant on the functionality and capability of the system under investigation. The surface hot dam is an integral part of the system. It is essential to be able to estimate the dam level on an hourly basis.

Dam level estimation is calculating by using Equation 9:

$$\boxed{NewDamLevel\% = \frac{\left[\left(\frac{CurrentDamLevel\%}{100}\right)\times DamCapacity + (\dot{m}_{in} - \dot{m}_{out})\times 3600\times t\right]}{DamCapacity}\%} \text{..........} \textit{Equation 9}$$

Where

$\dot{m}$: flow rate in L/s

t *: time in hours*

A typical dam level estimation will be as follows:

Present dam level = 87.34%

Dam capacity = 4789 kL

Total average hourly inflow = 234.54 L/s

Total average hourly outflow = 256.02 L/s

Time = 1 hour

$$\boxed{\begin{aligned} &NewDamLevd\% = \frac{\left[\left(\frac{87.34}{100}\right)\times 4{,}789{,}000 + (234.54-256.02)\times 3600\right]}{4{,}789{,}000} \\ &NewDamLevd\% = 85.72\% \end{aligned}}$$

Dam level capacities must be correct if the electricity consumed by the refrigeration system is to be optimised. The refrigeration machines will be switched off during the evening peak period. This means that hot dam will have no outflow for two hours during the evening peak period and the cold dam no inflow.

Hot dams must be able to accommodate the inflow from the mining levels even though there will be no outflow to the refrigeration system. Cold dams must be able to continuously supply cold water to mining levels and the BAC despite having no inflow from the refrigeration plant.

Figure 40 indicates the surface dam level estimations obtained when applying the load shifting DSM method:

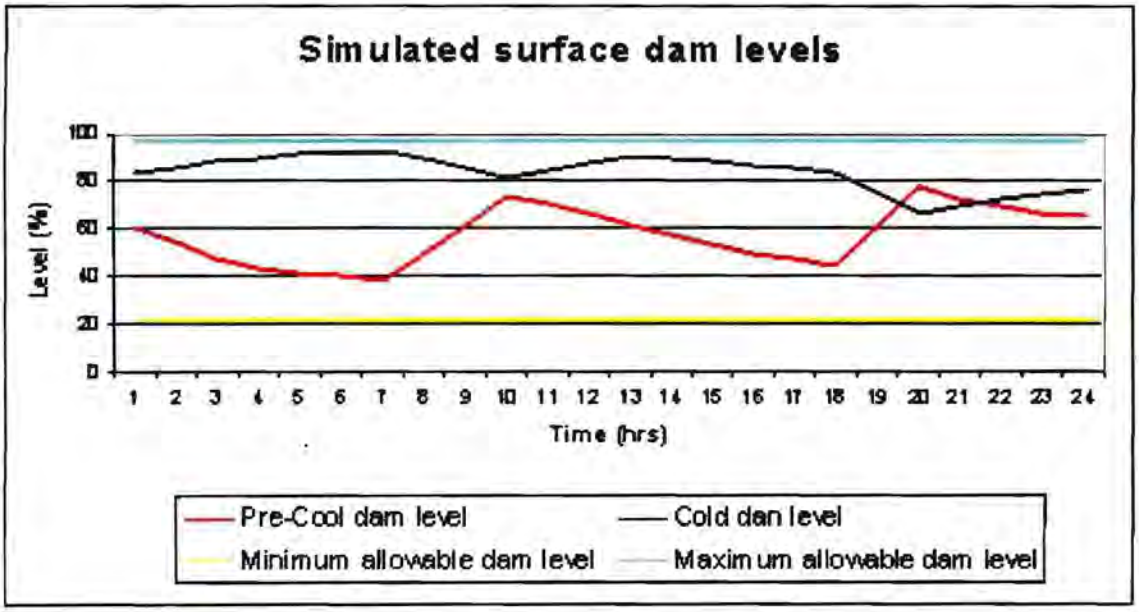


Figure 40: Surface dam level estimation

The pre-cool dam is a major constraint. It has a capacity of 2500 kL and does not have sufficient storage capacity to prevent outflow during the peak periods. However the outflow rate can be reduced which will reduce the power consumed.

The dams have a maximum allowable level of 98% and minimum of 20%. Cold dam temperature is the next critical factor.

Water temperature can be calculated using Equation 10:

$$NewDamTemp = \frac{\left[\left(\frac{PreviousDamLevel\%}{100}\right) \times DamVolume \times PreviousDamTemp + (\dot{m}_{in} \times T_{in} - \dot{m}_{out} \times T_{out}) \times 3600/1000\right]}{\left(\frac{PreviousDamLevel\%}{100}\right) \times DamVolume + (\dot{m}_{in} + \dot{m}_{out}) * 3600/1000} \text{..........}\mathit{Equation\ 10}$$

A worked example is given using the following values:

Present dam level = 87.34%
Dam capacity = 2500 kL
Total average inflow = 234.54 L/s
Total average outflow = 256.02 L/s
Average inflow temperature = 6.07 °C
Average dam temperature = 6.64 °C
Time = 1 hour

$$\begin{aligned} NewDamTemp &= \frac{\left[\left(\frac{87.34}{100}\right) \times 2{,}500{,}000 \times 6.64 + (234.54 \times 6.07 - 256.02 \times 6.64) \times 3600\ /1000\right]}{\left(\frac{87.34}{100}\right) \times 2{,}500{,}000 + (234.54 - 256.02) * 3600\ /1000} \\ NewDamTemp &= 6.32\,°C \end{aligned}$$

It is important to create an accurate temperature curve. This is due to the fact that inflows from various levels may vary in temperature and it must be taken into consideration. Figure 41 indicates the estimated surface dam temperatures applying the load shifting DSM method and using Equation 13.

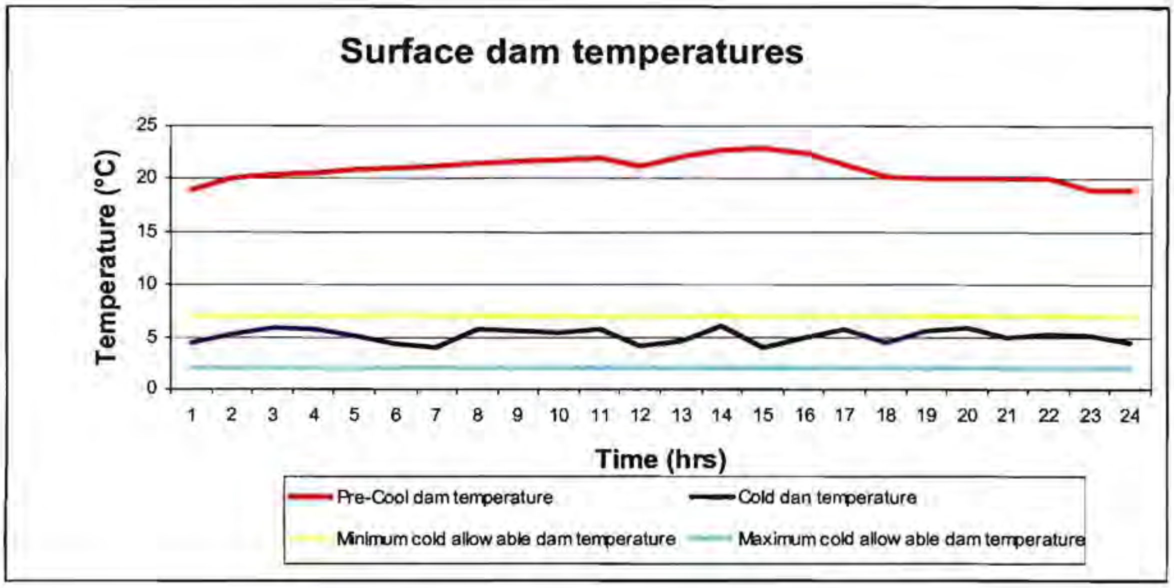


Figure 41: Surface dam temperature estimation

The cold dam temperature can be controlled in such a way that considerable electrical savings can be obtained. The system layout allows for the two lagging machines to be shut down. This will result in an increase in the cold dam temperature. However, the maximum cold dam water temperature of 7 °C will not be exceeded. The minimum temperature of 2°C is not breeched.

This simulation shows that an electrical saving on the surface refrigeration plant is possible. It is possible by switching off two lagging refrigeration machines. It will not be possible to switch off one set of lead-lag machines. The outflow from the pre-cool dam would then be too small and this dam will overflow.

A saving of 4 170 kW is possible during the evening peak period and 1 457 kW during the morning peak period. The optimised energy curve produces 0.5% less thermal energy than the baseline. This is an acceptable reduction in thermal relief.

Figure 42 shows the baseline and the optimised load profile of the surface refrigeration plant:

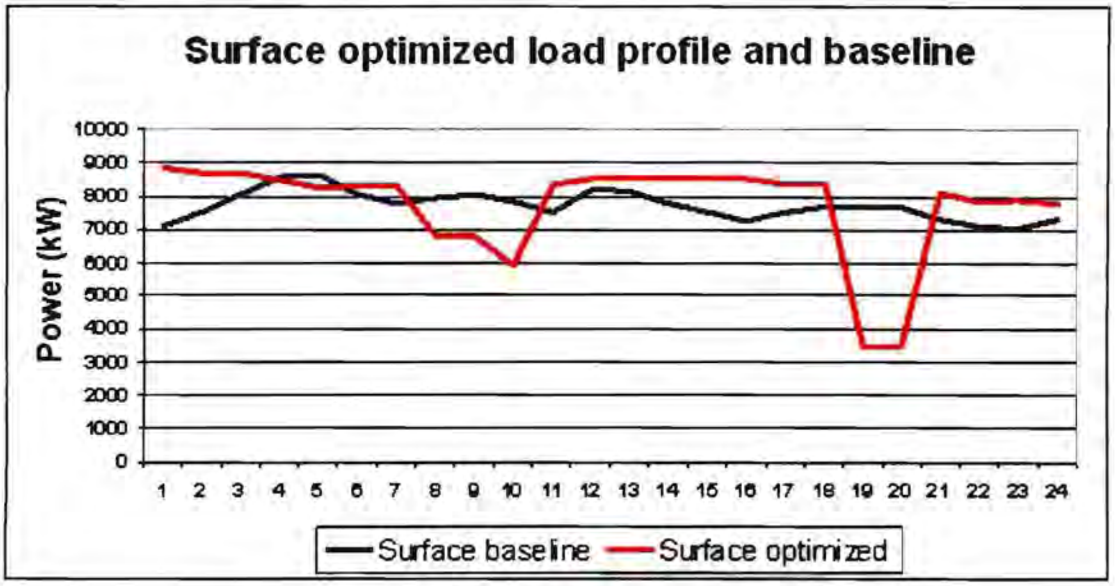


Figure 42: Optimised surface load profile and baseline

Figure 43 indicates the revised 71L layout (dashed lines indicate additional pipe work):

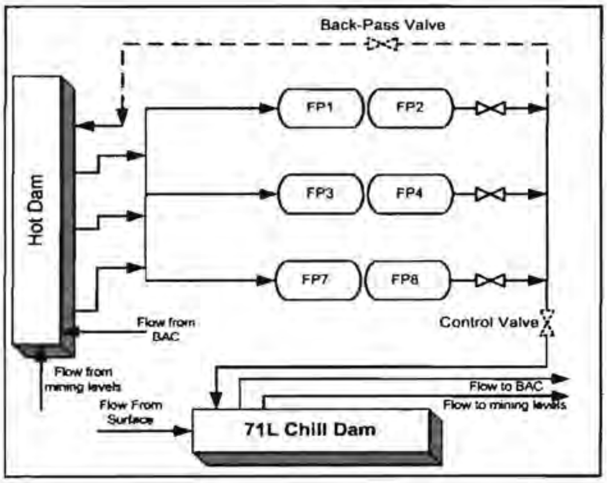


Figure 43: Layout of the revised underground refrigeration system.

The 71L refrigeration plant will follow the same control strategy as the surface plant. The hot dam must also be able to accommodate inflow during the evening peak period with no outflow. The cold dam must also be able to provide enough cold water to the 75L BAC and sub-plant levels with no inflow.

Figure 44 indicates the estimated dam levels on 71L. All the refrigeration machines can successfully shut down during the evening peak period. The cold dam will be able to continuously supply cold water and the hot dam will be able to continuously receive hot water from mining sublevels. Both dams have a maximum level of 95% and a minimum level of 30%.

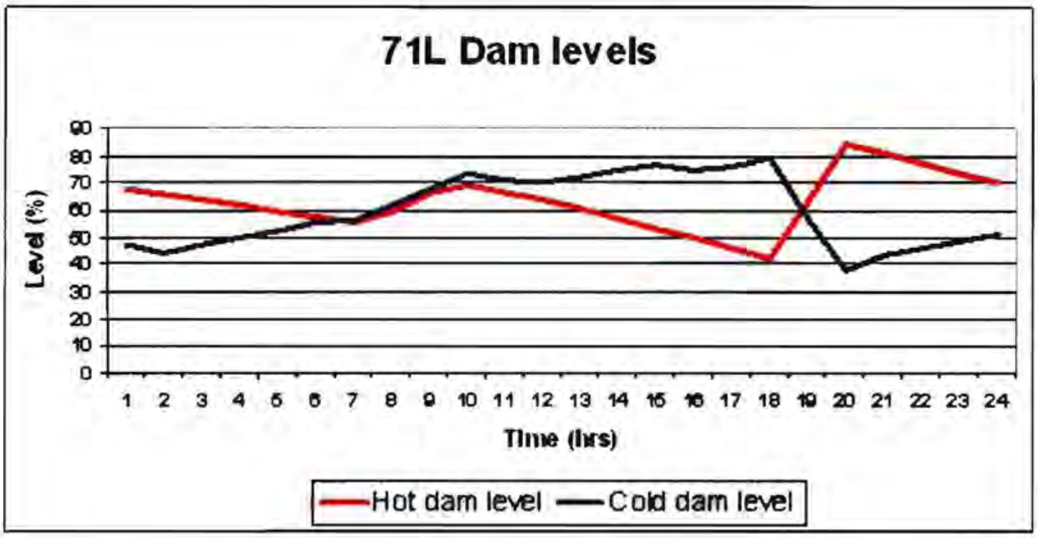


Figure 44: Simulated 71L dam levels

Figure 45 indicates the temperatures of 71L dams. The slight increase in cold dam temperature during the evening peak period is due to the ambient air temperature. No significant increases in dam temperatures were experienced. The hot dam temperature is lower due to back-passing of cold water into the dam.

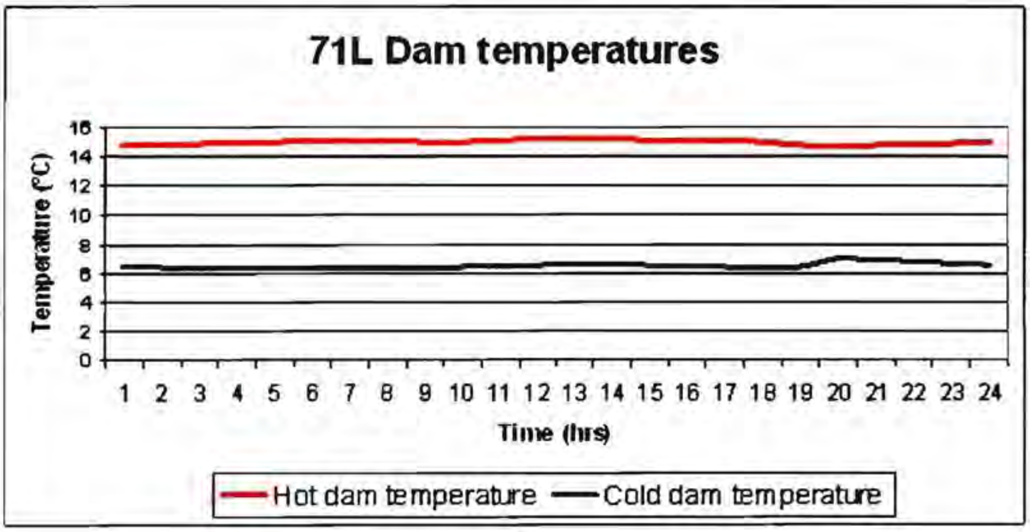


Figure 45: Simulated 71L dam temperatures

Figure 46 indicates the 71L refrigeration machines' estimated load curve and baseline. They are not energy neutral because of the energy efficient component resulting from the back-passing of cold water into the hot dam. It is possible to save 6421 kW during the evening peak period.

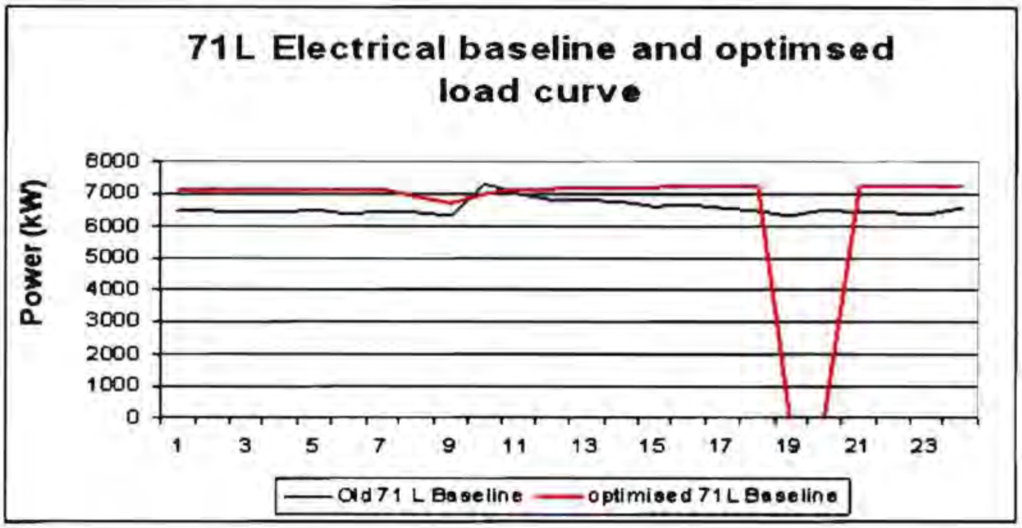


Figure 46: 71L refrigeration machines optimum load curve and baseline

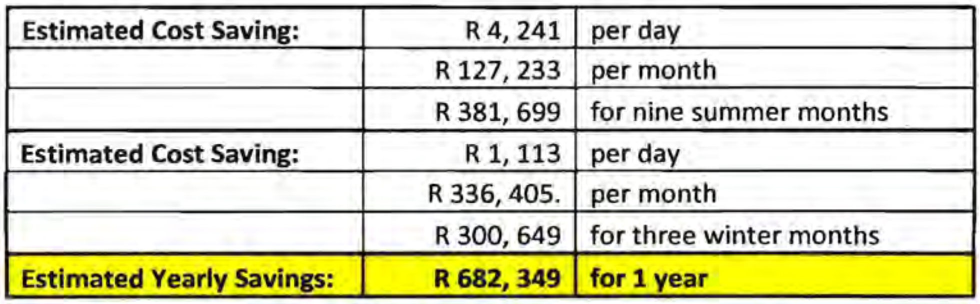
This simulation model development was based on flow rates during the summer months. However, during the winter months temperatures and flow rates will be considerably lower. The same principle was applied to the data collected in the winter period and similar results were obtained. It can be concluded that load shifting is feasible.

3.5. Conclusion

Theoretically, DSM on underground refrigeration systems is feasible. The required refrigeration component upgrade is essential for the feasibility of this study. It is possible to save 10,591 kW during the evening peak period and 1,457 kW during the morning peak period.

The winter months will require less cooling. Thus the energy saving will be less during the winter months. According to data collected, the thermal energy in winter periods is 68% of the thermal energy required during the summer periods. A theoretical saving of 7,201 MW is feasible during the winter periods.

Table 2 shows the possible saving that can be achieved:

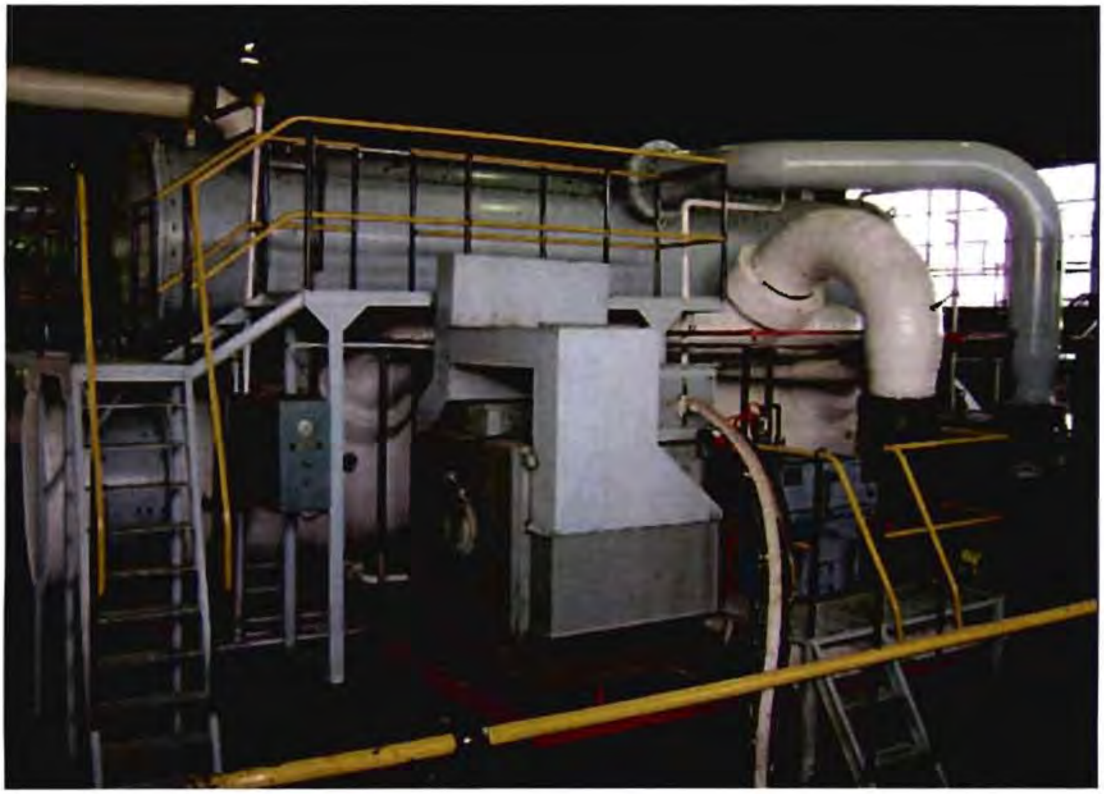


Estimated Cost Saving:	R 4, 241	per day
	R 127, 233	per month
	R 381, 699	for nine summer months
Estimated Cost Saving:	R 1, 113	per day
	R 336, 405.	per month
	R 300, 649	for three winter months
Estimated Yearly Savings:	**R 682, 349**	**for 1 year**

Table 2: Numerical saving calculations

4

VERIFICATION OF THE SIMULATION



The procedures developed in Chapter 3 are verified on the Elandsrand Gold Mine underground and surface refrigeration system.

4. VERIFICATION OF THE SIMULATION

4.1. Implementation on an underground refrigeration system

Refrigeration systems used for cooling mine water have very specific design parameters. This is due to the Occupational Health and Safety Act requirements. The machinery used in this process has limited controlling capabilities. In this section the various designs will be discussed.

The objective of this study is to reduce electrical energy consumption within the refrigeration process of the mine. This must be accomplished without adversely affecting the operational parameters. Water outlet temperatures and flow rates must not exceed prescribed limits.

The Real Time Energy Management Systems (REMS) developed by HVAC International will be implemented on the refrigeration system at EGM. REMS will monitor and control the electricity consumption of the refrigeration system. The focus will be on electricity reduction during the Eskom evening peak period.

Generally, refrigeration machines are not designed to be stopped repeatedly. It is considered to be a bad maintenance practice as a result of the mechanical strains generated. The mechanical limitations can be overcome through optimised control procedures.

Figure 47 indicates the REMS platform:

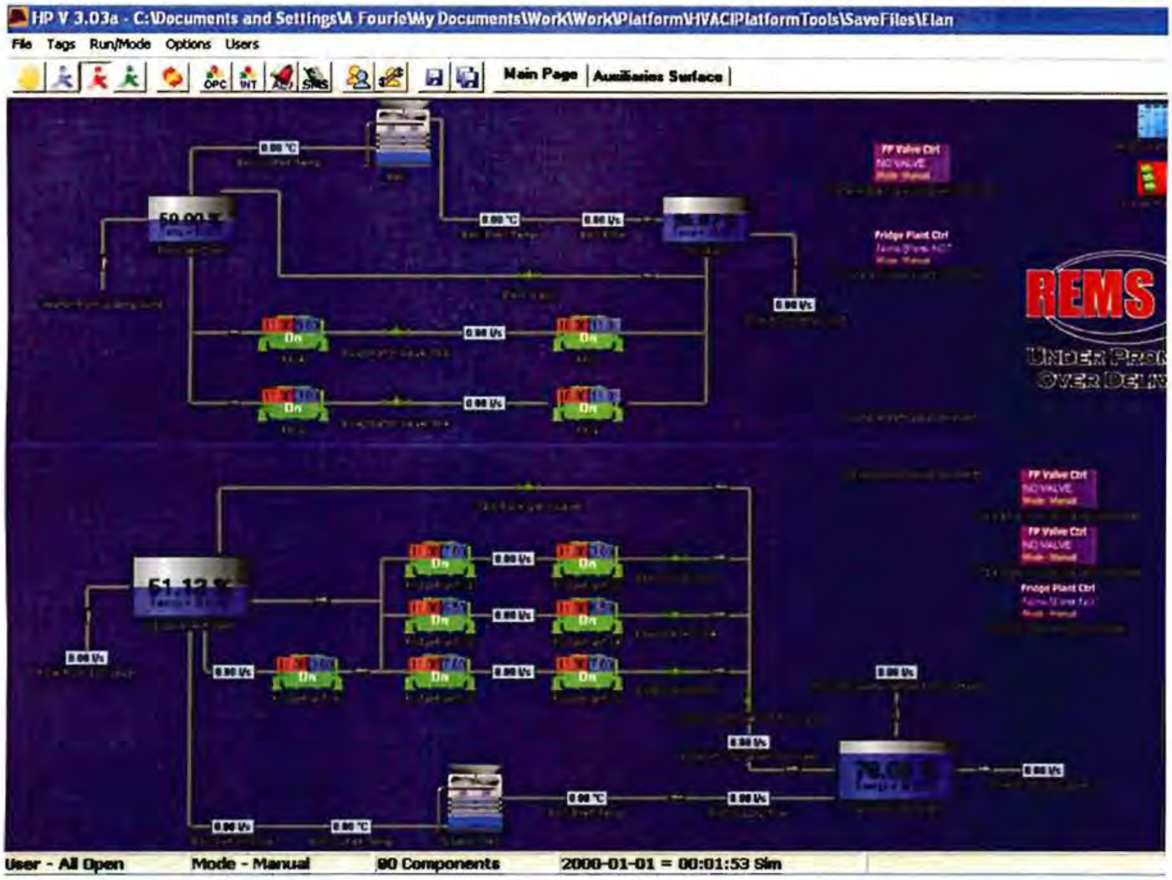


Figure 47: REMS platform representing the refrigeration system of EGM

REMS communicates with the Supervisory Control and Data Acquisition (SCADA) system by an Object Linking and Embedding for Process Control (OPC) connection. This enables REMS to continuously monitor and control the refrigeration system.

REMS is able to control the following surface system elements:

- The back-passing valve and hence the amount of cooled back-passed water into the surface pre-cool dam.
- The inlet temperature of the refrigeration machines and hence the power consumption of the compressor motors.

- The water levels of the pre-cool and cold dam on the surface by controlling the amount of water processed by the evaporator pumps.
- REMS will have the capability to switch off certain compressor motors.

REMS is also able to control the following system elements on 71L:

- The open/close valve and modulating valve controlling the amount of cooled back-passed water into the 71L hot dam.
- The inlet temperature of the refrigeration machines, and hence the power consumption of the compressor motors.
- The water levels of the pre-cool and cold dam on 71L by controlling the amount of water processed by the evaporator pumps.

REMS will also have the capability to switch off certain compressor motors.

4.2. Back pass valve control

The surface and 71L refrigeration systems will back-pass cooled water. The amount of water back passed at the surface will be controlled by the surface REMS FP valve controller. This valve controller will modulate to ensure optimal dam levels and temperatures as previously explained.

The valve controller will manage the temperature of the pre-cool dam by regulating the amount of back-passed water. Thus it will allow control of the inlet temperature of the refrigeration machines by modulating the valve opening.

Figure 48 below illustrates the information and water flow.

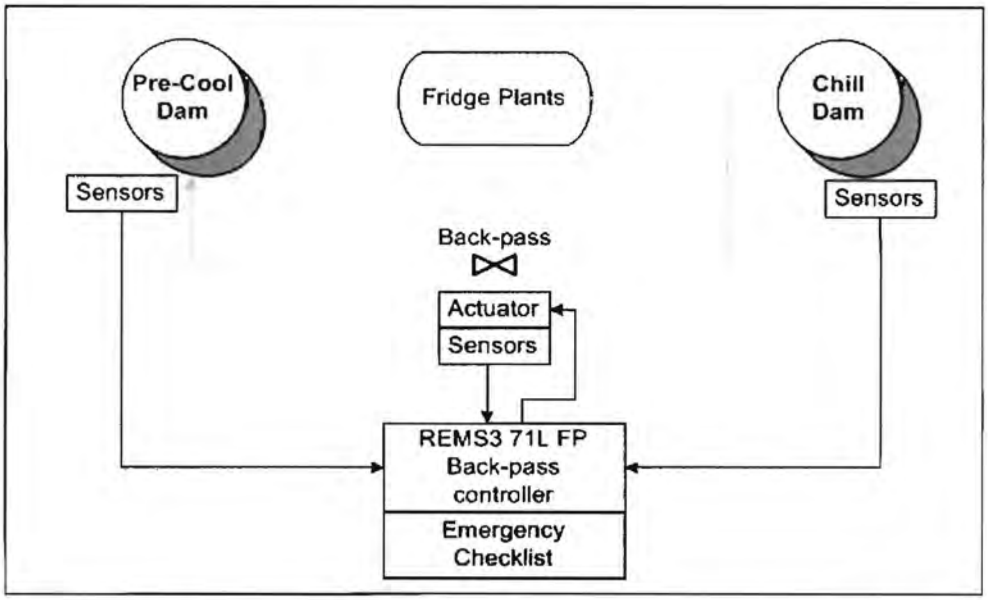
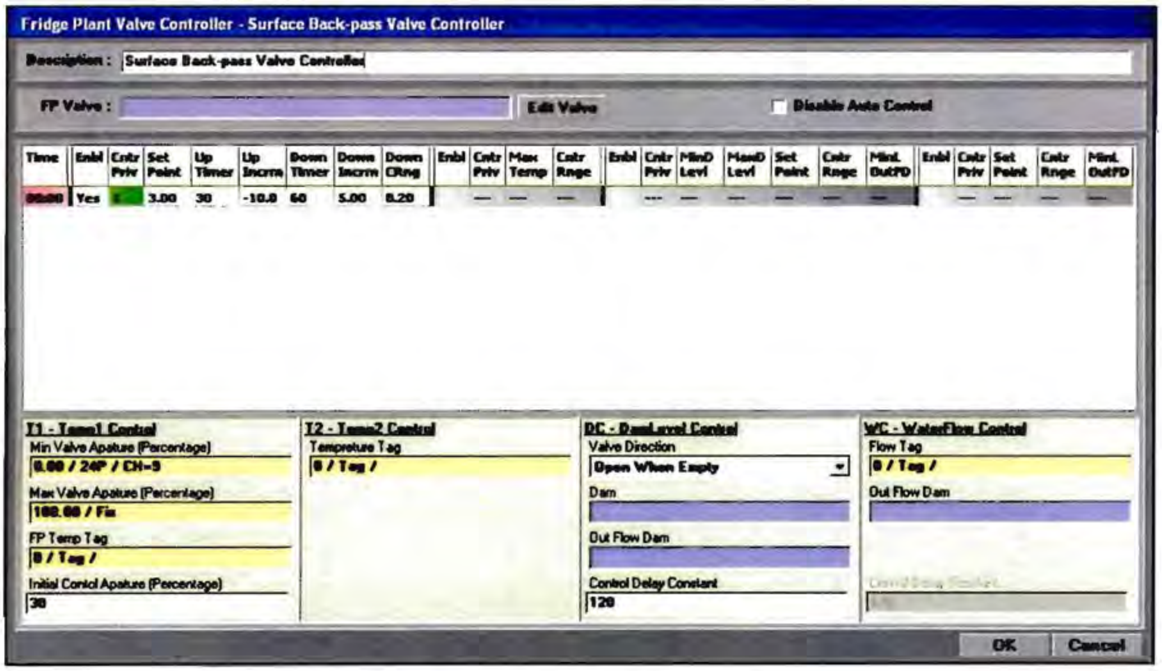


Figure 48: Surface back-pass valve controller water and information flow



Description : Surface Back-pass Valve Controller

FP Valve :

☐ Disable Auto Control

Time	Enbl	Cntr Priv	Set Point	Up Timer	Up Incrm	Down Timer	Down Incrm	Down CRng	Enbl	Cntr Priv	Max Temp	Cntr Rnge	Enbl	Cntr Priv	MinD Levl	MaxD Levl	Set Point	Cntr Rnge	MinL OutFD	Enbl	Cntr Priv	Set Point	Cntr Rnge	MinL OutFD
00:00	Yes	1	3.00	30	-10.0	60	5.00	0.20		—	—	—		---	—	—	—	—	—		—	—	—	—

T1 - Temp1 Control

Min Valve Apature (Percentage)
0.00 / 24P / CH-3

Max Valve Apature (Percentage)
100.00 / Fix

FP Temp Tag
0 / Tag /

Initial Contol Apature (Percentage)
30

T2 - Temp2 Control

Temprature Tag
0 / Tag /

DC - DamLevel Control

Valve Direction
Open When Empty

Dam

Out Flow Dam

Control Delay Constant
120

WC - WaterFlow Control

Flow Tag
0 / Tag /

Out Flow Dam

Figure 49: Interface of the REMS FP surface valve controller

Figure 49 is the REMS FP valve controller interface.

The following data must be declared:

- The valve to be controlled
- The downstream dam
- The upstream dam
- The set point temperature of the downstream dam
- Flow to the downstream dam

The back-pass valve controller will use the data supplied by the SCADA system to determine the percentage opening. This is done according to predetermined set points. First it will complete a checklist, and should there be any irregularities in the back-pass control range it will signal an alarm.

The main purpose of the flow chart shown in Figure 50 is to monitor the control signals from the controller and ensure the optimum operation of the valve. The valve controller will send command signals via the SCADA after the checklist is completed and the set points are verified within the control range.

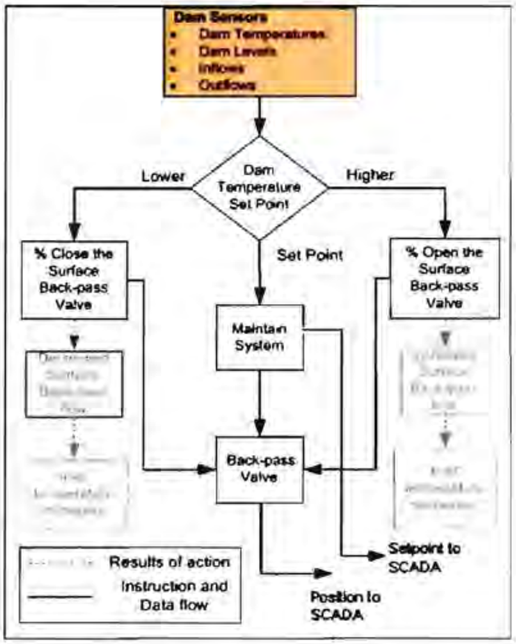


Figure 50: Surface back-pass valve controller diagram

The back–pass mechanism on 71L applies valve sequencing and there must be two separate valve controllers. The downstream valve is a modulating valve and the upstream valve is an open/close valve. The modulating valve determines the amount of cold water that flows through the open/close valve.

The modulating valve controller calculates the amount of water flow required and the valve will modulate accordingly. The water will then pass through the open/close valve.

Figure 51 indicates the signals and sensor tags of the 71L valve controllers:

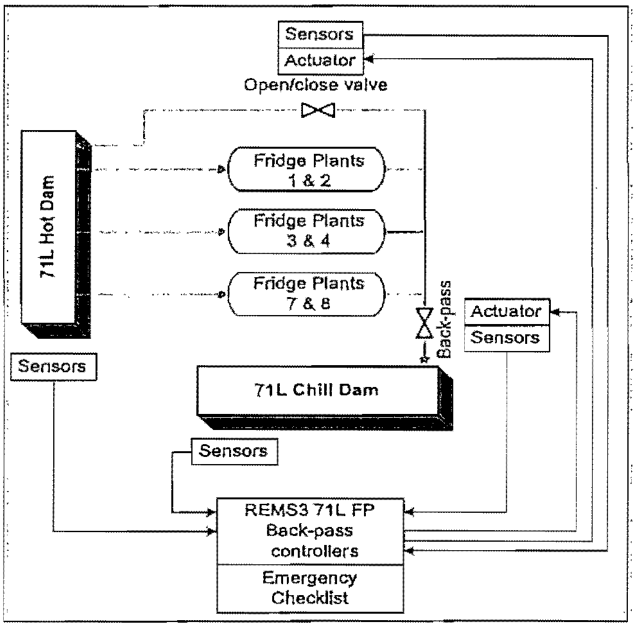


Figure 51: 71L Back-pass valve controller water and information flow

As in the case of the surface valve controller, the 71L valve controller will send signals via the SCADA system. The modulating valve will be controlled to ensure optimal distribution of cold water to the hot and chill dams.

Figure 52 indicates the checklist of the 71L modulating valve controller:

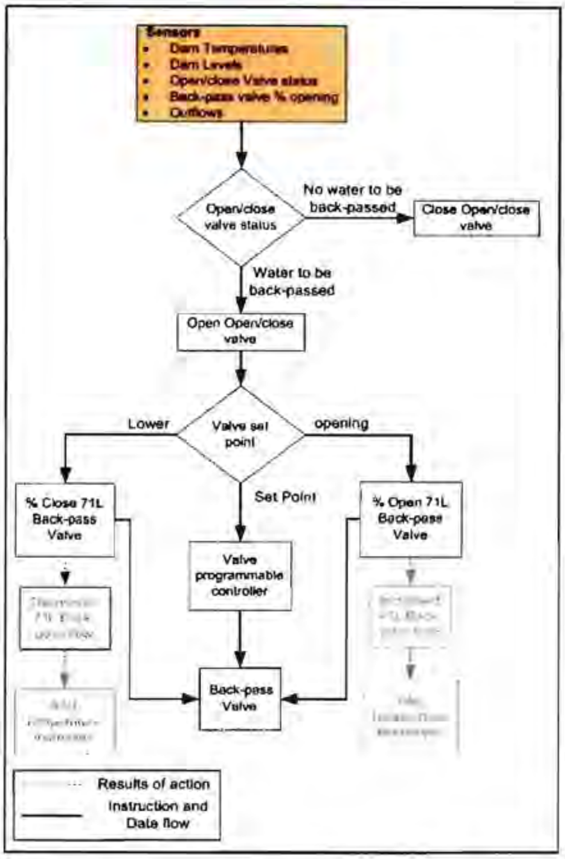


Figure 52: 71L Back-pass valve controller diagram

4.3. Dam level control

Dam level control is an essential part of load-shifting. The REMS FP controllers will manage the dam levels according to the established minimum and maximum levels. The procedure is to prepare the cold dam levels to a maximum level and the hot dams to a minimum level just before the evening peak period.

The REMS FP controller applies dam control to ensure that a dam is at the correct hourly set point. A set point can either be a constant throughout the day or it may vary per hourly value and it will have a control range. Dam level control will be applied to the hot and cold dams on the surface and at 71L.

The 71L cold dam is the main distributor of cold water to the mining areas. In this control strategy the chill dam is of higher priority than the hot dam. If there is no alarm or caution signal from the REMS FP controllers the system will commence with 71L cold dam control.

Figure 53 indicates the decision list of the 71L REMS FP cold dam control:

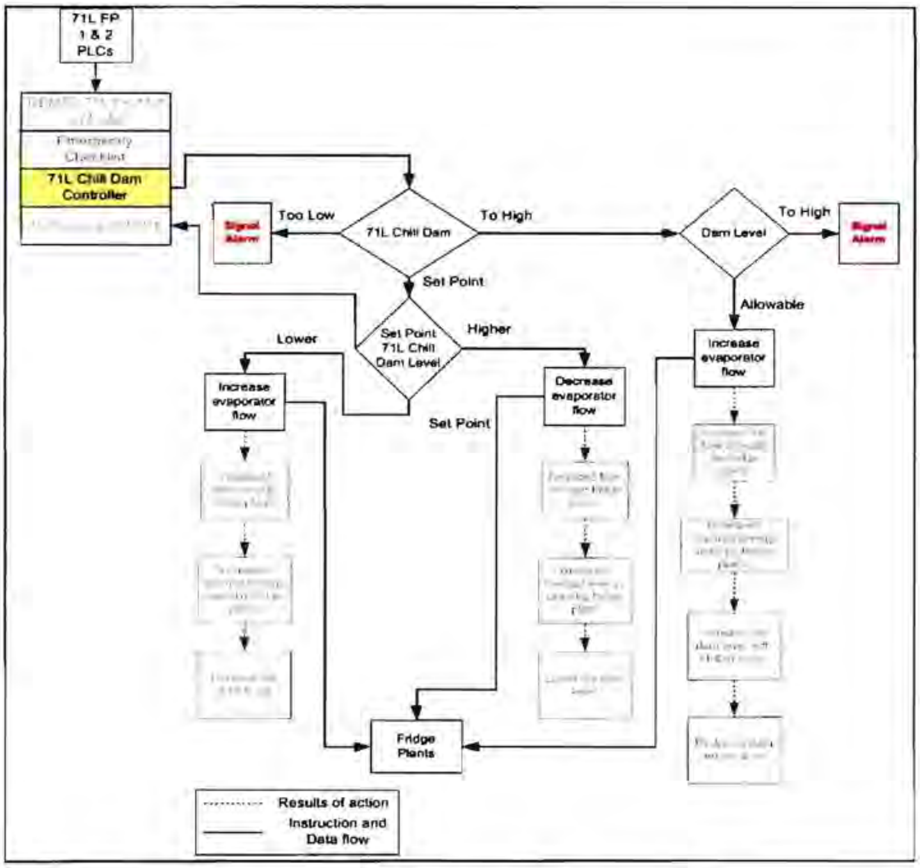


Figure 53: 71L REMS FP chill dam controller

The controller signals are determined by the decision list. These signals are sent to individual refrigeration machine actuators via the SCADA system. The chill dam control will briefly conclude if there are no alarms or cautions. The 71L FP Controller will then take over control of the hot dam level.

Figure 54 indicates the decision list of the 71L REMS FP hot dam control:

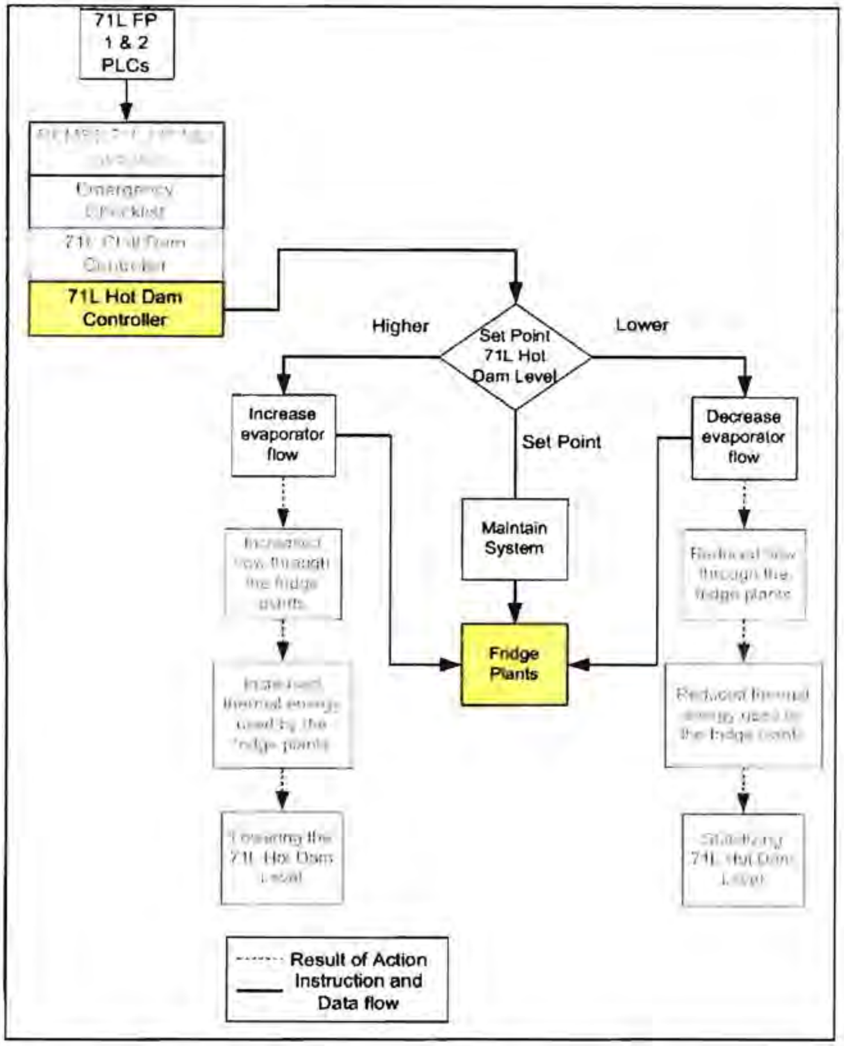


Figure 54: 71L REMS FP hot dam controller

The 71L chill dam control will ensure that there is enough capacity in the chill dam to accommodate the inflow from the hot dam throughout the day. It will also prepare the chill dam to supply cold water during the evening peak period without receiving any inflow.

The 71L hot dam control will provide the refrigeration machines with water throughout the day. The control will allow a continuous inflow of water during the evening peak period without any outflow. The hot dam will be prepared to a minimum level in order to create this storage capacity.

The surface FP controllers apply dam level control in a similar manner. Figure 55 indicates the decision list for the surface REMS FP chill dam control:

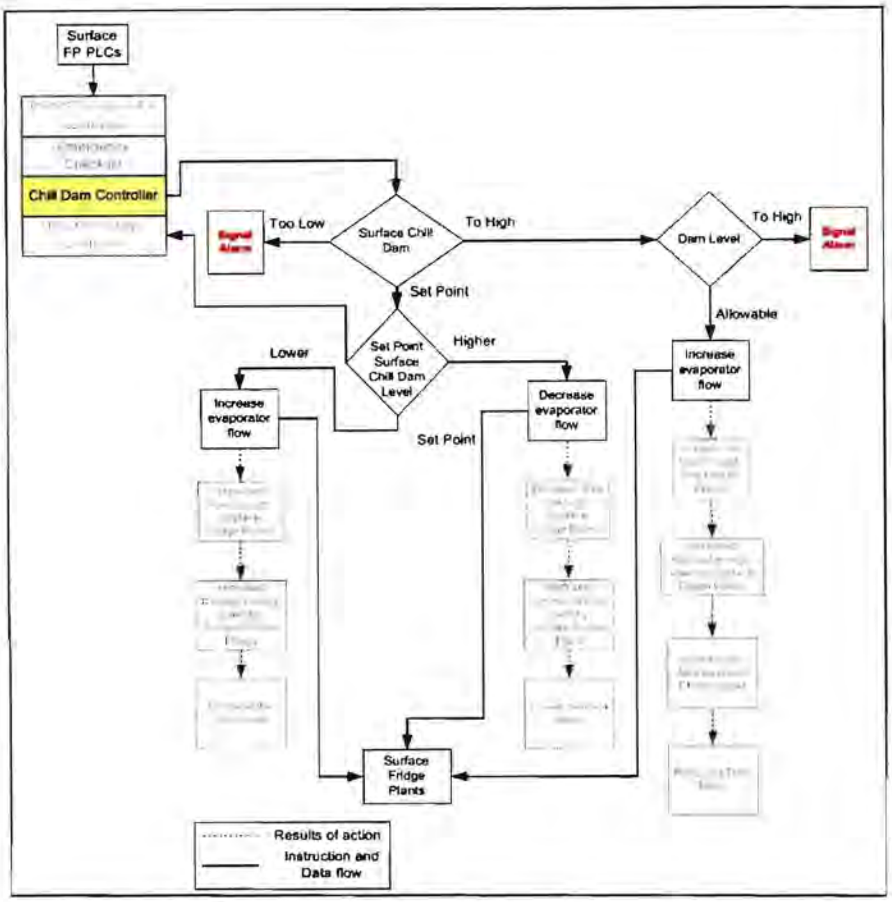


Figure 55: Surface REMS FP chill dam controller

The decision course followed will also determine the control signals. These signals are sent to individual refrigeration machine actuators via the SCADA system. If there are no alarms or cautions the surface chill dam control will be completed. The surface FP controller will commence the control of the pre-cool dam.

Figure 56 indicates the decision list for the surface REMS FP pre-cool dam control:

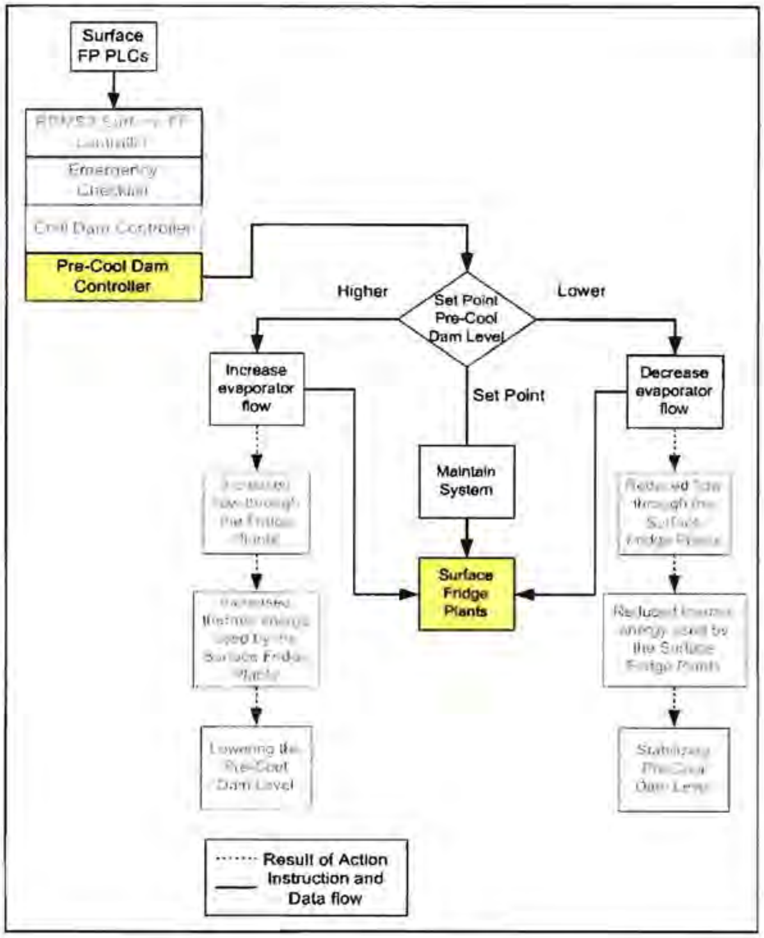


Figure 56: Surface pre-cool dam controller

The REMS FP pre-cool dam control will ensure a continuous flow of water to the refrigeration machines. The pre-cool dam does not have the capacity to store water for two hours if the outflow is closed off. Pre-cool dam level control will thus manage the level according to the specified control range.

4.4. Refrigeration machine control

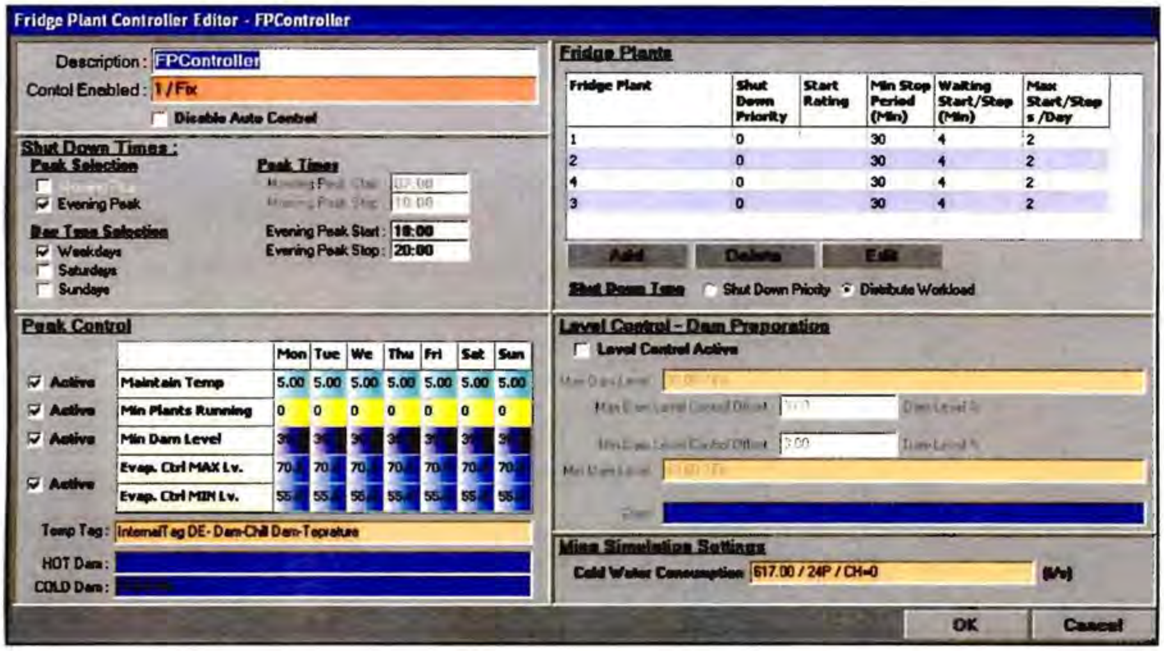
The surface refrigeration system must be optimised to use the least amount of electricity during the peak periods. The REMS Refrigeration System (REMS FP) controller must control the refrigeration machines accordingly. It is also important to ensure that thermal energy is kept to a minimum during the course of the day.

In order for REMS FP to optimally control the surface refrigeration system it must receive real time information from the SCADA system. REMS FP will use this critical information to execute calculations and hence make appropriate control decisions.

The SCADA-system provides the following information:

- Hot water dam temperature
- Hot water dam level
- Water flow through the pre-cool towers
- Pre-cool dam temperature
- Pre-cool dam level
- Inlet temperature to each refrigeration machine
- Outlet temperature from each refrigeration machine
- Water flow through each refrigeration machine
- Chill dam water level
- Chill dam water temperature
- Back-pass valve opening
- BAC flow rate
- BAC outlet temperature
- Underground water consumption

The REMS FP controller will be created for both the surface and 71L refrigeration systems. A data logger will be used to log all this information. Figure 57 indicates the REMS FP controller of the surface refrigeration system used to ensure an optimised profile:



Description : FPController
Contol Enabled : 1/Fix
☐ Disable Auto Control

Shut Down Times :

Peak Selection
☐ [illegible]
☑ Evening Peak

Day Type Selection
☑ Weekdays
☐ Saturdays
☐ Sundays

Peak Times
Evening Peak Start : 18:00
Evening Peak Stop : 20:00

Peak Control

		Mon	Tue	We	Thu	Fri	Sat	Sun
☑ Active	Maintain Temp	5.00	5.00	5.00	5.00	5.00	5.00	5.00
☑ Active	Min Plants Running	0	0	0	0	0	0	0
☑ Active	Min Dam Level	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
☑ Active	Evap. Ctrl MAX Lv.	70	70	70	70	70	70	70
	Evap. Ctrl MIN Lv.	55	55	55	55	55	55	55

Temp Tag : InternalTag DE- Dam-Chill Dam-Tepratue
HOT Dam :
COLD Dam :

Fridge Plants

Fridge Plant	Shut Down Priority	Start Rating	Min Stop Period (Min)	Waiting Start/Stop (Min)	Max Start/Stops /Day
1	0		30	4	2
2	0		30	4	2
4	0		30	4	2
3	0		30	4	2

Shut Down Type ○ Shut Down Priority ● Distribute Workload

Level Control - Dam Preparation
☐ Level Control Active

Mine Simulation Settings
Cold Water Consumption 617.00 / 24P / CH=0 (l/s)

Figure 57: REMS FP controller

The REMS FP controller interface enables the user to display the following:

- Shut down times
- Shut down days
- Peak time schedules
- The refrigeration machines to be controlled
- Dam level control strategy

REMS FP will send the following actuator tags to the Programmable Logic Controller (PLC) which controls the refrigeration system:

- Optimum evaporator flow rate of refrigeration machines 1 and 2
- Stop or start command signal to machine 1 and 2
- Optimum evaporator flow rate of refrigeration machines 3 and 4
- Stop or start command signal to machine 3 and 4
- Back-pass valve opening

Figure 58 indicates the required sensor and actuator tags for the surface refrigeration system:

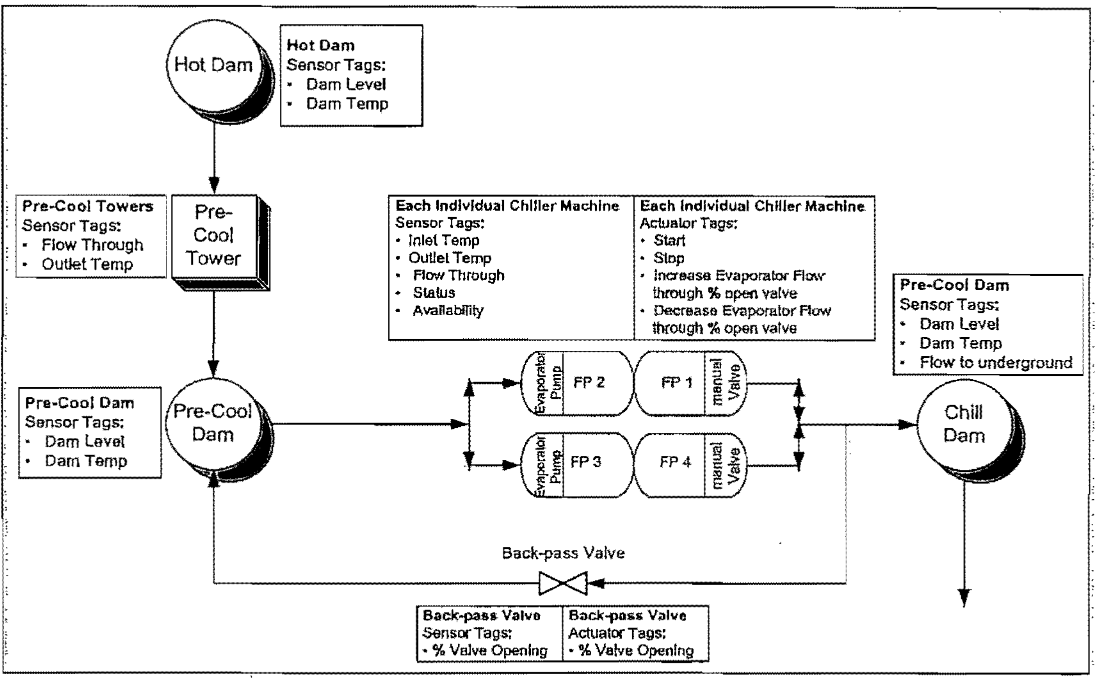


Figure 58: Sensor and actuator tags for the surface refrigeration system

The surface REMS FP controller uses the water level and temperature of the surface cold and pre-cool dams to make decisions. The cold dam level and temperature have a higher priority than the level and temperature of the pre-cool dam. Figure 59 illustrates the water (grey) and information flow (black).

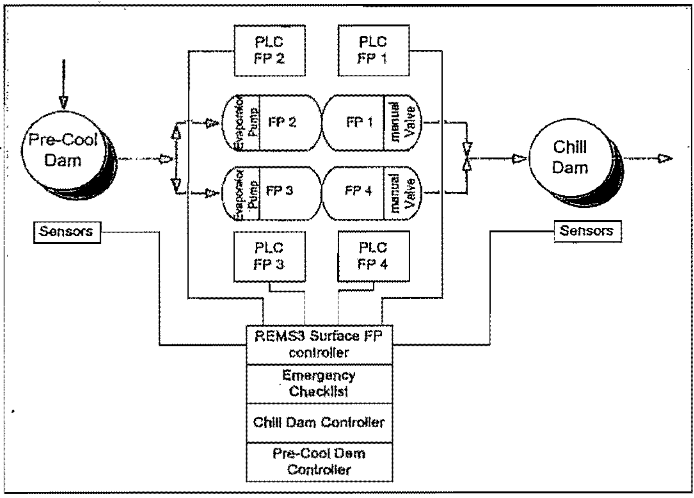


Figure 59: Surface REMS FP controller with water and information flow

REMS FP will use the information obtained from the different dams and refrigeration machines to perform an emergency checklist. The parameters for this checklist must be entered; otherwise the surface REMS FP controller will not allow control over the flow rates of the refrigeration machines.

Figure 60 indicates the emergency checklist for the surface refrigeration system:

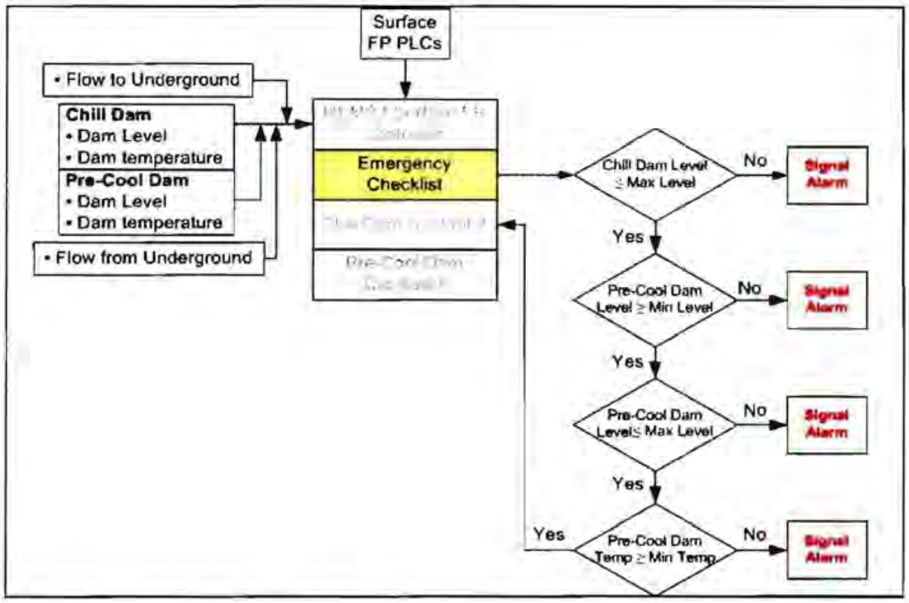


Figure 60: Surface refrigeration machine emergency checklist

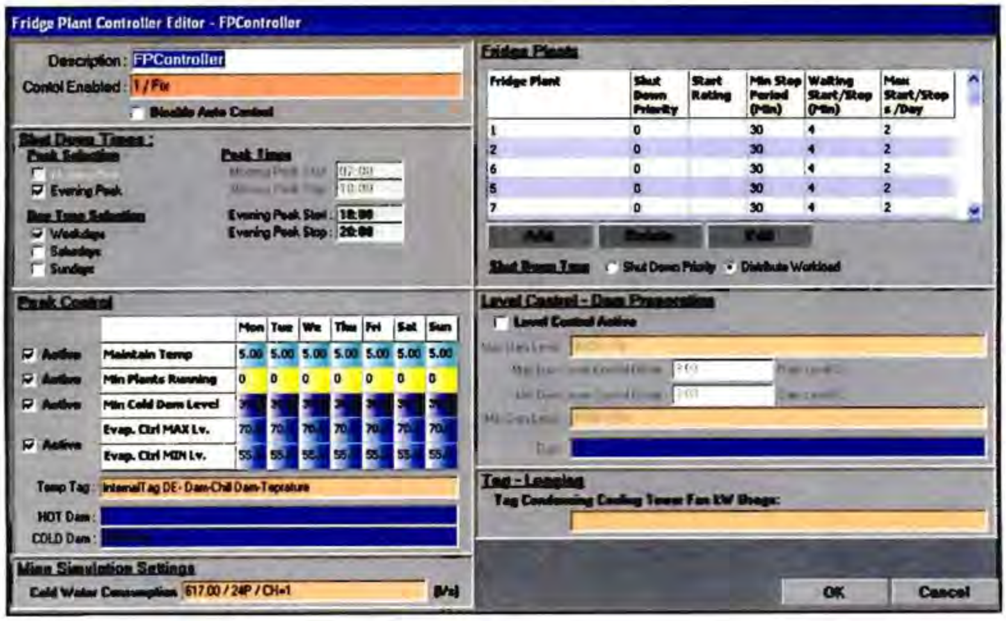
The primary objective of the surface REMS FP controller is to insure that there is sufficient cold water in the surface cold dam. The water must be able to supply the mining levels throughout the entire day, including peak periods, with limited inflow to the cold dam.

The refrigeration machines on 71L will be controlled by an independent REMS FP controller. The controller will be used to control refrigeration machines 1, 2, 7 and 8. This will be done according to the critical information provided by the 71L refrigeration system. The critical information is:

- Flow rate of hot water into the hot dam
- Hot dam water temperature
- Hot dam water level

- Inlet water temperature of refrigeration machines 1 and 2
- Outlet water temperature of refrigeration machines 1 and 2
- Water flow rate through refrigeration machine 1 and 2
- Inlet water temperature of refrigeration machines 7 and 8
- Outlet water temperature of refrigeration machines 7 and 8
- Water flow rate through refrigeration machine 7 and 8
- Inlet water temperature of refrigeration machines 3 and 4
- Outlet water temperature of refrigeration machines 3 and 4
- Water flow rate through refrigeration machine 3 and 4
- Cold water consumption of mining levels
- Chill dam water level
- Chill dam water temperature
- 75L BAC water flow rate
- 75L BAC outlet water temperature
- Open/close valve status
- Modulating valve open

The 71L REMS FP controller is indicated in Figure 61:



Description: FPController
Contol Enabled: 1/Fix
☐ Disable Auto Control

Shut Down Times:
Peak Selection
☐ Morning Peak
☑ Evening Peak
Day Type Selection
☑ Weekdays
☐ Saturdays
☐ Sundays

Peak Times
Morning Peak Start: 07:00
Morning Peak Stop: 10:00
Evening Peak Start: 18:00
Evening Peak Stop: 20:00

Fridge Plants

Fridge Plant	Shut Down Priority	Start Rating	Min Stop Period (Min)	Waiting Start/Stop (Min)	Max Start/Stops /Day
1	0		30	4	2
2	0		30	4	2
6	0		30	4	2
5	0		30	4	2
7	0		30	4	2

Shut Down Type ○ Shut Down Priority ● Distribute Workload

Peak Control

		Mon	Tue	We	Thu	Fri	Sat	Sun
☑ Active	Maintain Temp	5.00	5.00	5.00	5.00	5.00	5.00	5.00
☑ Active	Min Plants Running	0	0	0	0	0	0	0
☑ Active	Min Cold Dam Level	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
☑ Active	Evap. Ctrl MAX Lv.	70	70	70	70	70	70	70
	Evap. Ctrl MIN Lv.	55	55	55	55	55	55	55

Temp Tag: InternalTag DE- Dam-Chill Dam-Teprature
HOT Dam:
COLD Dam:

Level Control - Dam Preparation
☐ Level Control Active

Tag - Logging
Tag Condensing Cooling Tower Fan kW Usage:

Mine Simulation Settings
Cold Water Consumption 617.00 / 24P / CH=1 (l/s)

Figure 61: 71L REMS FP controller

The 71L REMS FP will transmit the following actuator tags to the PLC of refrigeration machines on 71L:

- Optimum evaporator flow rate refrigeration machines 1 and 2
- Stop or start command signal to refrigeration machine 1 and 2
- Optimum evaporator flow rate refrigeration machines 5 and 6
- Stop or start command signal to refrigeration machine 5 and 6
- Optimum evaporator flow rate refrigeration machines 7 and 8
- Stop or start command signal to refrigeration machine 7 and 8
- Back-pass Valve-1 percentage opening
- Status of Valve-2

Figure 62 shows the sensor and actuator tags of the 71L refrigeration machine:

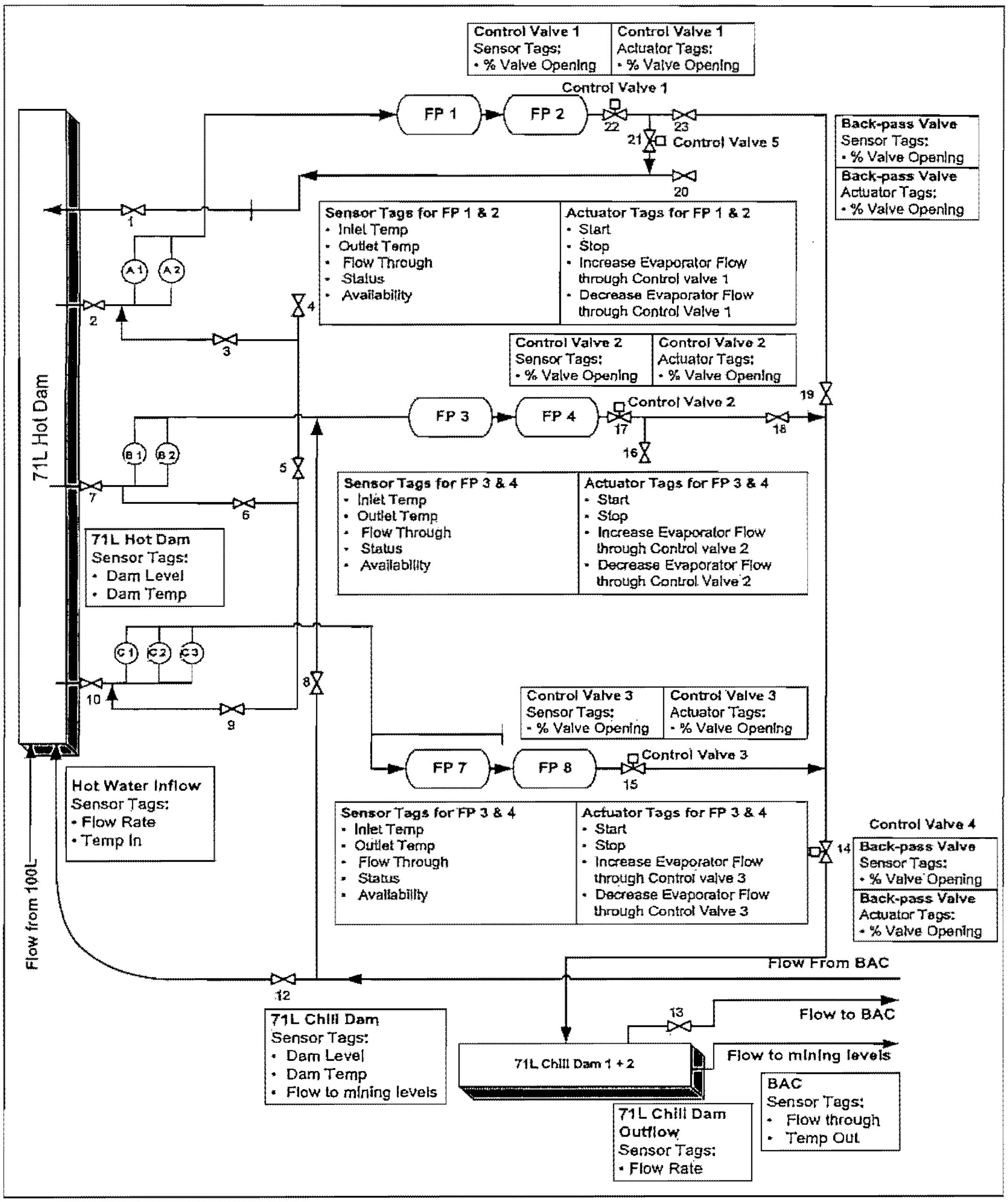


Figure 62: Sensor and actuator tags for 71L refrigeration system

Figure 63 represents the information and water flow paths of the 71L refrigeration machines:

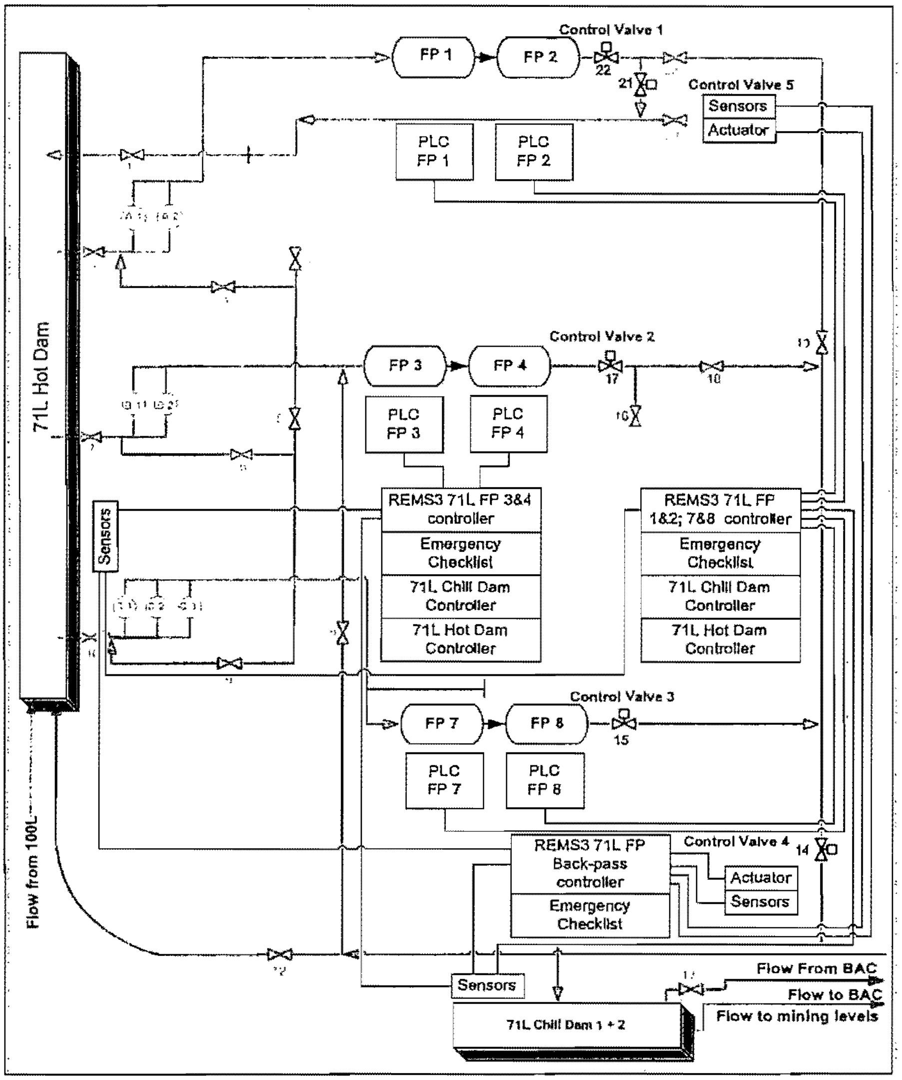


Figure 63: 71L REMS FP controller with water and information flow

The 71 LREMS FP will record the dam levels and temperatures of the hot dam and the chill dam via the SCADA-system. This data will be verified and will signal an alarm if an alarm criteria is encountered.

Figure 64 indicates the operation of this emergency checklist:

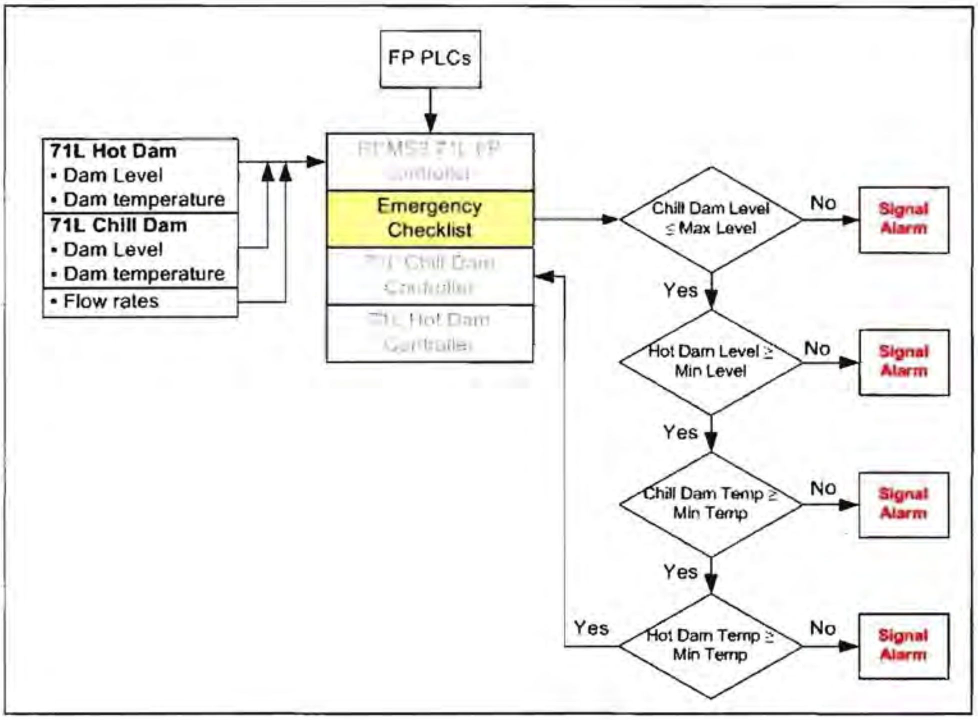


Figure 64: Refrigeration machine controller emergency checklist

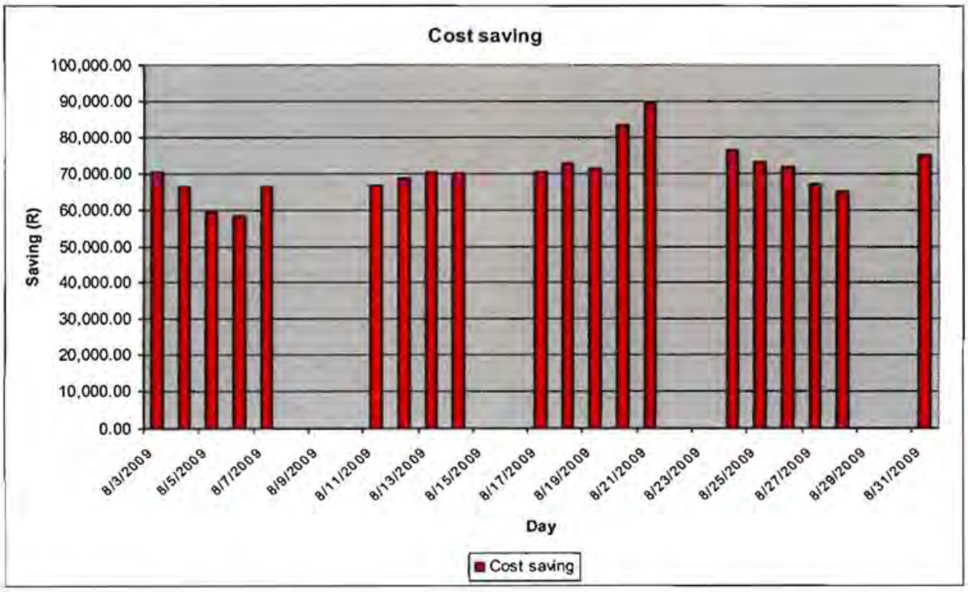


Figure 65: Cost savings from 1 August 2009 to 31 August 2009

Figure 65 indicates the total monetary savings generated by REMS on the refrigeration system during August 2009. The total saving for the period from 1 August 2009 to 31 August 2009 is R1,409,304.10. This excludes weekends and public holidays.

The average load reduction for the evening peak, excluding condonable days, is 6.60 MW. The average morning load reduction, excluding condonable days, is 8.06 MW. Figure 56 shows the average load and baseline (MW) for the week days from 1 August 2009 to 31 August 2009.

The scaled electrical baseline is obtained by multiplying each of the hourly values by a scaling factor. This scaling factor is the ratio of the total daily thermal energy base value to the actual total thermal energy produced by the refrigeration system of that day.

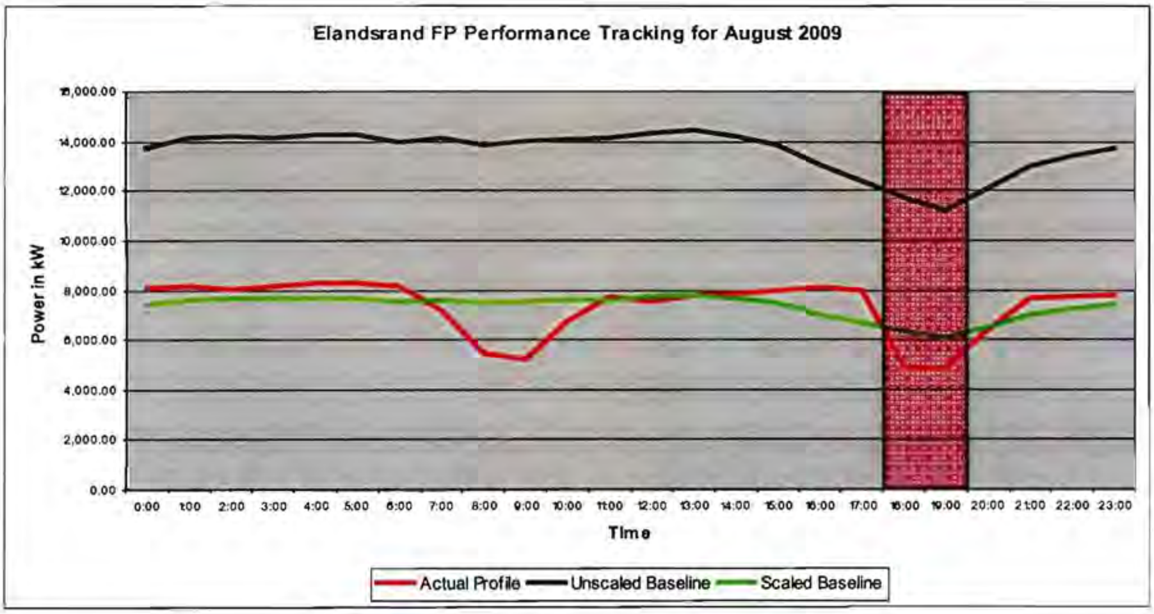


Figure 66: Load profile and baseline from 1 August 2009 to 31 August 2009 (including condonable days)

Figure 66 indicates the electrical power consumed by the compressor motors of the surface and underground refrigeration machines.

Figure 58 indicates the total morning and evening load reduction achieved from 1 August 2009 to 31 August 2009

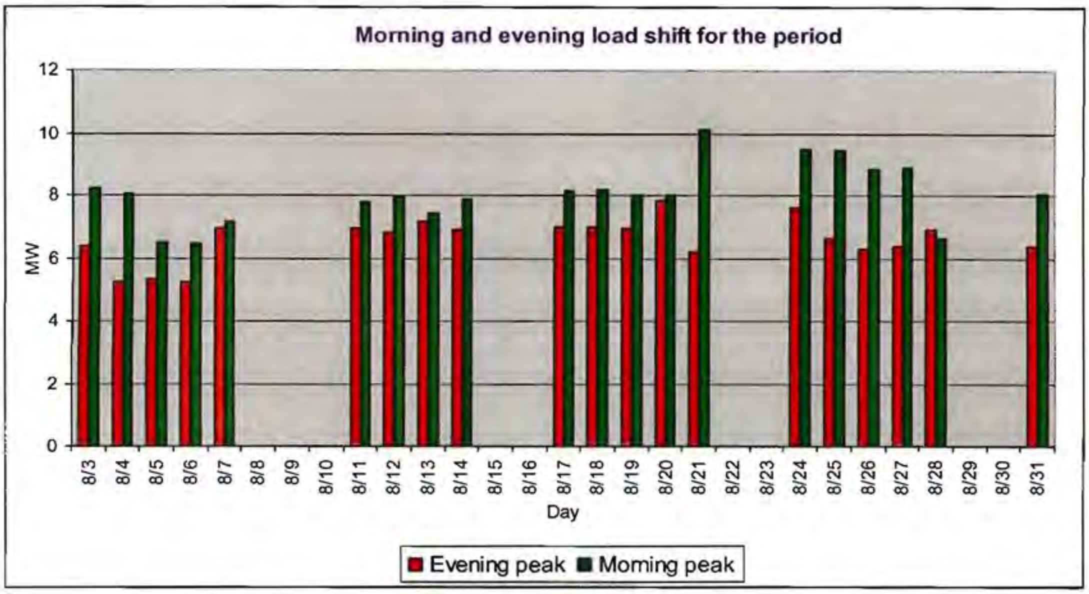


Figure 67: Morning and evening load shift from 1 August 2009 to 31 August 2009

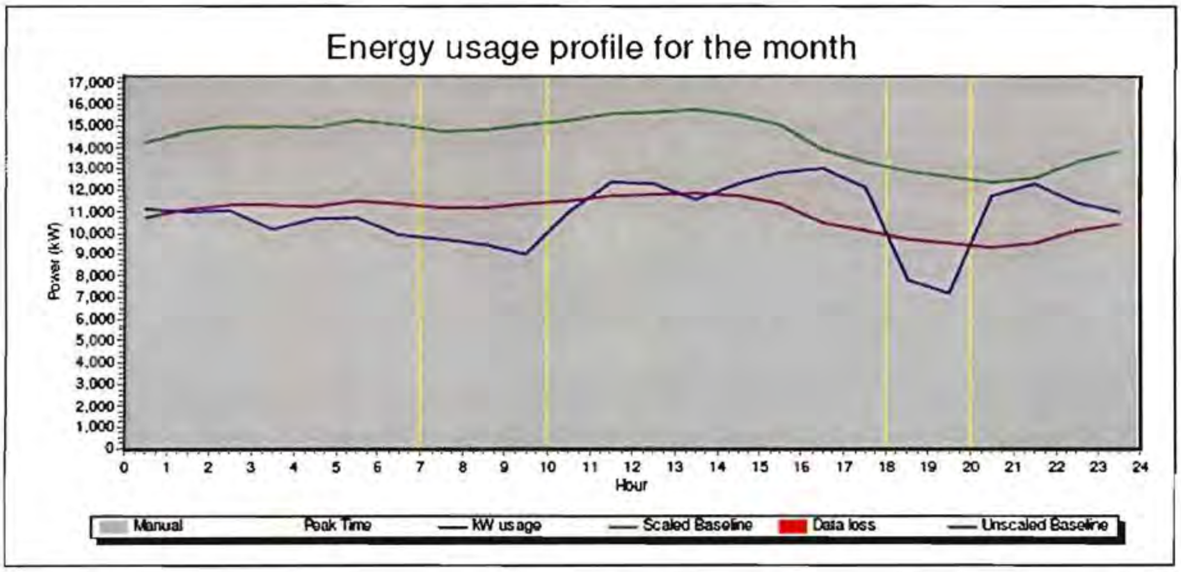


Figure 68: Average load profile for the month of October 2009 until 15 October 2009.

Figure 68 indicates the electrical load curve, the electrical baseline and the scaled electrical baseline. These load profiles are for the month of October 2009 until 15 October 2009. The average load reduction for the evening peak, excluding condonable days is 5.24 MW.

If this saving is sustainable throughout the summer then an average yearly evening load reduction of 5.58 MW is achievable.

The baseline was not scaled with the method originally proposed. It was decided to scale the baseline with the daily average ambient temperature in comparison with the average ambient temperature of baseline. The data is obtained from the South African Weather service.

Theoretically, in Chapter 3, it was calculated that a saving of 7,201 MW is possible. September and October has reached 72.8% and 77.5% of the potential saving respectively. By means of stricter control and familiarity of the system the full potential will be realised in the near future.

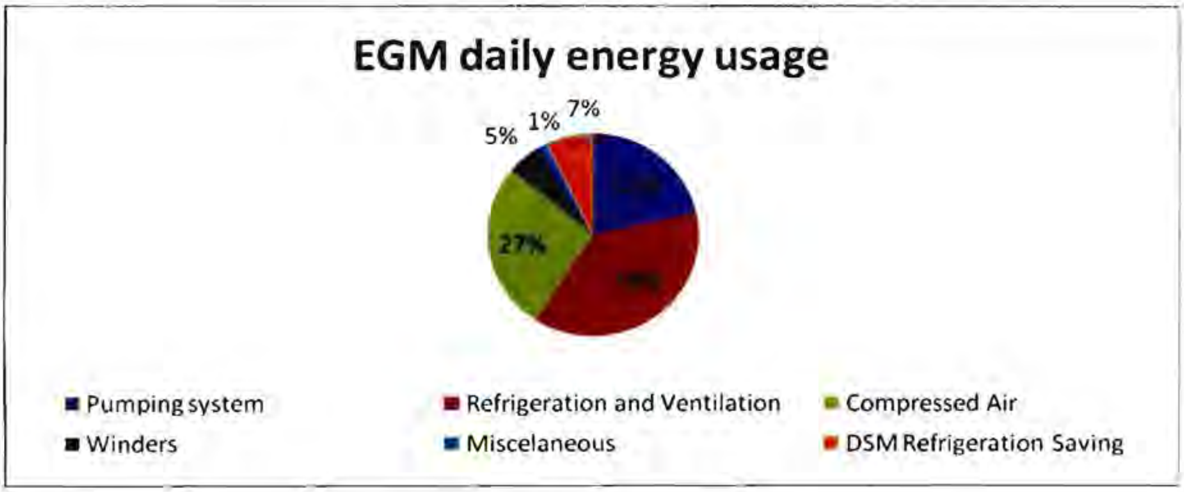


Table 3: EGM daily energy usage

The daily electricity saving associated with the DSM intervention is approximately 7% of the total daily electricity consumption of the mine. This amounts to a total of 26,622 kWh saved during the entire day.

The baseline shows that the refrigeration system consumes an average of 342, 807 kWh daily. The average energy consumption during August 2009 was 316,185 kWh. As can be seen in Table 3 this reduces the CO_2 emission by 25.1 tons, the coal required by 25.6 tons, and water needed by 36 kL, of a generating facility per day.

		Baseline	**Aug-09**	**Saving**	**Unit**
		342807	**316185**	**26622**	**kWh**
kL of water per kWh	**1.35**	463.6	427.6	36	kL
kg of Coal per kWh	**0.96**	329.6	304.0	25.6	kg
kg of CO2 per kWh	**0.94**	323.2	298.1	25.1	kg

Table 4: Water, CO_2 and coal savings per day

The total monetary saving achieved in August is R434, 636 and the monetary saving in September is R140, 622. The return on investment will be less than 3 years.

4.5. Conclusion

The successful implementation of energy management will have a major influence on the micro and macro economy. The financial savings generated will have a positive influence on the mine's cost per kilogram of ore extracted, and a sustainable electricity saving on the national electricity power grid will be realised.

The results obtained show that:

- Hot dam temperatures on surface and 71L did not exceed the minimum temperature set point and no pump surge occurred.
- The cold dams on the surface and 71L successfully supplied the surface and 75L BAC with a continuous supply of cold water at the required temperature.
- The daily thermal relief remains acceptable even though no thermal relief was supplied during the evening peak period.
- The back passing valve on the surface operated successfully and controlled the inlet temperature of the surface refrigeration machines within the limits.
- The back passing valves at 71L operated successfully to control the inlet temperature of the 71L refrigeration machines.

- Refrigeration machines 2 and 4 on surface were successfully stopped during the evening peak periods.
- All the refrigeration machines at 71L were successfully stopped during the evening peak periods.
- The same amount of electricity was consumed but the times of consumption were shifted to off peak periods.
- It was possible to reduce the evening peak period load by 6.6 MW during August 2009.
- It was possible to reduce the evening peak period load by 5.24 MW during the first half of October 2009.

5

APPLICATIONS ON OTHER SOUTH AFRICAN MINES

This chapter will discuss other possible DSM studies on mines that operate underground refrigeration machines

5. APPLICATIONS ON OTHER SOUTH AFRICAN MINES

5.1. Preamble

DSM on EGM was successfully implemented. This creates the opportunity to utilise the experience gained and apply similar DSM studies on other mines that possess underground refrigeration machines. Three other South African mines operate underground refrigeration machines:

- Bambanani Gold Mine
- Target Gold Mine
- Tau Tona Gold Mine

Investigations were conducted on each of these mines. Data were obtained and analysis reports were completed. The information obtained was used to create a simulation. The systems were optimised and various control strategies evaluated. The best option per mine will be discussed.

5.2. Target Gold Mine

Target Gold Mine is situated 10 km north of Odendaalsrus and about 40 km south of Bothaville in the Free State province. It forms part of the Welkom Gold Reef and is close to President Steyn 3-Shaft Gold Mine and Tshepong Gold Mine. The mine operates a single underground refrigeration system only.

Figure 69 indicates the refrigeration system at Target Gold Mine:

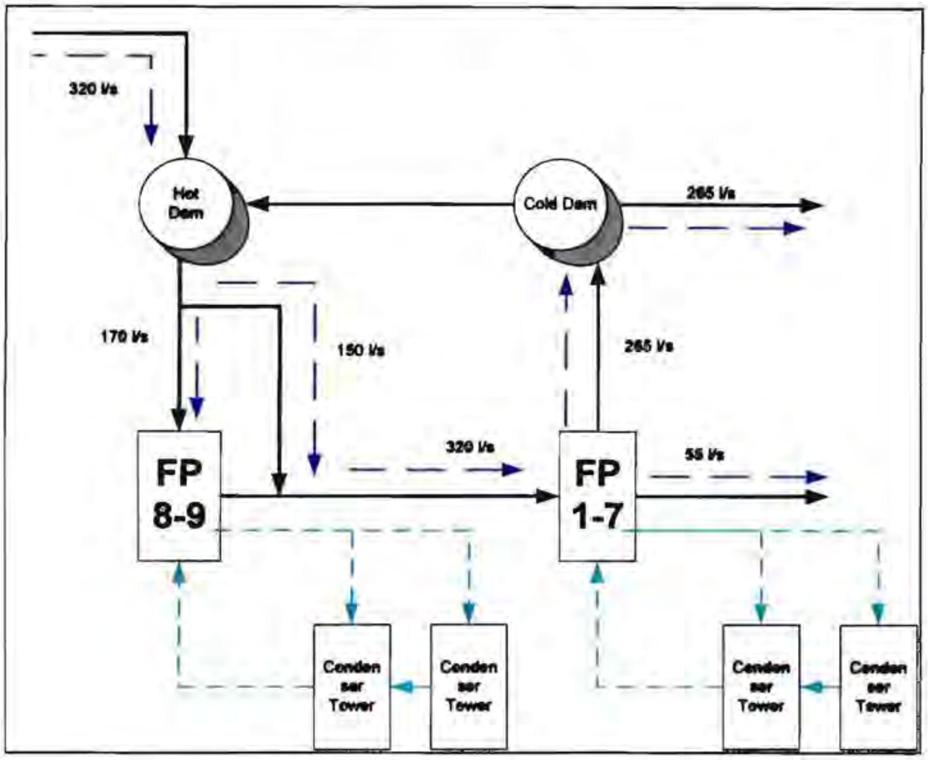


Figure 69: Target underground refrigeration system.

The refrigeration system consists of nine refrigeration machines and all are situated on 72L. The refrigeration system receives water from the 72L hot dam and stores the cold water in the 72L cold dam. The cold dam supplies water to other mining levels, as well as 3 BACs.

This mine operates a lead-lag refrigeration machine configuration. A lead-lag machine configuration is where a set refrigeration machines receives water from a hot water dam. The water is then distributed to another set of refrigeration machines. The first set is the leading set, and the second set is the lagging set.

Two parallel configured machines lead the rest of the machines. The seven lagging machines are also configured in parallel. One of these machines is in a closed loop configuration with a BAC. The combined rated power of the refrigeration machines is 9150 kW.

Refrigeration machines 8 and 9 process water at a flow rate of 170 L/s with an outlet temperature of 6°C. It has a combined COP of 2.9. The cooled water is then mixed with hot water from the hot dam to reduce the inlet temperature of the lagging refrigeration machines.

The lagging seven refrigeration machines receive a water mixture from the hot dam and the leading refrigeration machines. They have a combined flow rate of 320 L/s and an outlet temperature of 4°C and a combined COP of 3.13. Processed cold water from six of these lagging machines is stored in the 72L cold dam.

Applying load shift DSM two of the lagging machines can switch off during the evening peak period if the correct dam level control is applied. The theoretical saving is 3,150 kW during the evening peak period.

5.3. Bambanani Gold Mine

Bambanani Gold Mine is situated 10 km south-east of Welkom and 20 km north of Virginia in the Free State province. It forms part of the Welkom Gold Reef and is close to Masimong Gold Mine and Saaiplaas Gold Mine. Bambanani possesses three refrigeration systems, one is situated on the surface and two are underground.

Figure 70 indicates the clear water cycle at Bambanani Gold Mine

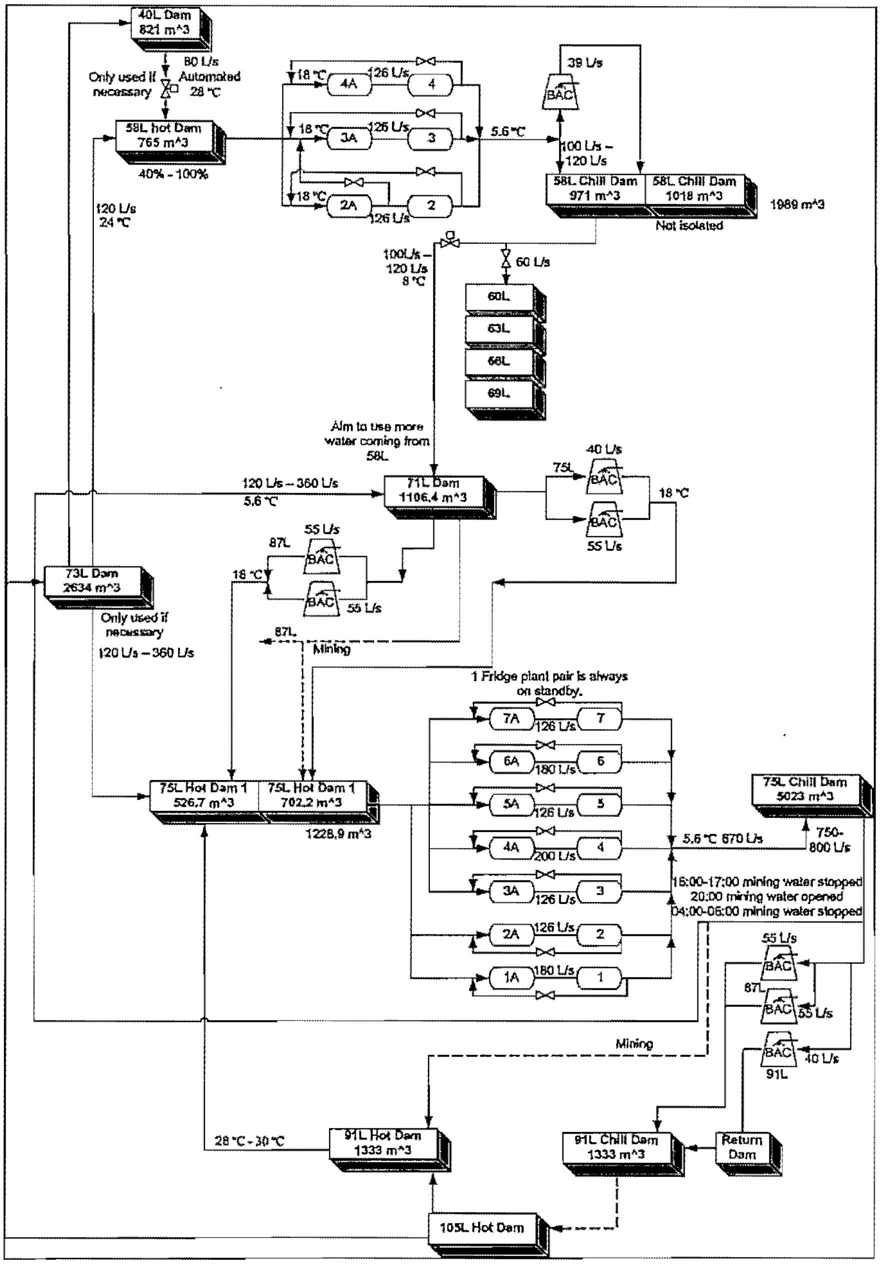


Figure 70: Layout of Bambanani clear water system.

The rated electrical power of the refrigeration system at 58L is 3500 kW. The refrigeration system on 58L consists out of three pairs of refrigeration machines, each in a lead-lag configuration. This system processes water at an average flow rate of 256 L/s with an outlet temperature of 6.5°C and a combined COP of 5.4.

The cooled water from refrigeration machine 2A is distributed to refrigeration machine 3A, acting as a pre-cooling mechanism. The cold water is stored in the cold dam on 58L. The BAC on 58L uses cold water from these machines. The levels between the surface and 75L receive cold water from this cold dam.

At 75L there are seven pairs of lead-lag refrigeration machines. Only four pairs are presently operational. They receive water from the 75L hot dam and distribute the cold water into the 75L cold dam. At the time of this study, insufficient information was available regarding these refrigeration machines.

Little can be done to the refrigeration with regards to DSM with the refrigeration machines on 58L. The refrigeration machines on 75L however load shifting will be possible if the correct dam level control is applied. All refrigeration machines can be stopped and a total saving of 2800 kW during the evening peak period.

5.4. Tau Tona Gold Mine

Tau Tona Gold Mine is one of the Western Deep Levels mines of the West Wits gold field situated 100 km west of Johannesburg. The mine is situated near the town of Carletonville. Tau Tona, Mponeng and Savuka share service utilities. All three mines are owned by AngloGold Ashanti.

The surface refrigeration system at Tau Tona is mainly used to supply the surface BAC with a constant cold water supply. Hot return water from the mining levels is pumped to the surface refrigeration system for cooling. The hot water is stored in the surface hot dam.

The total daily water processed by the mine is estimated to be between 13 and 16 ML/day.

Figure 71 indicates the clear water pumping cycle:

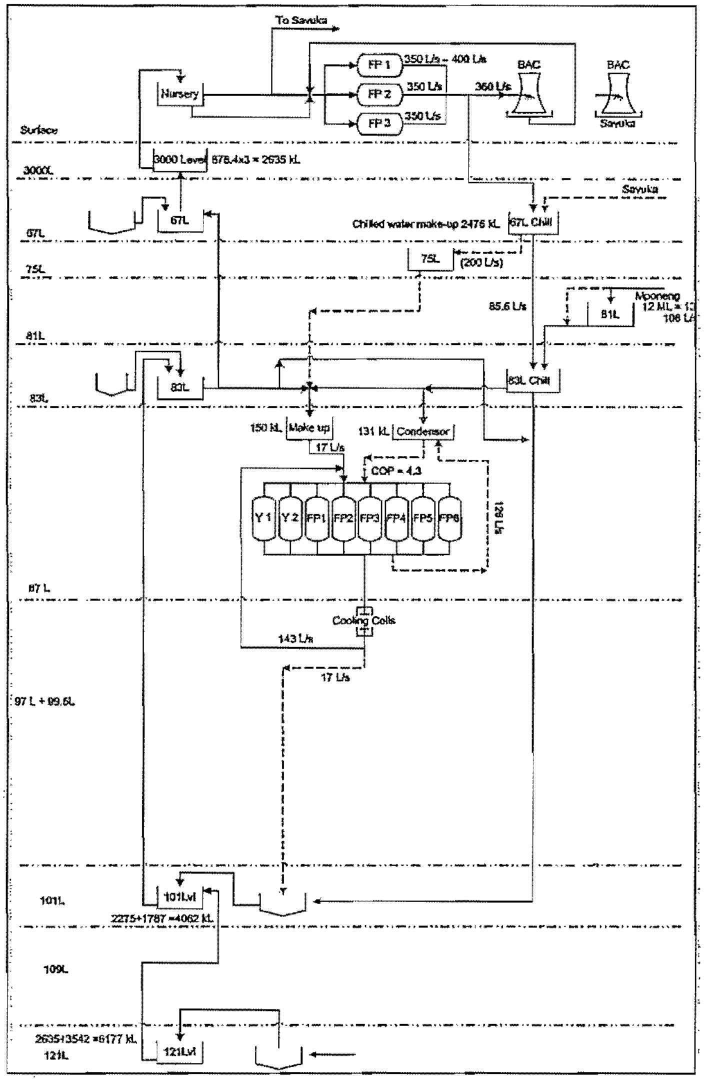


Figure 71: Tau Tona water system layout

Hot water is distributed to the surface refrigeration system and Savuka Gold Mine. The refrigeration system consists of three refrigeration machines with an installed electrical capacity of 4500 kW. They have an individual flow rate of 350 – 400 L/s and a combined outlet temperature of 12°C. The refrigeration machines have a combined COP of 4.9.

The surface BAC consumes an average of 360 L/s. This water is returned into the feeder pipe leading to the refrigeration system which also serves as a pre-cooling mechanism. The rest of the cooled water is stored in the cold dam situated on 67L. Water is then distributed to the 83L cold dam and the 75L cold dam.

The water from the 75L dam is used for underground cooling and is distributed to the small dam on 87L. The 87L refrigeration system processes water at 160 L/s at an outlet temperature of 9°C. It has an installed capacity of 2500 kW. The combined COP of these machines is 4.3.

There is not sufficient storage capacity for cold water in the underground dams. This is a terrific opportunity to investigate the possibility of DSM on cooling and ventilation systems. Results show there is an electrical savings possibility of 2,500 kW. However the cooling coils will not receive any cold water during the evening peak period. Test must be conducted in order to show the difference in underground temperature.

5.5. Conclusion

Table 5 indicates the number of underground refrigeration systems that have the potential for DSM intervention:

Mine	Number of underground machines	Level	Installed capacity
Bambanani	6	58L	3500 kW
	14	75L	N/A
Target	9	72L	9150 kW
Tau Tona	8	87L	2500 kW

Table 5: Summary of underground refrigeration systems with DSM possibility

A total 37 underground refrigeration machines are operational on three mines. They have a combined installed capacity of 15.15 MW. At the time of this study, no information on the installed capacity of the 75L refrigeration machines at Bambanani was available. There are 14 machines of which only eight are presently being used.

It is recommended that DSM interventions be applied on these systems in the future. However, the cost of infrastructure modifications and improvements will play a deciding role on the viability of any future DSM studies at this mine. Detailed quotations must be obtained prior to project proposal submission.

6

CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

This chapter will discuss the main conclusions from this dissertation

6. CONCLUSION

It was shown in this dissertation that there is an electricity shortage in South Africa. DSM is a programme that will enable electricity to be used sparingly and economically. The mining and industrial sectors consume a large percentage of the generating capacity of ESKOM. Electricity intensive equipment on mines was investigated.

Previous studies have shown DSM was successfully implemented on surface refrigeration machines. This study focused on DSM opportunities in underground refrigeration systems. It was shown that DSM can be successfully implemented in underground refrigeration systems.

Elandsrand Gold Mine was used as a case study. The mine possesses a refrigeration plant on surface and a subsurface refrigeration plant situated at 71L. A thermal and electrical baseline was created and system capabilities were analysed. A revised control strategy was implemented promoting energy reduction during the evening peak period.

The average load reduction for the evening peak, excluding condonable days, for the month of August 2009 was 6.60 MW. The average morning load reduction, excluding condonable days, was 6.06 MW. Load profiles for the period 1 October 2009 until 15 October 2009 showed that a reduction for the evening peak, excluding condonable days, was 5.24 MW. September and October has reached 72.8% and 77.5% of the potential saving respectively.

DSM significantly reduced the evening peak period electricity consumption. During August 2009 the evening peak period load was reduced by approximately 45% and during the first 15 days of October it reduced the evening peak period load by 36%. However, the correct scaling method should be analysed due to the back flow mechanism implemented.

DSM was successfully implemented on underground refrigeration systems. There are, however, various fields that can be investigated further. These fields include:

- DSM possibilities on refrigeration systems configured in a closed loop with a BAC.
- DSM in refrigeration systems that utilise ice coolers.

These can be investigated in a manner similar to this dissertation.

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Appendix A

Prime
Instrumentation

ELANDSRAND FRIDGE PLANT AUTOMATION

EM	DESCRIPTION	UNIT	Qty		AMOUNT	TOTAL
1	**PRELIMINARY AND GENERAL**	LOT	1			R -
1.1	**Site establishment costs**	LOT	1		R -	
	Medical & Teba	PERSON	10		R -	
	Induction ,Health and Safety Costs	PERSON	10		R -	
	Labour rate for crew (3days medical 4 days induction)	CREW	1		R -	
	Traveling	CREW	1		R -	
1.2	**Time Related continuing and variable costs**	MONTH	5		R -	
	Project management/meetings	MONTH	6		R -	
	Equipment	MONTH	5		R -	
	Transport costs	MONTH	6		R -	
	Vehicle costs	MONTH	6		R -	
2	**FIELD INSTRUMENTATION SURFACE**				R -	R -
	Pressure Transmitters (Oil & Freon) EJX530A-DBS4N-019EF	EACH	15		R -	
	Pressure Transmitters (Oil & Freon) EJX110A-DH4G9-19EB	EACH	4		R -	
	Pressure Transmitters IFM PA 3024 C/W adaptor and cable	EACH	16		R -	
	Mechanical Pressure Switches IFM PK 6524 (0 - 10Bar)	EACH	8		R -	
	Mechanical Pressure Switches IFM PK 6522 (0 - 100Bar)	EACH	4		R -	
	Mechanical Differential Press Switch Fima - DCMV3	EACH	8		R -	
	Flow Transmitters Krohne DN 300 - Remote Mount Integrator	EACH	1		R -	
	Temperature probe c/w Transmitter IFM TA 3231c/w cable	EACH	7		R -	
	Barksdale Temperature Switches THR-H 4S-10R (DPST)	EACH	2		R -	
	Vibration Transmitters Metrix ST 5484E-121-014-00	EACH	4		R -	
	Vane Actuators; EMG Drehmo DSM	EACH	4		R -	
	Flow Control Actuators; EMG Drehmo DSM with Profibus	EACH	3		R -	
	Current Transducers 300-5 Amp to 4-20mA Isolated 2-Wire output.	EACH	4		R -	
	IPACK L RTD converters	EACH	96		R -	
	Temperature Probes Epoxy Sealed	EACH	72		R -	
	Thermowell Length 100mm 1/2" NPT Male Thread	EACH	40		R -	
	Thermowell Length 200mm 3/4" NPT Male Thread	EACH	32		R -	
3	**GENERAL EQUIPMENT SURFACE**				R -	R -
	Process Sockets Material 316 SS 3/4" Female BSP Thread;	EACH	24		R -	
	Process Isolators-Water 1/2" F BSP Thread at both ends.	EACH	55		R -	
	Process Isolators	EACH	10		R -	
	Process Fittings	EACH	82		R -	
	Process Piping	EACH	240		R -	
	Sinetech UPS 2 KVA	EACH	1		R -	
	Relays and Bases 24VDC 11Pin;	EACH	84		R -	
	Relays and Bases 220VAC 11Pin;	EACH	4		R -	
	Relays and Bases 110VAC 11Pin	EACH	4		R -	
	E/Stop + Lockout Push Button Station	EACH	20		R -	
	Warning Light + Alarm unit	EACH	4		R -	

ELANDSRAND FRIDGE PLANT AUTOMATION

EM	DESCRIPTION	UNIT	Qty		AMOUNT	TOTAL
4	**PANELS SURFACE**				**R -**	**R -**
	Field junction boxes	EACH	12		R -	
	Field remote box	EACH	1		R -	
	PLC panels	EACH	5		R -	
	IDB c/w breakers	EACH	1		R -	
5	**FIELD INSTRUMENTATION 71 LEVEL**				**R -**	**R -**
	Pressure Transmitters (Oil & Freon) EJX530A-DBS4N-019EF	EACH	8		R -	
	Pressure Transmitters (Oil & Freon) EJX110A-DH4G9-19EB	EACH	2		R -	
	Pressure Transmitters IFM PA 3024 C/W adaptor and cable	EACH	8		R -	
	Mechanical Pressure Switches IFM PK 6524 (0 - 10Bar)	EACH	4		R -	
	Mechanical Pressure Switches IFM PK 6522 (0 - 100Bar)	EACH	2		R -	
	Mechanical Differential Press Switch Fima - DCMV3	EACH	2		R -	
	Flow Transmitters Krohne DN 350 - Remote Mount Integrator	EACH	1		R -	
	Temperature probe c/w Transmitter IFM TA 3231c/w cable	EACH	4		R -	
	Barksdale Temperature Switches THR-H 4S-10R (DPST)	EACH	1		R -	
	Vibration Transmitters Metrix ST 5484E-121-014-00 with the	EACH	2		R -	
	Vane Actuators; EMG Drehmo DSM	EACH	6		R -	
	Flow Control Actuators; EMG Drehmo DSM with Profibus	EACH	5		R -	
	Current Transducers 300-5 Amp to 4-20mA Isolated 2-Wire output.	EACH	2		R -	
	IPACK L RTD converters	EACH	38		R -	
	Temperature Probes Epoxy Sealed	EACH	36		R -	
	Thermowell Length 100mm 1/2" NPT Male Thread	EACH	20		R -	
	Thermowell Length 200mm 3/4" NPT Male Thread	EACH	16		R -	
6	**GENERAL EQUIPMENT 71 LEVEL**				**R -**	**R -**
	Process Sockets Material 316 SS 3/4" Female BSP Thread;	EACH	16		R -	
	Process Isolators-Water 1/2" F BSP Thread at both ends.	EACH	35		R -	
	Process Isolators	EACH	5		R -	
	Process Fittings	EACH	48		R -	
	Process Piping	EACH	120		R -	
	Sinetech UPS 2 KVA	EACH	3		R -	
	Relays and Bases 24VDC 11Pin;	EACH	32		R -	
	Relays and Bases 220VAC 11Pin;	EACH	4		R -	
	E/Stop + Lockout Push Button Station	EACH	10		R -	
	Warning Light + Alarm unit	EACH	2		R -	
7	**PANELS 71 LEVEL**				**R -**	**R -**
	Field junction boxes	EACH	8		R -	
	PLC panels	EACH	2		R -	
	75L plc	EACH	1		R -	
	Pipe raise JB	EACH	1		R -	
	IDB c/w breakers	EACH	3		R -	

ELANDSRAND FRIDGE PLANT AUTOMATION

EM	DESCRIPTION	UNIT	Qty		AMOUNT	TOTAL
8	**SURFACE PLC EQUIPMENT**				R -	R -
.1	**Surface RefPlant C/Room**				R -	
	SIMATIC S7-300, RAIL L=530MM	EACH	1		R -	
	6ES73901AF300AA0					
	SIMATIC S7-300,LOAD POWER SUPP. PS 307	EACH	1		R -	
	6ES73071EA000AA0					
	SIMATIC DP, INTERFACE IM 153-1, FOR ET 200M	EACH	1		R -	
	6ES71531AA030XB0					
	SIMATIC S7-300, DIGITAL INPUT SM 321,	EACH	1		R -	
	6ES73211BH020AA0					
	SIMATIC S7-300, FRONT CONNECTOR 20 pin	EACH	1		R -	
	6ES73921AJ000AA0					
	BUS CONNECTOR FOR PROFIBUS	EACH	1		R -	
	PC477 15" TOUCH, WITH XP EMBEDDED,	EACH	1		R -	
	6AV78430BF100LB0					
	WINCC FLEXIBLE /SM@RTSERVICE FOR WINCC FLEXIBLE	EACH	1		R -	
	6AV66187BD011AB0					
	WINCC FLEXIBLE /ARCHIVES FOR WINCC FLEXIBLE	EACH	1		R -	
	6AV66187ED011AB0					
3.2	**Surface RefPlant MACHINE 1&2**				R -	
	SIMATIC S7-300, RAIL L=530MM	EACH	2		R -	
	6ES73901AF300AA0					
	SIMATIC S7-300,LOAD POWER SUPP. PS 307	EACH	2		R -	
	6ES73071EA000AA0					
	SIMATIC DP, INTERFACE IM 153-1, FOR ET 200M	EACH	2		R -	
	6ES71531AA030XB0					
	SIMATIC S7-300, DIGITAL INPUT SM 321,	EACH	2		R -	
	6ES73211BH020AA0					
	SIMATIC S7-300, DIGITAL OUTPUT SM 322 HIGH SPEED,	EACH	2		R -	
	6ES73221BH100AA0					
	U/I/RESISTANCE/PT100, NI100, NI1000, LG-NI1000,	EACH	11		R -	
	6ES73311KF010AB0					
	SIMATIC S7-300, FRONT CONNECTOR 20 pin	EACH	4		R -	
	6ES73921AJ000AA0					
	SIMATIC S7-300,FRONT CONNECTOR 40-Pin	EACH	10		R -	
	6ES73921AM000AA0					
	BUS CONNECTOR FOR PROFIBUS	EACH	13		R -	
	SIMATIC DP,RS485 REPEATER For CONNECTION OF PROFIBUS/MF	EACH	1		R -	
	6ES79720AA010XA0					
3.3	**Surface RefPlant MACHINE 3&4**				R -	
	SIMATIC S7-300, RAIL L=530MM	EACH	2		R -	
	6ES73901AF300AA0				R -	
	SIMATIC S7-300,LOAD POWER SUPP. PS 307	EACH	2		R -	
	6ES73071EA000AA0					
	SIMATIC DP, INTERFACE IM 153-1, FOR ET 200M	EACH	3		R -	
	6ES71531AA030XB0					
	SIMATIC S7-300, DIGITAL INPUT SM 321,	EACH	2		R -	
	6ES73211BH020AA0					
	SIMATIC S7-300, DIGITAL OUTPUT SM 322 HIGH SPEED,	EACH	2		R -	
	6ES73221BH100AA0					

EM	DESCRIPTION	UNIT	Qty		AMOUNT	TOTAL
	U/I/RESISTANCE/PT100, NI100, NI1000, LG-NI1000, 6ES73311KF010AB0	EACH	11		R -	
	SIMATIC S7-300, FRONT CONNECTOR 20 pin 6ES73921AJ000AA0	EACH	4		R -	
	SIMATIC S7-300,FRONT CONNECTOR 40-Pin 6ES73921AM000AA0	EACH	10		R -	
	BUS CONNECTOR FOR PROFIBUS	EACH	13		R -	
	SIMATIC DP,RS485 REPEATER For CONNECTION OF PROFIBUS/MI 6ES79720AA010XA0	EACH	1		R -	
.4	**Surface HMI equipmnet**				**R -**	
	PC477 15" TOUCH, WITH XP EMBEDDED, 6AV78430BF100LB0	EACH	2		R -	
	WINCC FLEXIBLE /SM@RTSERVICE FOR WINCC FLEXIBLE 6AV66187BD011AB0	EACH	2		R -	
	WINCC FLEXIBLE /ARCHIVES FOR WINCC FLEXIBLE 6AV66187ED011AB0	EACH	2		R -	
.5	**Surface RefPlant JB box**				**R -**	
	SIMATIC S7-300, RAIL L=530MM 6ES73901AF300AA0	EACH	1		R -	
	SIMATIC S7-300,LOAD POWER SUPP. PS 307 6ES73071EA000AA0	EACH	1		R -	
	SIMATIC DP, INTERFACE IM 153-1, FOR ET 200M 6ES71531AA030XB0	EACH	1		R -	
	SIMATIC S7-300, ANALOG INPUT SM 331 6ES73317KF020AB0	EACH	2		R -	
	SIMATIC S7-300,FRONT CONNECTOR 40-Pin 6ES73921AM000AA0	EACH	2		R -	
	BUS CONNECTOR FOR PROFIBUS	EACH	2		R -	
9	**PLC EQUIPMET 71 LEVEL**				**R -**	**R -**
.1	**71 Level Control Room**				**R -**	
	SIMATIC S7-300, RAIL L=530MM 6ES73901AF300AA0	EACH	1		R -	
	SIMATIC S7-300,LOAD POWER SUPP. PS 307 6ES73071EA000AA0	EACH	1		R -	
	SIMATIC DP, INTERFACE IM 153-1, FOR ET 200M 6ES71531AA030XB0	EACH	1		R -	
	U/I/RESISTANCE/PT100, NI100, NI1000, LG-NI1000, 6ES73311KF010AB0	EACH	1		R -	
	SIMATIC S7-300, FRONT CONNECTOR 20 pin 6ES73921AJ000AA0	EACH	4		R -	
	SIMATIC S7-300,FRONT CONNECTOR 40-Pin 6ES73921AM000AA0	EACH	10		R -	
	BUS CONNECTOR FOR PROFIBUS	EACH	9		R -	
	PC477 15" TOUCH, WITH XP EMBEDDED, 6AV78430BF100LB0	EACH	1		R -	
	WINCC FLEXIBLE /SM@RTSERVICE FOR WINCC FLEXIBLE 6AV66187BD011AB0	EACH	1		R -	
	WINCC FLEXIBLE /ARCHIVES FOR WINCC FLEXIBLE 6AV66187ED011AB0	EACH	1		R -	

ELANDSRAND FRIDGE PLANT AUTOMATION

EM	DESCRIPTION	UNIT	Qty		AMOUNT	TOTAL
).2	**71 Level RefPlant MACHINE 3&4**				**R -**	
	SIMATIC S7-300, RAIL L=530MM	EACH	2		R -	
	6ES73901AF300AA0					
	SIMATIC S7-300,LOAD POWER SUPP. PS 307	EACH	2		R -	
	6ES73071EA000AA0					
	SIMATIC DP, INTERFACE IM 153-1, FOR ET 200M	EACH	2		R -	
	6ES71531AA030XB0					
	SIMATIC S7-300, DIGITAL INPUT SM 321,	EACH	2		R -	
	6ES73211BH020AA0					
	SIMATIC S7-300, DIGITAL OUTPUT SM 322 HIGH SPEED,	EACH	2		R -	
	6ES73221BH100AA0					
	U/I/RESISTANCE/PT100, NI100, NI1000, LG-NI1000,	EACH	10		R -	
	6ES73311KF010AB0					
	BUS CONNECTOR FOR PROFIBUS	EACH	13		R -	
	SIMATIC DP,RS485 REPEATER For CONNECTION OF PROFIBUS/MI	EACH	1		R -	
	6ES79720AA010XA0					
9.3	**71 Level HMI equipmnet**				**R -**	
	PC477 15" TOUCH, WITH XP EMBEDDED,	EACH	1		R -	
	6AV78430BF100LB0					
	WINCC FLEXIBLE /SM@RTSERVICE FOR WINCC FLEXIBLE	EACH	1		R -	
	6AV66187BD011AB0					
	WINCC FLEXIBLE /ARCHIVES FOR WINCC FLEXIBLE	EACH	1		R -	
	6AV66187ED011AB0					
9.4	**71 Level pipe raise JB**				**R -**	
	SIMATIC S7-300, RAIL L=530MM	Each	1		R -	
	6ES73901AF300AA0					
	SIMATIC S7-300,LOAD POWER SUPP. PS 307	EACH	1		R -	
	6ES73071EA000AA0					
	SIMATIC DP, INTERFACE IM 153-1, FOR ET 200M	EACH	1		R -	
	6ES71531AA030XB0					
	U/I/RESISTANCE/PT100, NI100, NI1000, LG-NI1000,	EACH	1		R -	
	6ES73311KF010AB0					
	SIMATIC S7-300,FRONT CONNECTOR 40-Pin	EACH	1		R -	
	6ES73921AM000AA0					
9.5	**71 Level machine 1&2 and 7&8 upgrade**				**R -**	
	CP343-1 lean(ethernet)	EACH	1		R -	
	CP443-1(ethernet)	EACH	1		R -	
9.6	**75 Level BAC PLC**				**R -**	
	SIMATIC S7-300, RAIL L=530MM	EACH	1		R -	
	6ES73901AF300AA0					
	SIMATIC S7-300,LOAD POWER SUPP. PS 307	EACH	1		R -	
	6ES73071EA000AA0					
	SIMATIC DP, INTERFACE IM 153-1, FOR ET 200M	EACH	1		R -	
	6ES71531AA030XB0					
	SIMATIC S7-300, DIGITAL INPUT SM 321,	EACH	1		R -	
	6ES79538LG110AA0					
	U/I/RESISTANCE/PT100, NI100, NI1000, LG-NI1000,	EACH	3		R -	
	6ES73311KF010AB0					
	SIMATIC S7-300, DIGITAL OUTPUT SM 322 HIGH SPEED,	EACH	1		R -	
	6ES73221BH100AA0					

ELANDSRAND FRIDGE PLANT AUTOMATION

EM	DESCRIPTION	UNIT	Qty		AMOUNT	TOTAL
	SIMATIC S7-300, FRONT CONNECTOR 20 pin 6ES73921AJ000AA0	EACH	1		R -	
	SIMATIC S7-300,FRONT CONNECTOR 40-Pin 6ES73921AM000AA0	EACH	3		R -	
	BUS CONNECTOR FOR PROFIBUS 6ES73921AJ000AA0	EACH	2		R -	
	SIMATIC S7-300,FRONT CONNECTOR 40-Pin 6ES73921AM000AA0	EACH	3		R -	
10	**NETWORK EQUIPMENT**				R -	R -
	Moxa EDS408 switch	EACH	9		R -	
	19" Splice Tray	EACH	8		R -	
	Multi mode patch leads (1meter)	EACH	60		R -	
	Midcouplers ST/850	EACH	128		R -	
	Pigtails ST/850	EACH	128		R -	
	Splicing	EACH	128		R -	
11	**CABLES**				R -	R -
	1.5mm² 3Core cable SWA	P/ M	1500		R -	
	1mm² 1 Pair cable SWA	P/ M	1500		R -	
	1mm² 16 Pair cable SWA	P/ M	500		R -	
	Profibus cable SWA	P/ M	1500		R -	
	Ethernet cable	P/ M	300		R -	
	8 Fibre cable SWA	P/ M	1000		R -	
12	**TERMINATIONS**				R -	R -
	Terminations	EACH	650		R -	
13	**INSTALLATION AND COMMISSIONING**				R -	R -
3.1	**Surface installation.**					
	1* Technician	HRS	540		R -	
	1*Boilermaker	HRS	540		R -	
	4*helpers	HRS	2160		R -	
3.2	**71 Level installation**					
	1* Technician	HRS	445		R -	
	1*Boilermaker	HRS	445		R -	
	4*helpers	HRS	1780		R -	
14	**PLC AND SCADA DEVELOPMENT**				R -	R -
	PLC development	LOT	1		R -	
	Scada development	LOT	1		R -	
	Commissioning	LOT	1		R -	
	Drawings and commissioning	LOT	1		R -	

ELANDSRAND FRIDGE PLANT AUTOMATION

EM	DESCRIPTION	UNIT	Qty		AMOUNT	TOTAL
15	**VALVES**				**R -**	**R -**
	DN250 Okumura 612X Butterfly valve	EACH	1		R -	
	DN350 Okumura 615X Butterfly valve	EACH	4		R -	
	DN400 Okumura 615X Butterfly valve	EACH	2		R -	
	DN450 Okumura 615X Butterfly valve	EACH	2		R -	
16	**TACHI MODIFICATIONS**				**R -**	**R -**
	Induction	EACH	1		R -	
	Surface cooling towers including material	EACH	1		R -	
	71 Level chamber 1	EACH	1		R -	
	71 Level chamber 2	EACH	1		R -	
	71 Level chamber 3	EACH	1		R -	
	71 Level behind fan	EACH	1		R -	
	73 Level	EACH	1		R -	
	Transport	EACH	1		R -	
	PRICE SCHEDULE					
1	**PRELIMINARY AND GENERAL**					
2	**FIELD INSTRUMENTATION SURFACE**					
3	**GENERAL EQUIPMENT SURFACE**					
4	**PANELS SURFACE**					
5	**FIELD INSTRUMENTATION 71 LEVEL**					
6	**GENERAL EQUIPMENT 71 LEVEL**					
7	**PANELS 71 LEVEL**					
8	**SURFACE PLC EQUIPMENT**					
9	**PLC EQUIPMENT 71 LEVEL**					
10	**NETWORK EQUIPMENT**					
11	**CABLES**					
12	**TERMINATIONS**					
13	**INSTALLATION AND COMMISSIONING**					
14	**PLC AND SCADA DEVELOPMENT**					
15	**VALVES**					
16	**TACHI MODIFICATIONS**					
	TOTAL					R -