POTENTIAL FOR LOAD SHIFTING IN VENTILATION AND COOLING SYSTEMS

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ABSTRACT

Title:	Potential for load shifting in Ventilation and Cooling systems
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One of the major role players in the economy of South African is the mining industry. It forms almost 20% of the gross domestic product of South Africa, with sales of R76.5 billion for 1999. Of this, gold sales were 33% of the total sales, or R24.99 billion for 1999. Platinum sales were 19.5% of the total sales, or R14.92 billion for 1999.

In 1999 the energy consumption of the mining industry in South Africa was 114 325.2 TJ or 31.757 TWh per year at an average consumption of 3.63 GWh. This constitutes 18.4% of the country's total energy consumption for 1999. This forms a big part of the annual expenditure of the mining industry and contributes a large part of the base load of the country.

ESKOM is moving towards a price structure for electricity that reflects the real cost of generation, namely real time pricing (RTP). ESKOM developed various cost structures to coax customers to manage their electricity demand (DSM) to use more energy in off-peak periods (low cost of generation) and less energy in peak periods (high generation costs).

To use these structures to the fullest potential, the mines need to investigate their energy consuming components and see where these structures can be implemented. The ventilation and cooling (VC) system of mines use approximately 25% of the total energy used in the mining activities. This component is therefore a good place to investigate the implementation of such structures and their potential impact.

ABSTRACT

Most of the price structures from ESKOM are based on the fact that the consumer needs to be able to shift part of or its entire load for a period of time. The potential of this shift and the impact of it on the mine and ESKOM is complex and dynamic in nature. For such a purpose integrated, dynamic simulation software is needed.

In the mining industry there is no integrated and dynamic simulation software. This simulation field is much more developed in the building industry. Therefore, with much effort, a building simulation tool* was used to find the potential for shifting load in gold and platinum mines. A first pilot study was done for the VC system of a pilot mine, South Deep (PDWAJV). The mine has an installed cooling capacity of 28 MW and had a total energy consumption of 400 GWh for 1999. The mine was simulated and verified with measured results.

The VC system or cooling cycle attributes almost 40 % of the total load caused by the mine. Using current and new control, along with some different system configurations, the total potential load shift on VC was determined to be 19 MWh, sustained for five continuous hours per day. This causes a recovery period of six hours with an increase of 4.5 MWh on the maximum load.

If this could be replicated on all the mines in South Africa, a total load shift of 1,35 GWh could be achieved. But not all mines are that deep and therefore the influence of the cooling cycle might not be so great. If only half the potential load could be shifted it could still cause a load shift of 676 MWh for the South African network for a potential period of five hours a day.

Only when the entire mining industry is able to achieve the same results as South Deep, can ESKOM successfully implement all their new pricing structures and can South Africa profit from such devices. Our experience with this project also showed that a new integrated, dynamic simulation tool, aimed specifically at mines, must be developed before the above mentioned results can be achieved by ESKOM.

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* Software developed by TEMM International (Pty) Ltd and used with special permission

SAMEVATTING

Titel: Potential for load shifting in Ventilation and Cooling systems

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Sleutelterme: Ventilation and Cooling; System simulation; DSM; Pricing structures; Load shift; Thermal storage modeling.

Een van die grootste ekonomiese rolspelers in Suid Afrika is die myn industrie. Die industrie vorm ongeveer 20% van die bruto nasionale produksie met verkope van R76.5 biljoen vir 1999. Van hierdie bedrag was goud verkope 33%, of R24.99 biljoen en platinum was 19,5%, of R14.92 biljoen, vir die jaar 1999.

In 1999 was die totale energie gebruik van die Suid Afrikaanse myn industrie 114 325.2 TJ, of 31.575 TWh per jaar, teen 'n gemiddelde verbruik van 3.63 GWh. Dit maak 18.4% uit van die land se totale energie verbruik vir 1999. Dit is 'n groot deel van die jaarlikse uitgawes van die myn industrie en dra 'n groot deel by tot die basis las van die land.

ESKOM is besig om te beweeg na 'n prysstruktuur vir elektrisiteit wat die werklike koste van opwekking reflekteer naamlik intydse-prys tarief (RTP). ESKOM het verskeie prysstrukture ontwikkel om verbruikers te oorreed om hulle elektrisiteits aanvraag (DSM) beter te bestuur. Dit behels om meer energie te gebruik buite spitstyd (lae opwekkings koste) en minder tydens spitstyd (hoë opwekkings koste).

Om hierdie prysstrukture die beste te gebruik moet die myne hulle energie verbruikende komponente ondersoek en bepaal waar hierdie strukture die beste gebruik kan word. Die ventilasie en verkoeling (VC) stelsel gebruik ongeveer 25% van die totale energie gebruik vir myn aktiwiteite. Hierdie komponent is 'n goeie plek om die implimentering van sulke strukture en hul moontlike impak te ondersoek.

Meeste van die prysstrukture van ESKOM is gebasseer op die feit dat die verbruiker 'n gedeeltelike of totale las kan skuif vir 'n sekere tyd. Die potensiaal van hierdie skuif en die impak daarvan op die myn en ESKOM is kompleks en dinamies van aard. As gevolg daarvan is daar geïntegreerde, dinamiese simulasie sagteware nodig.

In die myn industrie is daar geen geïntegreerde en dinamiese simulasie sagteware nie. Hierdie simulasie area is baie meer ontwikkeld in die gebou industrie. Daarom, met baie moeite, is 'n gebou simulasie pakket* gebruik om die potensiaal vir lasverskuiwing in goud en platinum myne te bepaal. 'n Proefstudie is gedoen op die die VC stelsel van die proefmyn, South Deep (PDWAJV). Die myn het 'n geïnstalleerde verkoelingskapasiteit van 28 MW en 'n totale energie verbruik van 400 GWh vir 1999. Die myn is gesimuleer en geverifieer met gemete data.

Die VC stelsel of verkoelingsiklus dra amper 40% van die totale las van die myn by. Met die huidige en nuwe beheer, saam met 'n paar verskillende stelsel konfigurasies, is die totale potensiale lasverskuiwing bepaal as 19 MWh vir 'n periode van vyf aaneenlopende ure per dag. Dit veroorsaak 'n herstel periode van ses ure met 'n toename in maksimum las van 4.5 MWh.

As hierdie resultate herhaal kan word in al die Suid Afrikaanse myne, kan 'n totale lasverskuiwing van 1.35 GWh behaal word. Maar alle myne is nie so diep nie en die invloed van die verkoelingssiklus sal nie so groot wees nie. As slegs die helfte van die potensiale las verskuif kan word sal daar 676 MWh verskuif kan word vir vyf ure per dag in die Suid Afrikaanse netwerk.

Slegs as die hele myn industrie hierdie tipe resultate van South Deep kan herhaal sal ESKOM hulle nuwe tariefstrukture kan implimenteer en Suid Afrika daarby baat. Die ondervinding van hierdie studie het gewys dat nuwe dinamies, geïntigreerde simulasie gereedskap, spesifiek vir myne, ontwikkel moet word voor ESKOM sulke resultate sal kan behaal.

ACKNOWLEDGEMENTS

I would like to thank the following people for their help and contributions:

- Koen Benadie and Piet Oosthuizen at the surface plant of South Deep (PDWAJV)
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- Deon Arndt for his assistance and insights in the project
- Prof. E.H. Mathews for his guidance in this study
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NOMENCLATURE

Symbols

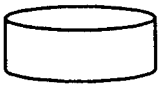
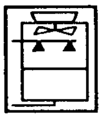
$\dot{m}_i, \dot{m}_o$	Mass-flow in and out (kg/s)
A	Heat transfer area (m^2)
C	Mass-flow constant (kJ/K)
C^0	Initial mass-flow constant (kJ/kg)
m_l	Mass-flow of water into the cooling tower (kg/s)
Q	Heat transferred (kW)
T_A	Ambient temperature (°C)
T_D	Temperature of the dam water (°C)
T_D^0	Initial temperature of the dam water (°C)
T_i	Temperature of the water flowing into the dam (°C)
t_{le}	Temperature of water leaving the cooling tower (°C)
t_{li}	Temperature of water entering the cooling tower (°C)
T_{owb}	Wet bulb temperature (°C)
T_S	Solar air temperature (°C)
U	Overall heat transfer coefficient ($W/m^2.°C$)
V_0	Initial volume (m^3)
ΔT	Temperature difference (°C)
Δt	Time increment (s)

Abbreviations

DSM	Demand side management
PDWAJV	Placer Dome Western Areas Joint Venture
VC	Ventilation and Cooling
TOU	Time of Use
RTP	Real Time Pricing

GRAPHICAL SYMBOLS

VC SYMBOLS

	Thermal storage dam
	Centrifugal Pump
	Controlled Valve
	Cooling Tower
	Controller

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CHAPTER 1

MOTIVATION FOR THIS STUDY

The need, contributions and the value of this study are presented in this chapter. The mining industry is one of the largest consumers of energy in South Africa. The purpose of this chapter is to generate the necessary knowledge to ensure the successful use, by the mines' VC systems, of ESKOM's price offerings, resulting in effective DSM opportunities. The need for a dynamic, integrated simulation tool is also discussed.

1.1 Introduction

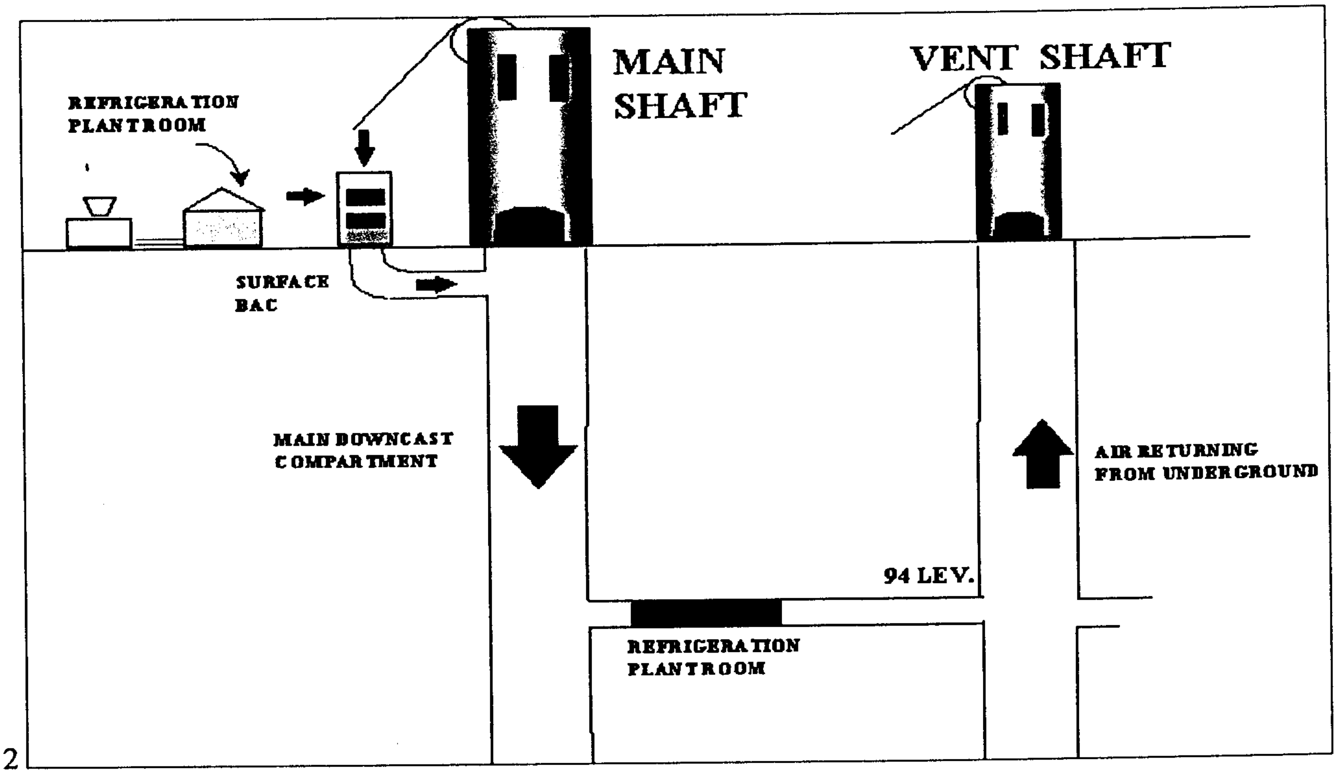
Mining is one of South Africa's biggest industries, along with manufacturing, trade and agriculture [1]. It forms almost 20% of the gross domestic product of South Africa, with sales of R76.5 billion for 1999 [2]. Of this, gold sales were 33% of the total sales, or R24.99 billion for 1999. Platinum sales were 19.5% of the total sales, or R14.92 billion for 1999.

The product prices vary with time and influence the profit margin of the mines. With the varying economy and mineral prices, the need for retrieving the maximum amount of ore at the most energy efficient way has become apparent. One of the techniques employed to achieve this goal is deep level mining with typical depths of between 3 - 5 kilometers.

For platinum mining below 1400 m will alter operations radically with the need for a lot more refrigeration and changes to the support systems [3]. For a gold mine, this crucial level is typically 3000 m below the surface. At these depths the virgin rock temperature rises above the acceptable human endurance levels and special ventilation and cooling is needed [4].

This presents a difficult and potentially dangerous situation, concerning the comfort and health of the workers. Satisfactory ventilation is needed, as well as a means to investigate the impact of machines, in the ventilation cycle, breaking or performing at lower efficiency [5].

Most mines use relatively standard ventilation and cooling layouts (see Figure 1-1). A conventional way of cooling the intake or fresh air is by placing the heat exchangers at the intake or down shaft of the mine. This is satisfactory for mines that are not too deep. When the mine becomes too deep, the air speed needed to convey the cold air to the stopes becomes too fast and uncomfortable. The airspeed is also dangerous at this point as it can propagate fires or dangerous gas. Special ventilation and cooling (VC) layouts are then needed.



1.2

Figure 1-1: Typical layout of mine's ventilation and cooling system

For most mines these layouts consist of a surface cooling plant, an underground storage and distribution plant and an underground pumping system. The surface plant contains the chillers or icemakers, water storage dams and cooling towers. The underground plant consists of a thermal storage dams and cooling coils or spray-chambers. This underground storage plant is typically between 1000 m and 2000 m below the surface.

If extra cooling is needed a further cooling plant or mobile plant can be installed below the surface. The warm intake air, heated by internal loads and the virgin rock, passes through the cooling coils or the chambers. Extraction fans, placed in the return airways, then suck the warm air out. Producing satisfactory cooling and ventilation for deep mines is a precise and necessary task.

Large and expensive equipment is needed for satisfactory ventilation and cooling. Along with the capital cost, the energy usage of this equipment is very high. The mining and industry sector consumes about 40% of ESKOM's total sellable energy production. Mines alone use nearly 20%

of the electricity provided by ESKOM [6]. This amounts to approximately R3 000 million of electricity per annum just for the gold mines, with the accompanying CO_2 pollution.

Ventilation and cooling (VC) uses approximately 25% or R750 million of this energy. The gold mines were recently in a crisis and some were threatening to close down (ERPM did close down in 1999). Every time the gold price drops, ESKOM stands a chance of losing some of their biggest clients.

It will therefore be beneficial if the mines can be more energy clever to reduce their operating costs. Secondly, it will provide the ESKOM with more DSM opportunities, e.g. spot pricing, load shedding, etc. A further benefit would be that with more efficient mining systems, the use of virtual power stations could be implemented [7].

ESKOM is moving towards a price structure for electricity that reflects the real cost of generation, namely real time pricing (RTP). ESKOM developed various cost structures to coax customers to manage their electricity demand (DSM) to use more energy in off-peak periods (low cost of generation) and less energy in peak periods (high generation costs). However, many industries do not effectively use these price offerings from ESKOM.

The best, if not the only way, to effectively use the ESKOM price structures without affecting operation is better control of the VC system for optimal use or for load shifting. However, this is difficult to predict, as a comprehensive, fully integrated, component based, dynamic simulation is needed to ensure that the safety of the miners is not compromised by any new DSM control strategy.

Extensive investigations and meetings with stakeholders have shown that VC control is the only option in mine VC to effectively use ESKOM's pricing and thus ensure DSM load shifting. However, control is also the most difficult to simulate as you need a fully integrated, dynamic, component based simulation tool. No such tool for mine VC could be found in the literature and through extensive discussions with specialists in the mining industry. Very little work was done overseas as most of the deep mines are in South Africa. This was confirmed during a special visit to Dr Sharma in the USA in October 1999 [8].

A comprehensive international survey showed that no such software is available for the mines. Investigations into other fields of cooling and ventilation showed that such software, used in large buildings, already exists. One such a software package that exists is QUICKcontrol[•]. This software has already been extensively tested and verified for building applications [9][10][11][12][13]. With effort it was used to solve the mining problem for ESKOM. However it was very inefficient trying to use building software for a mining application.

In order to believe the results of the building simulations, it had to be verified, using an average and well-maintained test mine. Such a mine was found in South Deep, Placer Dome Western Areas Joint Venture, a gold mine producing 1% of the total gold production in South Africa at about 140 tonnes a term. The average grade of the gold mined is 6.99 gm/t [14].

The mine was divided into two sections namely the surface plant and surrounding equipment and the underground pumping stations and dams. These two systems are linked by a Mine water dam on the surface. New models were inserted into the software, namely dams, valves and a new cooling tower model. Some of the existing models were modified to better represent the mining equipment. This is further discussed in Chapter 2.

With these two systems successfully verified, discussed in Chapter 3, new energy usage strategies were investigated, seen in more detail in Chapter 4. The main idea of these strategies was the investigation into the possibility of load shifting of the two systems' energy usage. Adjustments were made to the existing systems, either new configurations of equipment or optimization of the existing equipment.

The result of the study was that there is sufficient opportunity, using the existing equipment, with minor adjustments, to shift the load for a few hours. This is mainly due to the installed thermal storage capacity of the mine. This is fairly standard practice in most mines and it can

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[•] Software developed by TEMM International (Pty) Ltd and used with special permission therefore be concluded that most mines will be able to shift its VC load by a couple of hours, should it be needed for RTP purposes.

1.2 Pricing Structures for mines

Due to varying demand, the generation of electricity is not constant over time. The cost is dependant on the instantaneous load being supplied, the available generation and the state of the electricity network or grid. Economic efficiency criteria dictate that the price of a product should be equal to the marginal cost of generation and transmission by ESKOM[15]. For this reason ESKOM had devised various tariff structures for time of use (TOU) to accommodate and help large consumers. Some of these structures will be discussed later on.

The tariff of a large customer has various components that make up the final charge for the electricity. The following are relevant to large customers [16]:

Connection Fee: The connection fee is payable upfront in cash for the connection of a new supply point and is a contribution towards the cost of providing the supply.

Basic Charge: A fixed monthly charge for each point of delivery which is payable whether electricity is consumed or not. This charge increases every year with the annual price increase.

Demand Charge: Payable for each kilovolt ampere (kVA) or kilowatt (kW) of the maximum demand supplied during the month. It is calculated by integrating the measured demand over half-hourly periods for kVA measured supplies or hourly periods for kW measured supplies.

Active Energy Charge: A charge for each kilowatt-hour (kWh) of active energy consumed.

Reactive Energy Charge: This charge applies only to Megaflex, Miniflex and Ruraflex. It is levied on every excess kilovarhour (kvarh) registered. If the customer's installation is operating at a power factor of 0,96 or better, there will be no reactive energy charge. The method of calculating this excess differs between Megaflex, Miniflex and Ruraflex and is described with the respective tariff.

Voltage Discount: Electricity is transmitted at as high a voltage as practical to make transmission efficient. At times it has to be transformed to a lower voltage before being supplied to a customer. The higher the supply voltage, the higher the voltage discount granted. This is calculated as a percentage of demand (where applicable) and active energy charges.

Transmission Percentage Surcharge: The demand charge (where applicable), active energy charges and reactive energy charge (where applicable) are subject to a transmission surcharge after the voltage discount has been granted, depending on the distance from Johannesburg.

Monthly Rental: The monthly rental is a contribution to the capital cost of providing a supply and is payable each month in addition to the tariff charges. Monthly rentals are calculated using a 15,50% (2000) discount rate, and can be paid over any period of up to 25 years. (The capitalisation factor for 25 years is 1,242% per month.) The customer has an option of making a cash payment instead of the monthly payments. The monthly rental is rebated (not beyond extinction) as described with the respective tariffs.

Some of the structures that are relevant to the mining sector are discussed below. This includes RTP.

- **NightSave**

For the use in non-rural reticulation network supplies, previously on Standardrate (non-rural reticulation). This is for customers with a notified maximum demand of at least 25 kW/kVA and who elect to pay for demand measured only during peak periods. They must be able to move all or part of their electricity demand to ESKOM's off-peak period between 22:00 and 06:00 on weekdays and the entire Saturday, Sunday and public holidays. The supply may not be taken from rural reticulation networks.

The basic charges associated with this tariff system are:

Connection fee: The greater of R2 412,28 (VAT excl.) or 5% of actual project cost (VAT excl.) payable per point of delivery.

Basic charge: R166,16 + VAT = R189,42 per month per point of delivery whether electricity is consumed or not.

Monthly rental: When imposed in addition to the tariff, this is subject to a rebate (not beyond extinction) at the following rates: R2, 00 per kVA or kW of chargeable demand when the energy and demand charges are applicable: 1,35c/kWh of active energy consumption when the maximum charge is applicable.

Demand charge: Per kVA of maximum demand supplied during peak periods per month. 30-minute integrating periods are applicable: R38,24 + VAT = R43,59

Per kW of maximum demand supplied per month1,2. 60-minute integrating periods are applicable: R43,39 + VAT = R49,46

No demand charge is applicable during off-peak periods. Where a kW charge is applicable, the power factor under all loading conditions shall not be less than 0,85 lagging and shall not lead under any circumstances.

1. Customers previously supplied in terms of ESKOM's Rand and Orange Free State License 1983, with supply agreements originally concluded before 1 January 1984, can have their maximum demand measured in kilowatts (kW). Unless or until they request that their maximum demand be measured in kilovolt amperes (kVA), this will be determined in kW.

2. From April 1998 ESKOM introduced charges for excess demand, at the same rate as above. Excess demand will be calculated as follows: Excess demand = Actual demand in kVA x 0,85 - Actual demand in kW.

Active energy charge: 6,90c + VAT = 7,87c/kWh consumed in the month.

Maximum charge: If the total of the demand charge plus the energy charge above, divided by the number of kWh supplied in the month, exceeds 33,67c + VAT = 38,38c/kWh, then the customer will be charged at a rate of 33,67c + VAT = 38,38c/kWh of energy supplied in the month.

Voltage discount: This is calculated as a percentage of demand and active energy charges.

Supply voltage	Percentage discount
< 500 V	0,00%

> 500 V and < 66 kV	5,33%
> 66 kV and < 132 kV	7,13%
> 132 kV	12,75%

Transmission percentage surcharge: The demand charge and active energy charge are subject to a transmission surcharge, after the voltage discount has been granted, depending on the distance from Johannesburg.

- **MegaFlex**

This is applicable for customers with supplies of 1MVA and above. It is typically for customers with supplies of 1 MVA and above, who can shift their load to defined time periods and who are not being fed off rural reticulation networks. These customers need to be able to shift load for part of the day when electricity is charged at a maximum or peak cost. Figure 1-2 shows the different Time-of-Use (TOU) ratings.

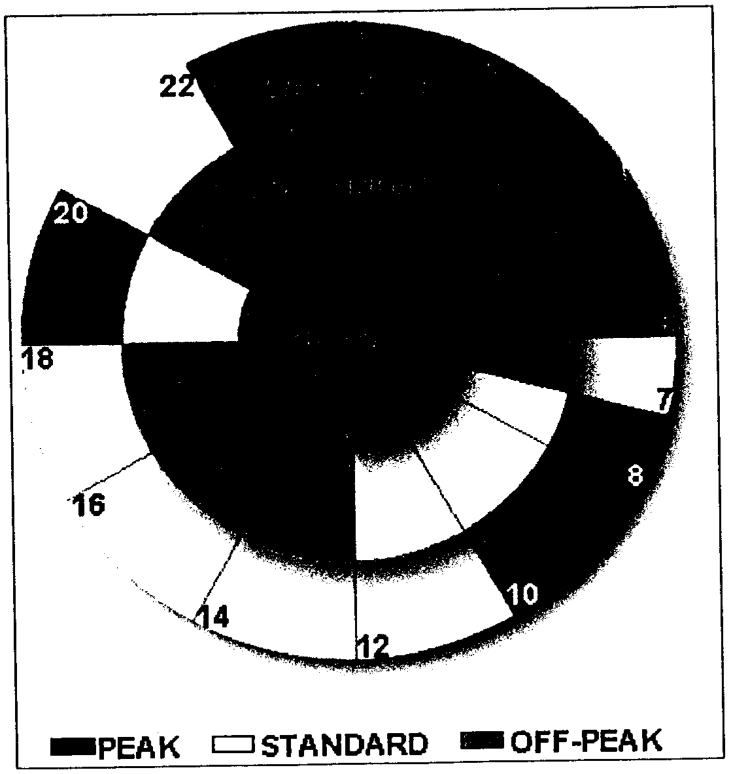

Figure 1-2: Time-of-Use ratings

The basic charges associated with this tariff system are:

Connection fee: The greater of R2 412,28 (VAT excl.) or 5% of actual project cost (VAT excl.) payable per point of delivery.

Basic charge: R58,49 + VAT = R66,68 per month per point of delivery whether electricity is consumed or not.

Monthly rental: When imposed in addition to the tariff, this is subject to a rebate (not beyond extinction) at the following rates:

R2, 00 per kW of chargeable demand when the energy and demand charges are applicable and 1,81c/kWh for peak-period active energy consumption when the maximum charge is applicable.

Maximum demand charge: Payable in peak or standard periods on weekdays and Saturdays. The integrating period is 30 minutes.

High demand (April - September)
R12,23 + VAT = R13,94/kW
Low demand (October - March)
R11,02 + VAT = R12,56/kW
No demand charge is applicable during the off-peak periods.

Active energy charge:

High demand (April - September)
Peak: 22,07c + VAT = 25,16c/kWh
Standard: 12,39c + VAT = 14,12c/kWh
Off-peak: 7,10c + VAT = 8,09c/kWh
Low demand (October - March)
Peak 19,87c + VAT = 22,65c/kWh
Standard 11,11c + VAT = 12,67c/kWh
Off-peak 6,39c + VAT = 7,28c/kWh

Maximum charge: If the total of the demand charge plus the energy charge above, divided by the number of kWh supplied in the month, exceeds 33,67c + VAT = 38,38c/kWh, then the customer will be charged a rate of 33,67c + VAT = 38,38c/kWh of energy supplied in the month.

Voltage discount: This is calculated as a percentage of demand and active energy charges.

Supply voltage	Percentage discount
< 500 V	0,00%
> 500 V and < 66 kV	5,33%
> 66 kV and < 132 kV	7,13%
> 132 kV	12,75%

<u>Reactive energy charge:</u> 2,55c + VAT = 2,91c/kvarh, supplied in excess of 30% (0,96PF) of kWh recorded during peak and standard periods. The excess reactive energy is determined per 30-minute integrating period and accumulated for the month.

<u>Transmission percentage surcharge:</u> The demand charge, active energy charges and reactive energy charge are subject to a transmission surcharge, after the voltage discount has been granted, depending on the distance from Johannesburg.

Distance from Johannesburg	
< 300 km	0%
> 300 km and < 600 km	1%
> 600 km and < 900 km	2%
> 900 km	3%

- **<u>Real Time Pricing (RTP)</u>**

Real Time Pricing is a methodology which sets the selling price of electricity equal to marginal and transmission cost plus profit. The marginal cost of electricity however includes a component which reflects the marginal outage cost. The marginal cost of electricity is defined as the hourly market price by which electricity is generated and transferred from the transmission system to the distribution system.

RTP offers a clear economic signal, motivating customers to adjust patterns of use to match ESKOM's marginal costs. The RTP structure includes a mechanism to ensure that the revenue requirements of ESKOM are met. RTP will likely become the dominant foundation of electricity transactions.

The objectives of the RTP product are [17]:

- □The promotion of economic efficiency through appropriate marginal cost based price signals.
- □To stimulate optimal behaviour through dynamic price signalling. This includes:
- □Energy conservation when the system is constrained, as signalled by high prices.
- □Increased energy sales when the system is unconstrained, as shown by low prices.
- □Reduced system peaks implying deferred capital expenditure.
- □Reduced operating cost resulting from not having to start up more expensive units to supply short peak loads.
- □Improved customer service, through lower overall average prices and more customer choice.

It is important to note that the consumer may not respond favourably to RTP or any other pricing system if the cost of the response is greater that the potential savings. This may also be if the consumer does not have sufficient information about the present and expected price levels to enable decision making concerning the level of consumption [18]. For this purpose good integrated simulation software will aid the consumer greatly.

1.3Beneficiaries

In order to determine the value of this study, the parties who will benefit the most from the work which was performed must be identified. For the beneficiaries listed below, the criterion for a successful study is discussed, along with the manner in which the results could be implemented, and the potential impact thereof.

Consulting engineers

The Ventilation and Cooling of mines is a specialised engineering field and the work is usually contracted out to engineering firms with more experience in the field. Their design and installations are for static demand and is usually over designed for a dynamic system that changes its demand.

With a new dynamic and integrated simulation tool it will be possible for the consulting engineers to design and install more cost effective systems. They can investigate the possibility for load shifting and other adjustments in equipment and the effect it will have on the mine's cooling and ventilation.

Mining companies and energy managers

To convince mining companies and energy managers to invest in or install energy-efficient VC systems, the return must prove profitable. The prediction of energy consumption must therefore be accurate to establish the potential for energy savings of these energy-efficient options.

It is also important that there is no reduction in the comfort levels of the underground climate. This implies accurate predictions of the chilled water entering the mine, by the simulation software.

ESKOM

The postponement of a new power station at a typical cost of about R16 billion can be achieved by promoting load shifting in mines nationwide. An integrated simulation tool will not only be a valuable tool but a necessity in obtaining load shifting for RTP.

1.4 Contributions of this study

- The following contributions have been made by this study:
- Extending the knowledge of the potential of shifting load in the VC systems of mines.
- Develop new VC systems models, a thermal storage dam, a valve and upgrade the cooling tower and chiller models.
- These models were verified.
- The potential for load shifting was predicted.

1.5Outline of this study

The integrated simulation tool for buildings, QUICKcontrol* is briefly described in Chapter 2. The new thermal storage dam model is derived along with a brief discussion on the cooling tower and valve models. An overview of other software in the field of mining and building simulation is also discussed.

In Chapter 3 the new models were used alongside QUICKcontrol* and verified. Measurements were taken from a well established mine with a well logged measuring system. The mine was Placer Dome Western Areas Joint Venture Gold Mine. The ventilation and cooling system, along with the pumping system was verified for flows, temperatures and dam levels. The energy usage of the systems were established and verified to determine the load profile of the mine.

Various retrofit options were tested to establish the potential for load shifting to compensate for ESKOM's RTP schemes, discussed in Chapter 4, along with an energy audit depicting the main energy users of the mine's VC system.

A summary of the results and the full impact of the load shifting is extrapolated to all the mines of South Africa, showing the full potential of load shifting, thus creating virtual power stations, all over South Africa.

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CHAPTER 2

SIMULATION SOFTWARE AND MODELS FOR MINES

To be able to accurately predict the response of the system it is necessary to have a dynamic, integrated simulation tool. Such a dynamic tool doesn't exist for mining applications but there are a number of tools available in the building industry. One such a tool is QUICKcontrol[*]*, which has already been thoroughly verified for building applications. In this chapter new models were developed and used, with effort, in conjunction with QUICKcontrol*[*] *for one mine application. The value of simulation could be seen, but the need for a mine specific software program became apparent.*

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2.1 Introduction

The energy usage and thermal response of the ventilation and cooling system (VC) is a dynamic system that can vary over time for each day. This is due to the varying demand from the underground working areas. The interaction between the changing demand (Load) and the cooling plant (Supply) needs to be simulated with dynamic, integrated computer software.

The simulation is divided into two parts, namely the aboveground cooling plant and the underground pumping system for pumping the mine-water to the cooling plant. They were treated separately for they posed different and unique problems. Both models used the new dam component. A specific dam, the mine-water dam, formed the link between the two systems.

The new models were mathematically or empirically established. These models represented the system according to the specifications for the actual system. Satisfactory simulations were conducted to test the functionality of the models.

2.2 Existing software

Having found the need for a dynamic, integrated simulation software package that could investigate and solve VC-systems on a component level, different software was evaluated. A short study into the available software in the mining industry was conducted. The most commonly used simulation software in the mining industry is ENVIRON [1]. This software concentrates more on the design of mining systems and the solving of the airflow below ground. It also specifies the cooling capacity that needs to be installed. This is however not a dynamic or integrated software package.

Other fields of study were also investigated. One of these fields was the building cooling and ventilation simulation field. A lot of work has been done in this field's energy analysis and system simulation. Some of the software available is POWERDOE [2], TRNSYS [3], and QUICKcontrol* [4].

It was realised that much effort would be needed to try and use a building program for mining applications. QUICKcontrol* was chosen, as it is a South African product, with help close at hand. Previous results for energy predictions have proved to be accurate to within 10% of the measured values for QUICKcontrol* [5].

2.3 New models

HVAC systems for buildings and mines obviously differ a lot. New models were therefore needed for the mining applications. They are used in conjunction with the dynamic simulation. The development of these mine models are given in this section.

2.3.1 Thermal storage dams

A new component, needed for the mining applications, was the dams that serve as thermal storage capacity of the chilled water. Most mines use thermal storage dams to store thermal energy in water. This water can be used as needed by the mine refrigeration system. It is especially necessary for when there is a breakdown in the main cooling plant. With these water dams, the effects of these breakdowns can be limited or at least provide time for the workers to react and reach a safe depth [6].

This kind of storage can also be used to save on the energy usage of the system. Through the use of off-peak filling of the dams, a system can use the cool stored water during peak load periods. The cool storage can be produced during off-peak periods by the extra capacity of the refrigeration system. These dams can also serve as mixing points for the control of water temperature [7].

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The benefits of using thermal storage is:

1. Reduced equipment size. Because the peak loads can be met by the cold storage, equipment sized to meet the peak load can be downsized.
2. Energy cost saving. A significant reduction of the time-dependant energy cost, like in-peak-time-of-use energy charges, can be saved on.
3. Energy savings. Cool storage systems allow chillers to operate more at night when lower condensing temperatures improve equipment efficiency.
4. Due to the stable nature of the mine's load on the system, minor fluctuations or dynamics of the load can be absorbed by the dams.

A schematic view of a dam can be seen in Figure 2-1. This is the basic model used for the mathematical model deduced from heat transfer equations.

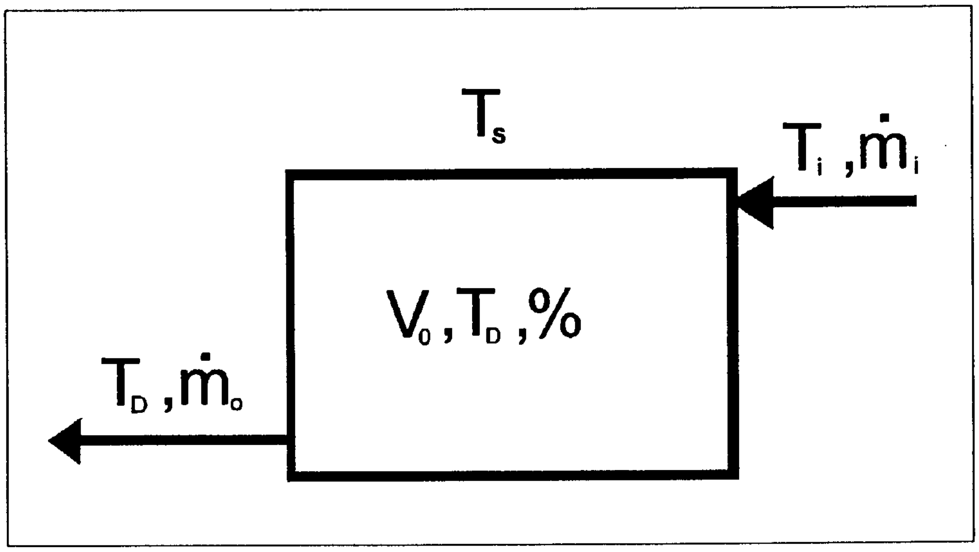

Figure 2-1: Schematic view of thermal storage dam

- **Mathematical modeling**

It can be assumed that the thermal storage dam reacts like an electrical capacitor [8]. It is further assumed that 100% mixing occurs and that no stratification takes place. This implies that the temperature of the water exiting the tank is the same as the water temperature within the tank.

The temperature within the tank is only a function of initial temperature, initial volume, solar air temperature, which includes the emittance and absorption of the air on the dam wall, and the convection coefficient on the wall surface. The exposed area, horizontal and vertical also need to be accounted for. Taking convection, emittance and absorbtance into account, the basic equation for dams can be given by:

$$C.\frac{dT}{dt} = \dot{m}_i .c_p.(T_i - T_D) + UA(T_S - T_D) \quad \ldots\ldots\ldots\ldots\ldots\ldots \mathbf{2.1}$$

Where **T**

Separating the terms and rearranging them results to:

$$\int_{T_D^0}^{T_D} \frac{1}{T_D.a-b}.dT = \int_0^1 \frac{-1}{C}.dt$$

Using exponential rules after integration, the equation becomes:

$$\frac{1}{a}.\ln\left(\left(\frac{T_D.a-b}{T_D^0.a-b}\right)\right) = \frac{-\Delta t}{C}$$

$$\boxed{T_D = \frac{1}{a}.\left(\left(T_D^0.a-b\right)e^{\frac{-a\Delta t}{C}}+b\right)} \quad \text{.........................2.3}$$

The conditions for this equation is that if **C** $\geq$ **max, C = max,** and if **C** $\leq$ **0,** then **C = 0** and $\dot{m}_o$ **= 0.**

Due to variation in flow rates of the inlet and outlet water of a dam, the volume or level of the dam will change over time. This change in level is also taken into account in the calculation of the water temperature of the dam. For the simulation model, the change in level is dependent on the flows in and out, measured in liters per second, and the time interval, Δt. The model can be formulated by:

$$\boxed{V_t = V_{t-1} + \frac{\left(\dot{m}_i - \dot{m}_o\right)\Delta t}{1000}} \quad \text{...........................2.4}$$

with

$\dot{m}_o = 0$, when $V_{t-1} = 0$;

$\dot{m}_i = 0$, $V_t = V_T$, when $V_{t-1} \geq V_T$;

2.3.2 Cooling towers

The current program does contain a cooling tower. This model does incorporate the changing climate that plays a big influence on the tower. The mathematical model used for the tower is an analytical model and doesn't produce consistent accurate answers needed for the simulation.

A possible temporary solution for this is using a water source, which is an already existing component. The assumption being made is that the cooling tower delivers water at a known temperature and that the influence on the energy usage by the fans is considerably less than the chillers.

- **Mathematical modeling**

The basic layout of the cooling tower can be seen in Figure 2-2. This is a schematic view of the tower with the symbols used to denote the mathematical model.

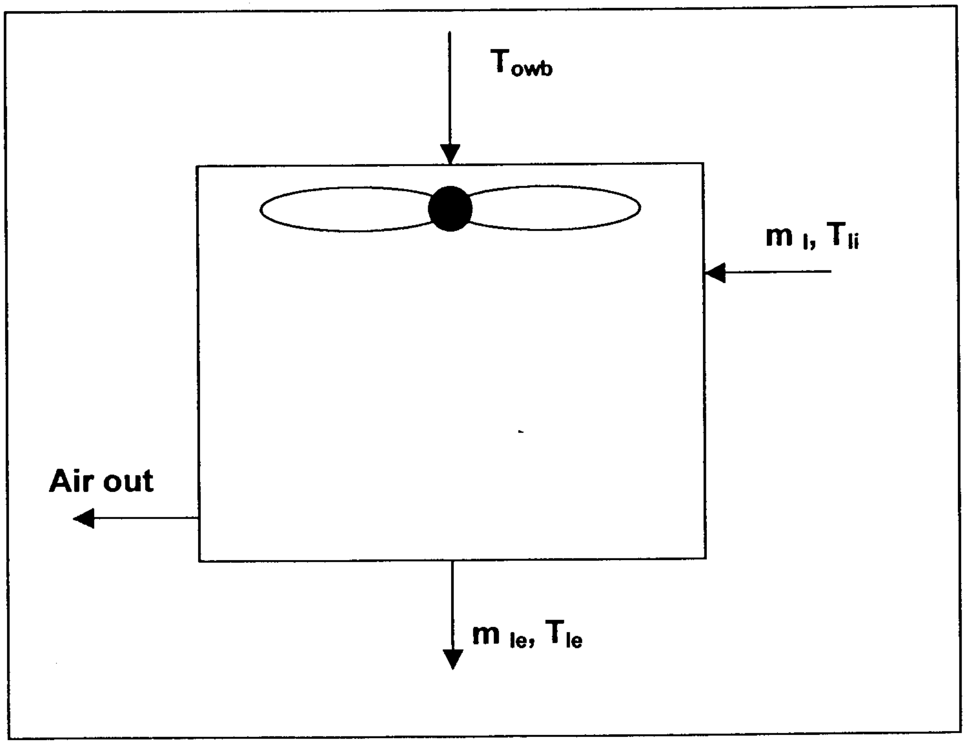

Figure 2-2: Schematic view of Cooling Tower

To incorporate the energy usage of the cooling tower's fans an empirical model has been developed that incorporates experimental data. This model proved to be more accurate than the existing model. The model can be seen below:

$$Q = [a_0 + a_1.towb + a_2.t_{li} + a_3.m_l + a_4.towb.t_{li} + a_5.towb.m_l + a_6.t_{li}.m_l + a_7.towb^2 + a_8.t_{li}^{\ 2} + a_9.m_l^{\ 2}].e^k$$

With **Q** the cooling capacity, $\mathbf{t_{owb}}$ the wet-bulb temperature of the air entering the tower. This information is retrieved from the climate data associated with the mine.

The **k**-term is given by:

$$k = a_{10} + a_{11}.towb + a_{12}.t_{li} + a_{13}.m_l + a_{14}.towb.t_{li} + a_{15}.towb.m_l + a_{16}.t_{li}.m_l + a_{17}.towb^2 + a_{18}.t_{li}^{\ 2} + a_{19}.m_l^{\ 2}$$

The temperature of the water leaving the cooling tower can be given by:

$$\boxed{t_{le} = -\left(\frac{Q}{m_{li}.c_p}\right) + t_{li}}$$

All of these equations are based on a curve fit through a wide range of cooling tower data.

2.3.3 Valves

The only method of specifying mass-flow in the system, using the old software, was through a pump. A typical situation, very relevant to mines, is the use of gravity pumps from higher areas to lower lying regions. This presents problems when the energy usage for the system is being investigated for there isn't actually a pump and therefore no energy usage by this component. To bypass this problem, a valve has been introduced. Valves just specify flow in a pipe with no energy used and no temperature effects.

2.4 Conclusions and recommendations for future work

Due to dynamic and intricate interactions between the components of a cooling plant, the need for dynamic, integrated software was established. Such a tool is furthermore needed to investigate the energy usage of the system. Tools like this are already used in the building industry. However, new models are needed for mine applications.

These components include the thermal storage dams, revised cooling tower and valves. Mathematical models were derived for these components and used in conjunction with the existing tool. Although satisfactory results were produced, a new application specific software tool must be developed for the future. This will be the only way to do practical work for the mines.

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CHAPTER 3

SIMULATION AND VERIFICATION

Before the results of the simulations are used to investigate the potential of load shifting or other strategies, it needs to be verified. A suitable mine, namely South Deep, Placer Dome Western Areas Joint Venture gold mine, was used. The mine's cooling cycle was divided into the surface plant and the underground pumping stations. These systems were measured over a period of time. The new mathematical models were used in conjunction with building simulation software. Results were compared to the measured data. From the accuracy of the verification it can be seen that the new models can be safely used for further studies and strategies. This study also showed the dire need for a software tool specifically aimed at the mines.

Chapter 3 – Simulation and Verification

3.1 Introduction

The cooling system of a mine is an integrated, dynamic process. Any simulation is only usable for investigations if it is properly verified, using the proper verification procedures. To verify the system properly, it is needed to physically measure the relevant information needed from the system. This information includes the temperatures, flows, levels and electricity consumption measured over a period, at specified time intervals. Different measuring equipment is needed, either installed in the system, or additionally provided.

The measured and simulated data is compared and gives a good and accurate result. The temperatures are mostly within 2°C of the measured data. The accuracy of the flows is within reasonable values and the power consumption is within 20% for 77% of the time. The results are satisfactory for verification purposes and the simulation model can therefore be used for further investigations.

3.2 Verification procedures

To be able to verify the simulations, it was needed to establish a proper procedure for the verification. This procedure needed to be systematic and incorporate various aspects. The procedure can be broken into the following steps:

1. The first step in the verification was to identify a suitable mine that can serve as the test mine. The mine needed to have a fairly typical cooling plant and pump system. The mine also had to be big enough to establish a good verification that would be acceptable for most of the other size mines.
2. A description of the system was needed to establish the setup of the simulation and to determine the measuring points needed for the data for verifications.
3. The measurements needed for verification on the system included the measuring of temperatures at various stages along the system, flows at certain points, the dam levels and the electricity usage of the power consuming equipment.

4. It was required to establish the usable installed measuring equipment and then the additional equipment needed to perform all the necessary measurements. The time-interval that the additional equipment used needed to correspond with time-intervals of the installed equipment.
5. A typical working day was selected along with an appropriate measuring interval to cover enough working conditions of the cooling cycle. Climate data was also taken for these days.
6. The additional measuring equipment was set up at the pre-determined points.
7. The data was collected and sorted into useful formats.
8. The simulations were set up for the measuring day, using the climate of these days.
9. The simulations were run and compared for the different aspects, temperature, flows, etc., with the measured values.
10. Corrections to the new models were made and then the simulations were run again and compared again.

3.3System description

Placer Dome Western Areas Joint Venture, a gold mine west of Johannesburg, was found to be a good mine as a test mine. The mine's cooling plant is well maintained with an extensively installed measuring system. The mine's underground pumping reticulation system is well maintained with an extensively implemented measuring system.

For the purpose of the verification the system can be broken into these two parts, namely the Surface Plant and the Underground Dams and Pumps. To be able to simulate these two systems, it is assumed that these systems are open-loop systems, broken by water sources that serve as the link between the two systems.

- **Surface Cooling Plant**

The mine has an installed cooling capacity of 30 MW in their surface plant, provided by four York R12 chillers and one Howden ammonia chiller. The Yorks provide 20MW cooling and the Howden provides the remaining 10 MW cooling. The system furthermore includes the use of various dams to serve as thermal capacitors for the system and cooling towers. The basic layout can be seen in Figure 3-1. A more detailed layout can be seen in Figure 4-2 in Chapter 4.

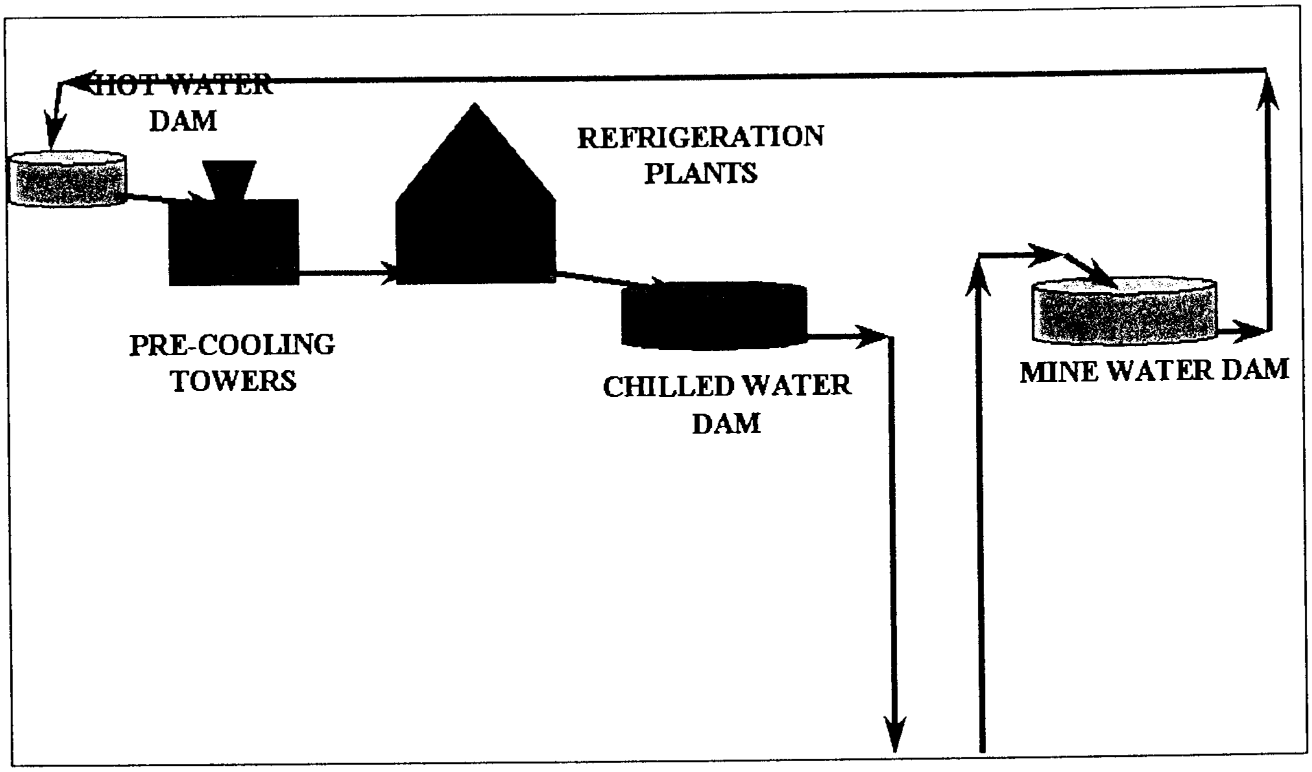

Figure 3-1: Schematic view of Surface cooling plant

The surface system begins with warm water pumped from the underground into the Mine Water dam. A pump station pumps the water to a Hot Water dam from where it is gravity fed to the pre-cooling towers. The water is pumped through filters and then led to the Refrigeration Plant with the chillers.

The path the water follows through the Refrigeration plant varies according to need. The operators can use different schemes to rout the path. Figure 3-2 shows the various schemes available to the operators. For the verification day, the operators used Scheme B.

Chill Water dams connect the chillers and serve as thermal storage of the chilled water as well as emergency reserve storage. From the Chill Water dams the chilled water is gravity fed to and down the shaft at a controlled temperature and flow rate. This is largely determined by the demand (Load) from the underground processes.

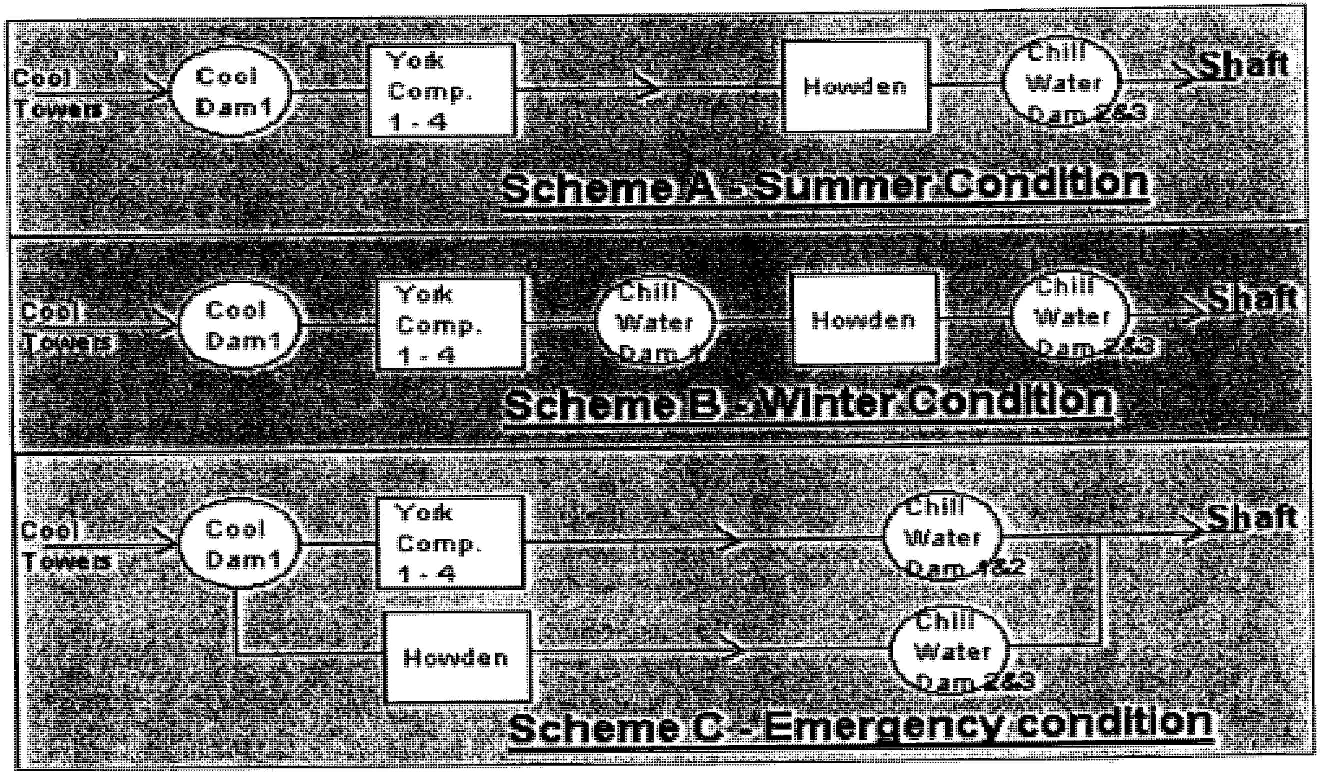

Figure 3-2: Various schemes for flow through plant

The water going down the shaft in the pipes builds up pressure. To break this pressure dams are placed at certain depths that serve as pressure breakers. These dams also serve as distribution centers of the chilled water to the different working points and cooling processes. The chilled water is used in the various processes, including air-cooling, spot cooling and equipment cooling. The detailed specifications of the Surface Plant equipment can be seen in Appendix A.

- **Underground Pumping Stations**

The first dam above ground is the Mine Water dam and it serves as the link between the underground operations and the surface cooling plant. The underground operations include the pumping of the mine water used in the mining and cooling processes, to the surface at different levels, seen in Figure 3-3.

The different dams at certain levels serve as pressure breakers for the pumps, for pumping with a single pump station, at those depths, would be very expensive and highly ineffective and near impossible. These dams also serve for emergencies, such as power failures. For this reason the dams on Level 80 has much larger storage capacity.

The dam on Level 95A is a series of conical dams that serve as collection dams for the water used in the different processes in the mine, either air-cooling or equipment cooling. The detailed specifications of the Underground Pumping Stations equipment can be seen in Appendix A.

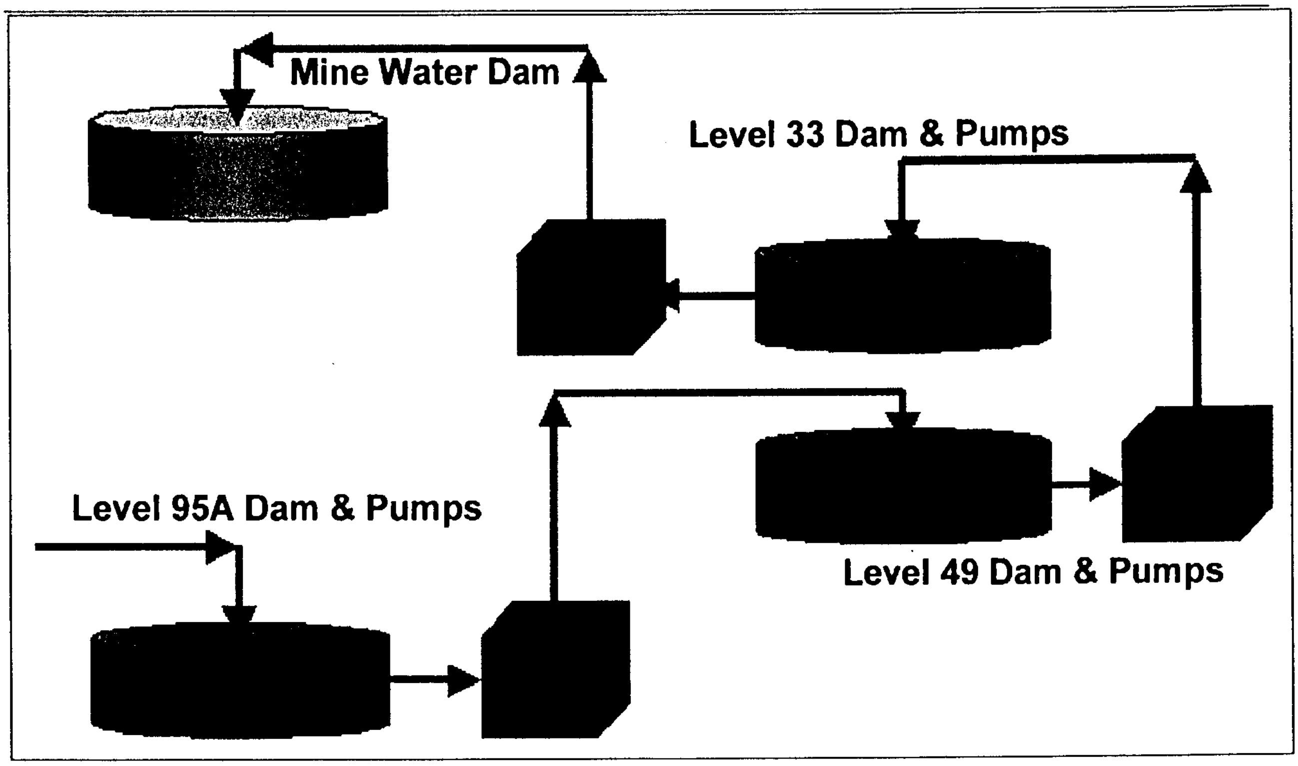

Figure 3-3: Underground storage dams and pump stations

It should be noted that measurements were taken on the clear water reticulation system, as it was decided that this system would be the major energy consumer of the total pumping reticulation system.

The clear water dams on levels 95A and 70 receive their water from settlers on levels 95 and 68. A settler basically collects mine water (Leakage refrigeration water, service water and fissure water) and separates the mud from the dirty mine water to provide clear water. Normal centrifugal pumps can then pump this water to the dams.

3.4 Measurement and simulation procedures

Measurements were taken over a period of four weeks to get familiar with the typical running of the plants and to get a good average day depicting the most common profiles of the equipment. From the downloaded data, a single representative day was selected to be compared with the 24-hour day predictions provided by the simulation software.

The following measurements were measured at different points by the installed measuring equipment:

Temperatures

1. The water from the Mine Water dam to the Hot water dam,
2. The water being fed into the Pre-cool towers and leaving the tower,
3. Water entering the cool water dam,
4. Water entering the York chillers before the pipe diverges,
5. After the converge of the York chillers and before the Howden chiller,
6. After the chilled water dams that is the same as the water going down the shaft.

Flows

1. From the Hot Water dam to the Pre-cooling Towers,
2. Through the York chillers (All four flows combined),
3. Through the Howden chiller,
4. Chilled water to the Shaft.

Levels

1. All the dams above ground.

The additional equipment was used on one of the Yorks and the Howden to ensure the accuracy of the installed measuring equipment and to build a model for the simulation software. The temperatures were measured at the in- and outlets of the evaporator and condenser of the chillers. The electricity usage of the compressors and pumps of the chillers were measured. All the other pumps' electricity was measured as well.

Furthermore the climate was also measured with the temperature and the relative humidity, as can be seen in Figure 3-4.

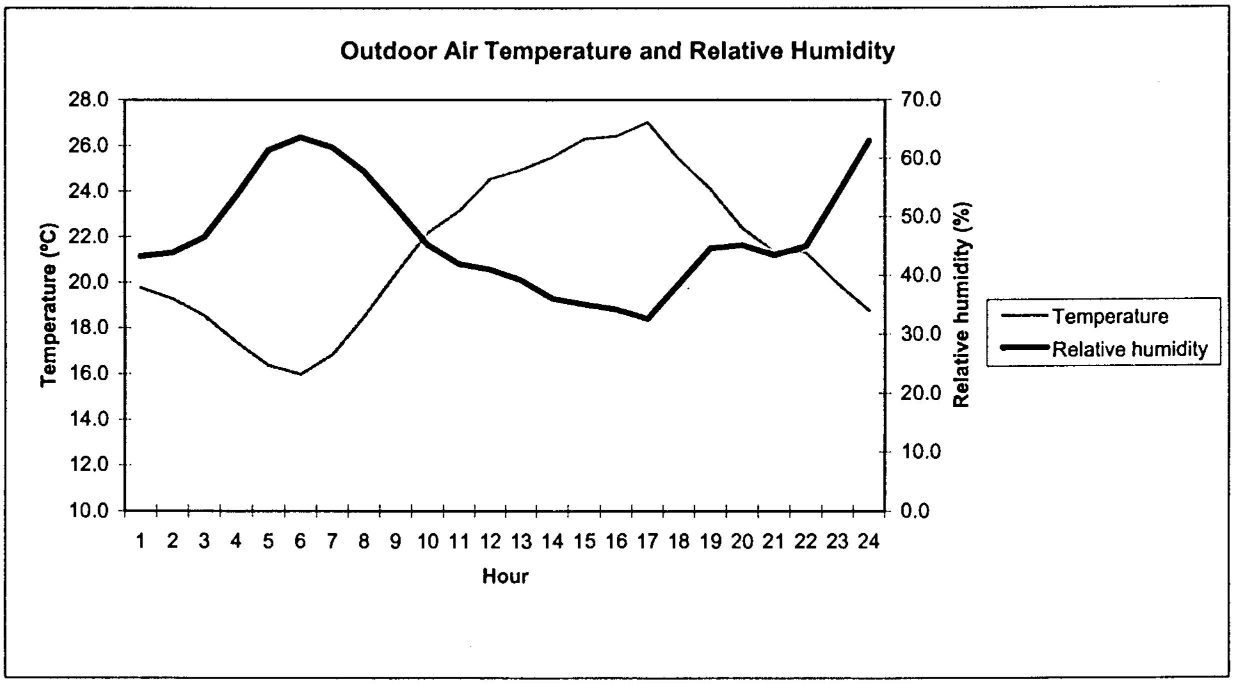

Figure 3-4: Typical climate for mine

This climate was also used in the simulations, along with a large number of other inputs. These inputs comprise mainly of all the design and performance data of various cooling and pumping equipment. The electrical power consumption that was measured was also used to set up the chiller models.

The current control strategies, including operating times and control parameters were obtained from the system operating manuals, operators and measurement, where needed. Further details of the cooling and pumping components and control parameters are described in Appendix A.

3.5Verification of temperatures, levels and flows

The verification results for the temperatures and flows of the system are shown graphically in this section. The measured data was used to verify the predictions. Figure 3-5 to Figure 3-12 display some of the results of the simulated and actual measured temperatures and flows.

- **Surface plant**

For the Surface plant temperatures were mostly verified. This was done to ensure the accuracy of the energy verifications to come. The most important flow verification was the flow going through the Howden, as this was dependent on the load demand from the mine.

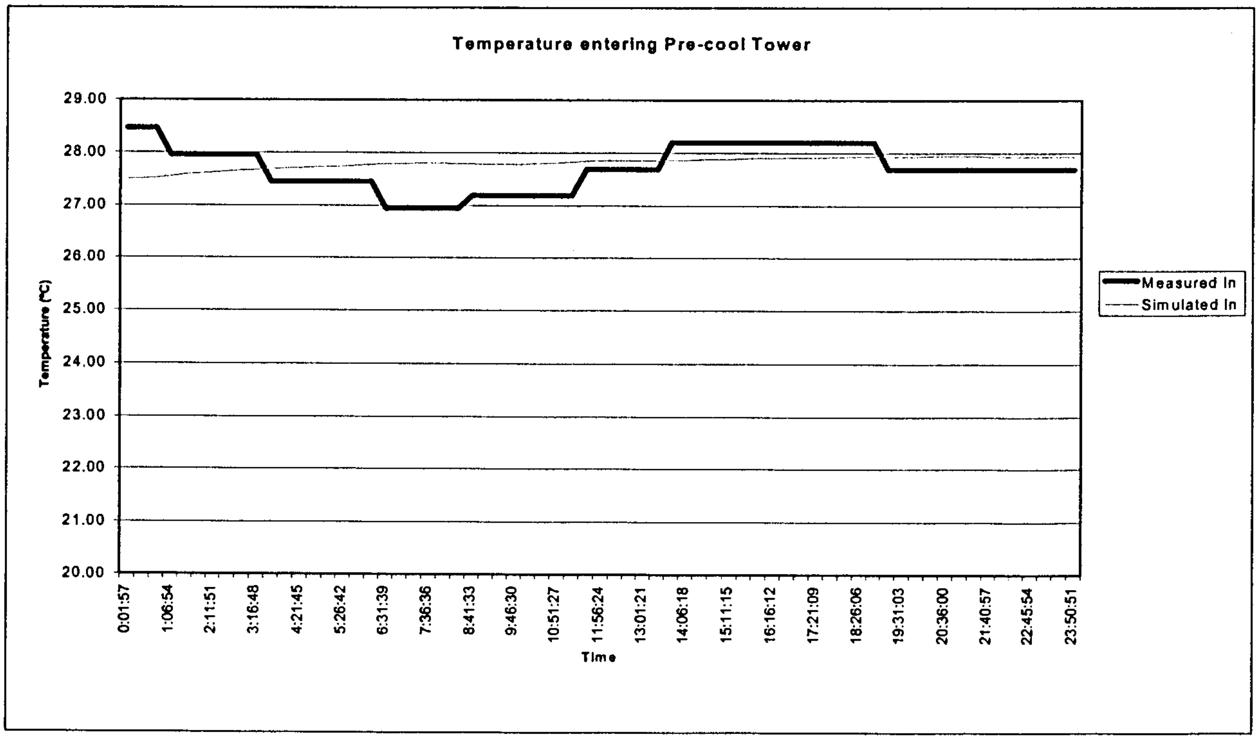

Figure 3-5: Pre-cooling towers inlet temperature verification

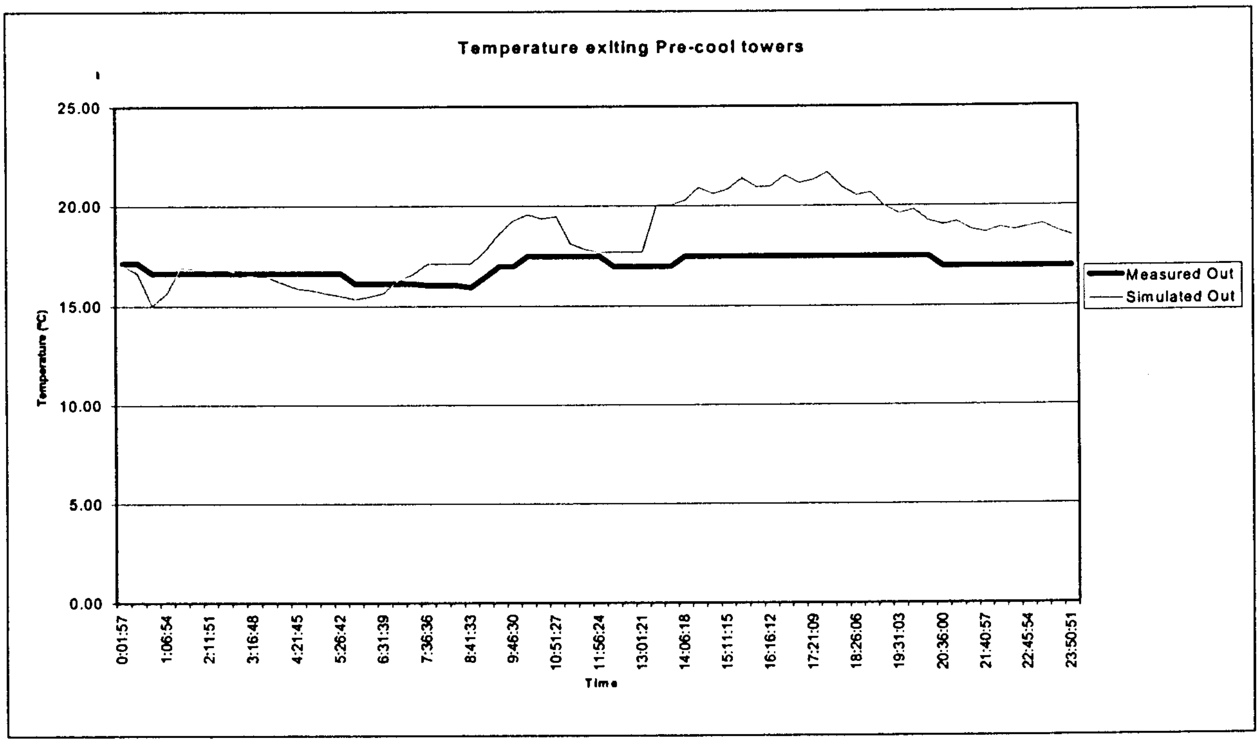

Figure 3-6: Pre-cool tower exiting water temperature verification

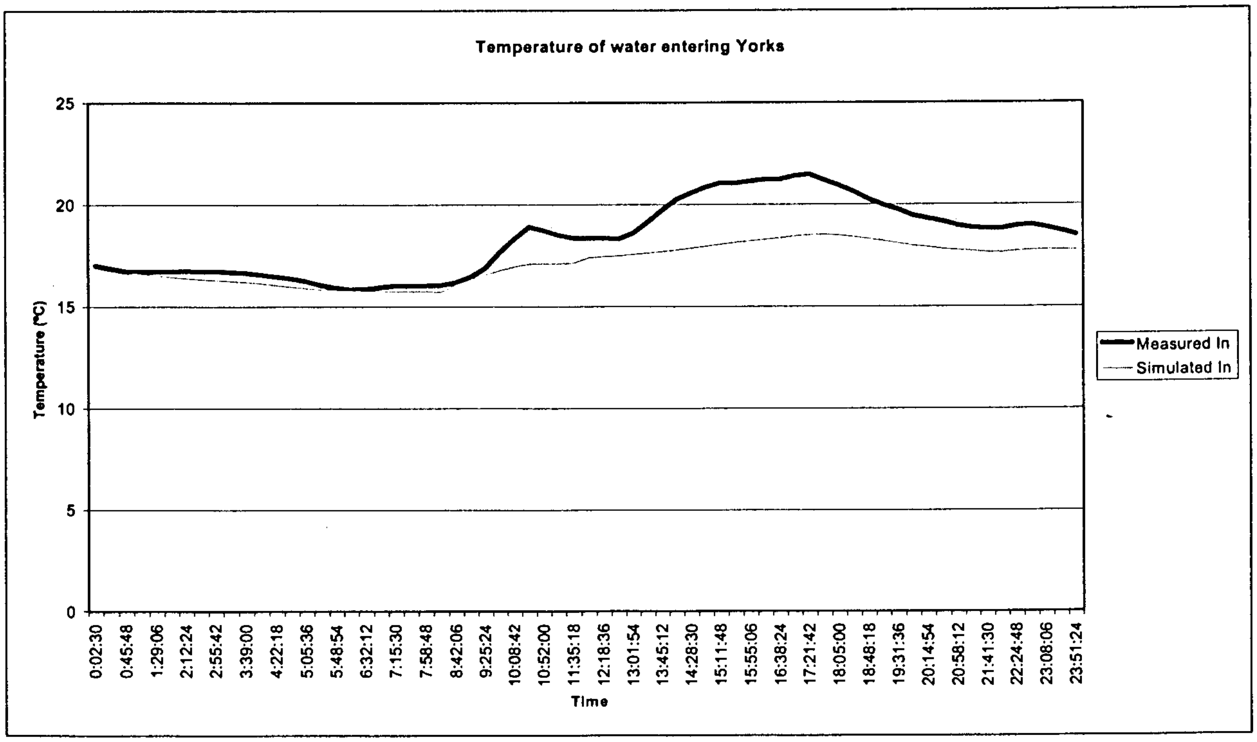

Figure 3-7: Temperature of water entering the York chillers

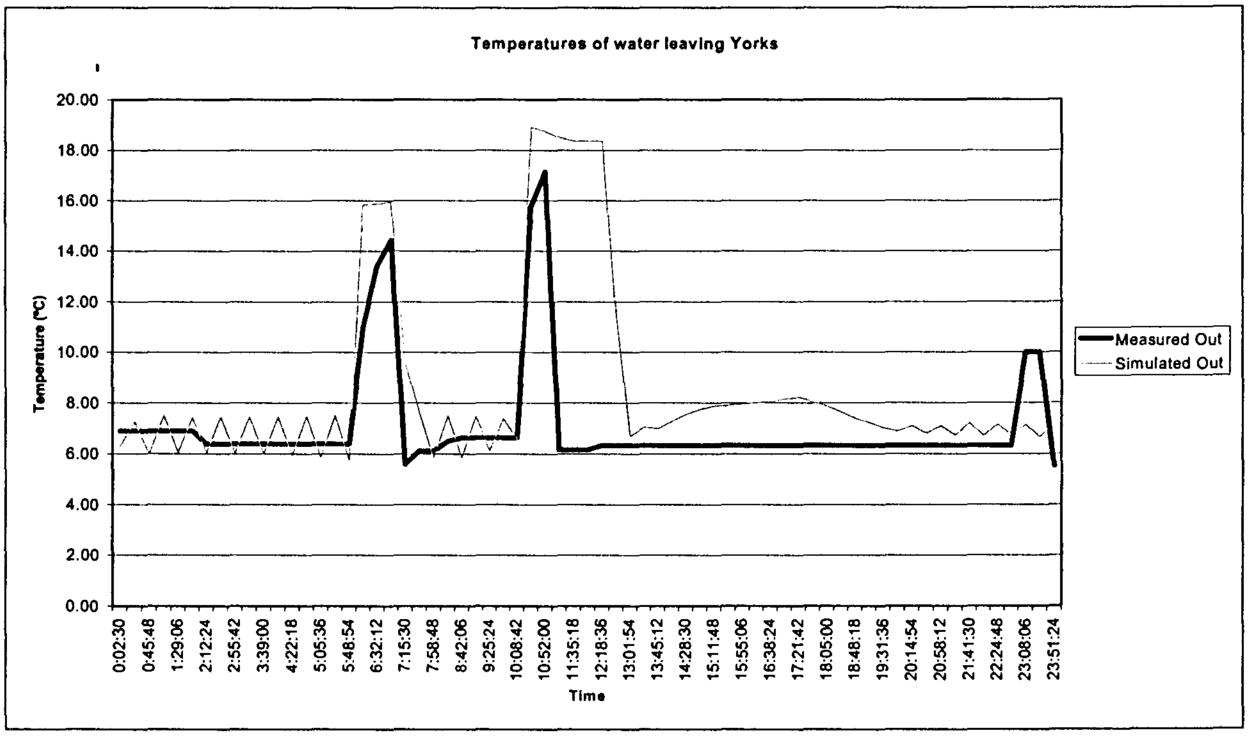

Figure 3-8: Temperature of water exiting York chillers

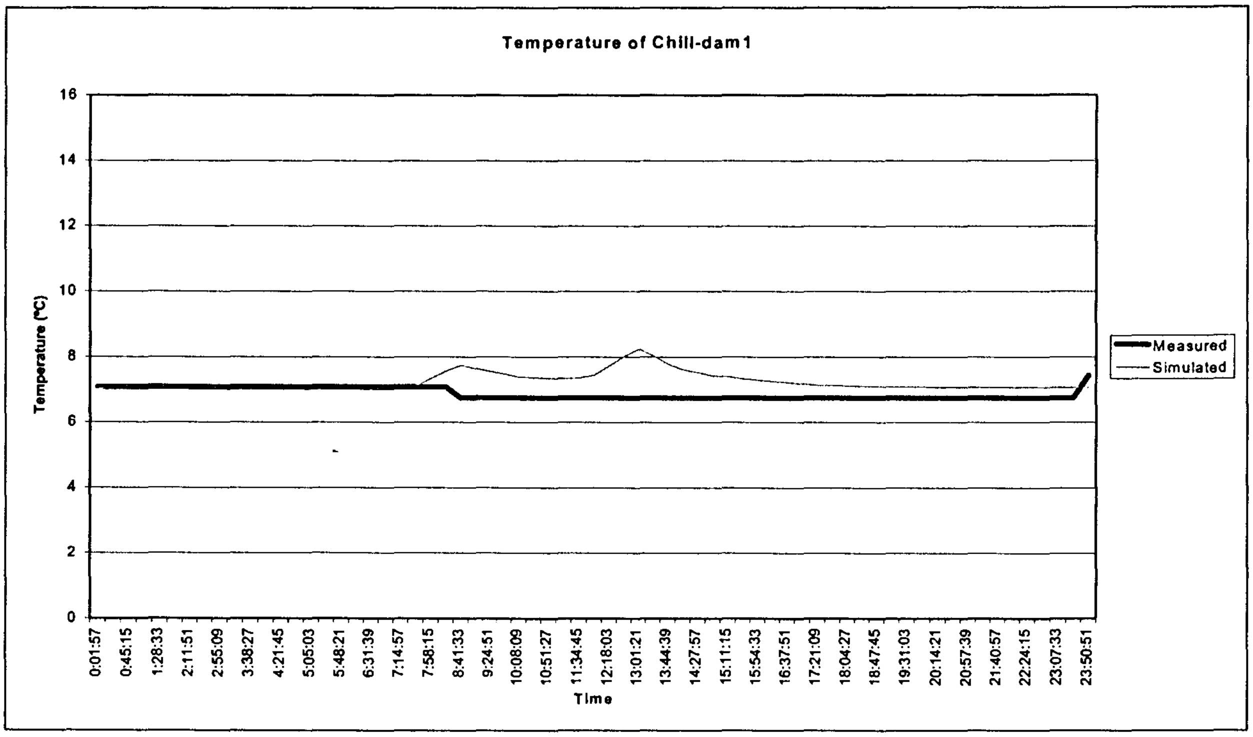

Figure 3-9: Temperature of water in Chill-dam1

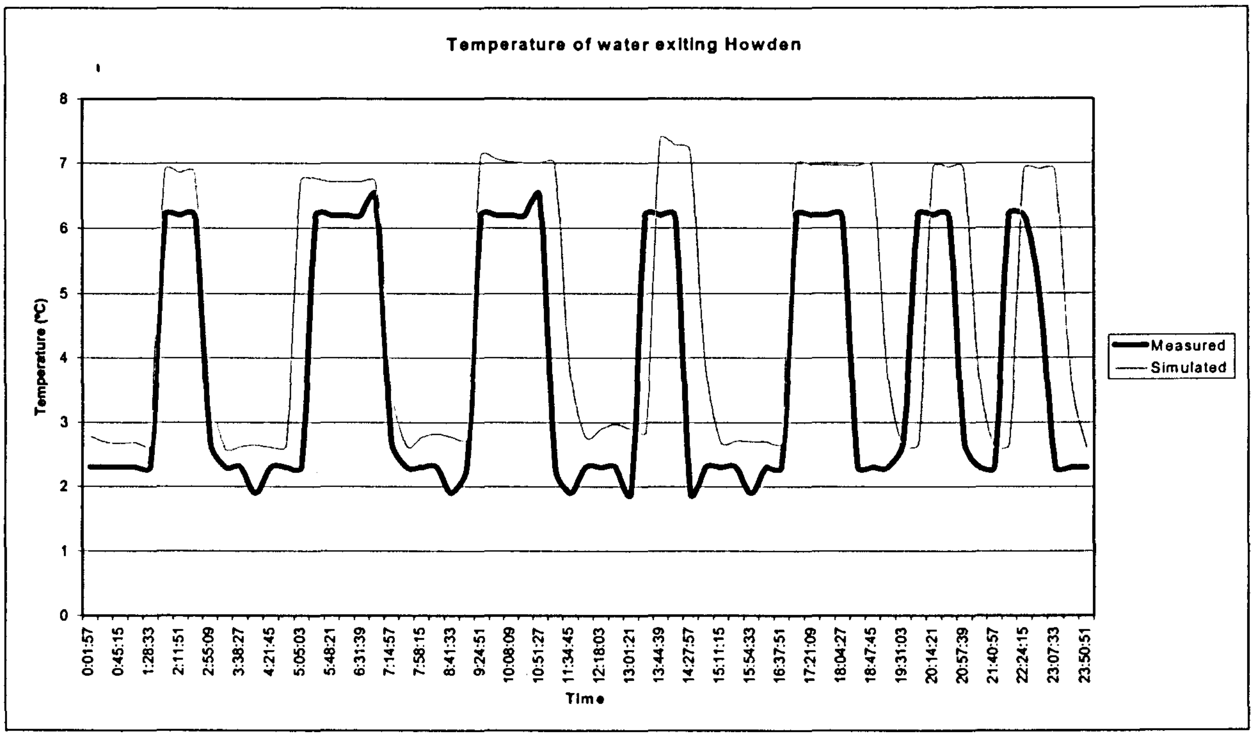

Figure 3-10: Temperature of water exiting Howden chiller

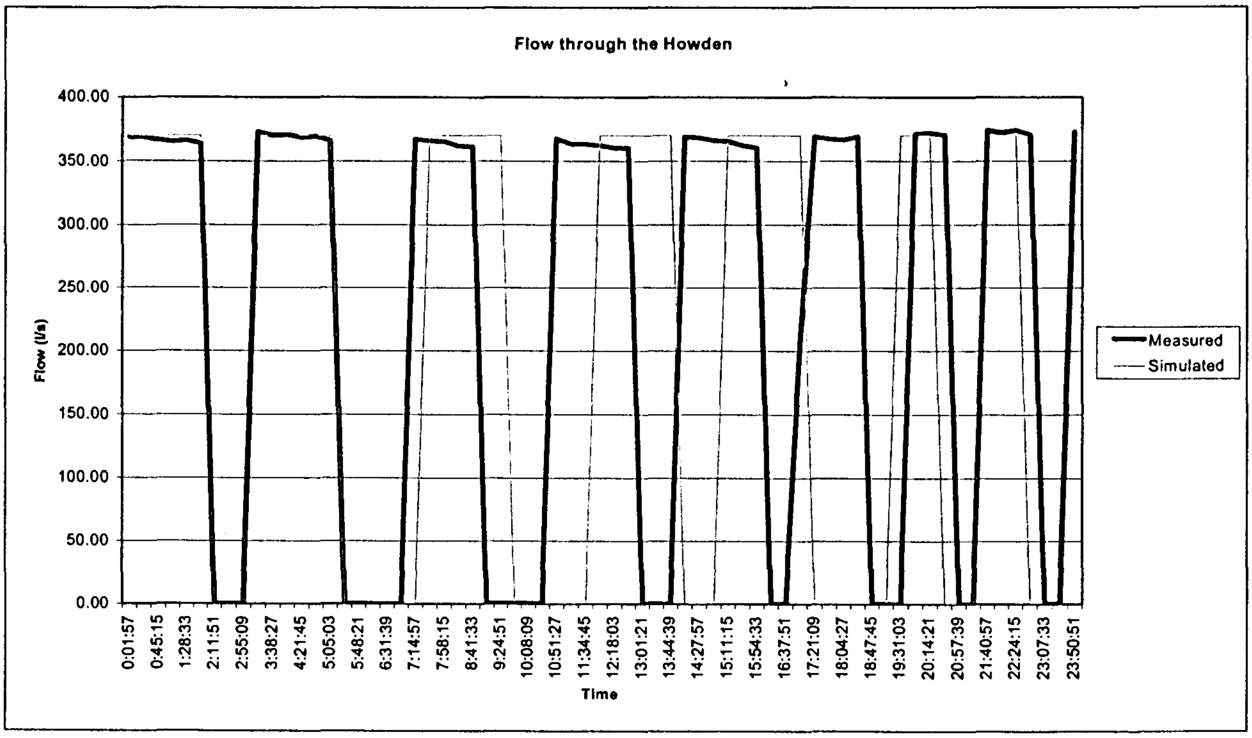

Figure 3-11: Flow through the Howden Chiller

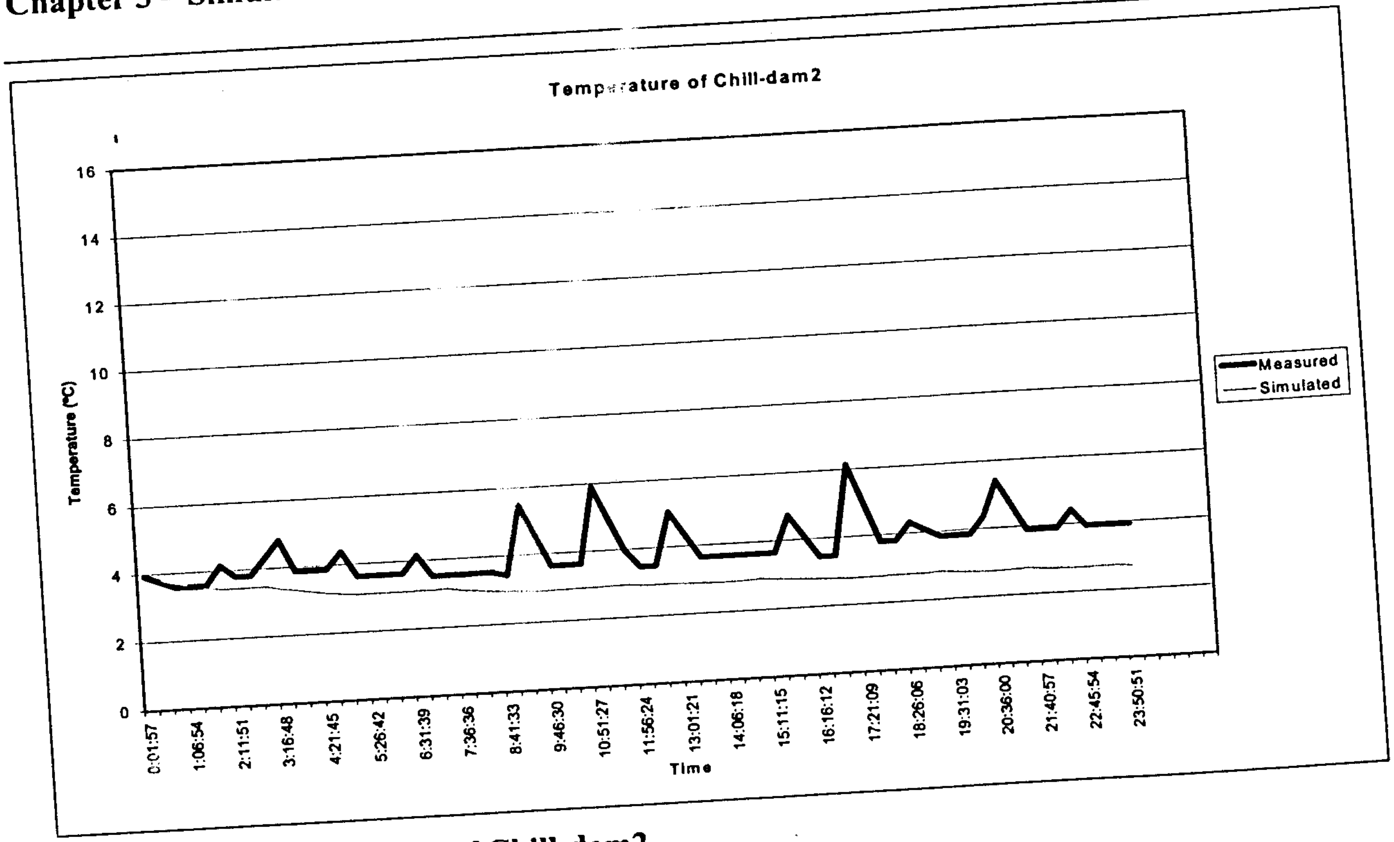

Figure 3-12: Temperature of Chill-dam2

Component	Within 2°C (%)	Within 3°C (%)
Pre-cool tower IN	100	100
Pre-cool tower OUT	64.18	77.61
Yorks IN	79.10	98.51
Yorks OUT	83.58	86.57
Chill-dam1	100	100.00
Howden OUT	85.07	85.07
Chill-dam2	91.04	98.51

Table 3-1: Summary of component temperature verification results

From Table 3-1 it is clear that the verification is satisfactory. For most parts the results are within an acceptable margin of satisfaction. The error of the temperature of the water exiting the Pre-cooling tower can be explained by the fact that the temperature was measured in a pipe, exposed to the sun. The simulation's temperature is calculated in the dam of the pre-cooling tower. Many of the other components' measuring points were also in pipes, exposed to the environment.

- **Underground Pumping Stations**

For the underground pumping stations the most important verifications are the dam levels, for it controls the flow of the water out of the mine. It is also important for the purpose of determining the load caused to the surface plant. The flow coming from the last dam below ground, 33Level dam, to the Mine Water dam on the surface was also verified. Figure 3-15 shows the status of the pumps on 33Level. This was done to show that the pumps are switched on at the appropriate times. The rest of the results can be seen in Figure 3-13 to Figure 3-18.

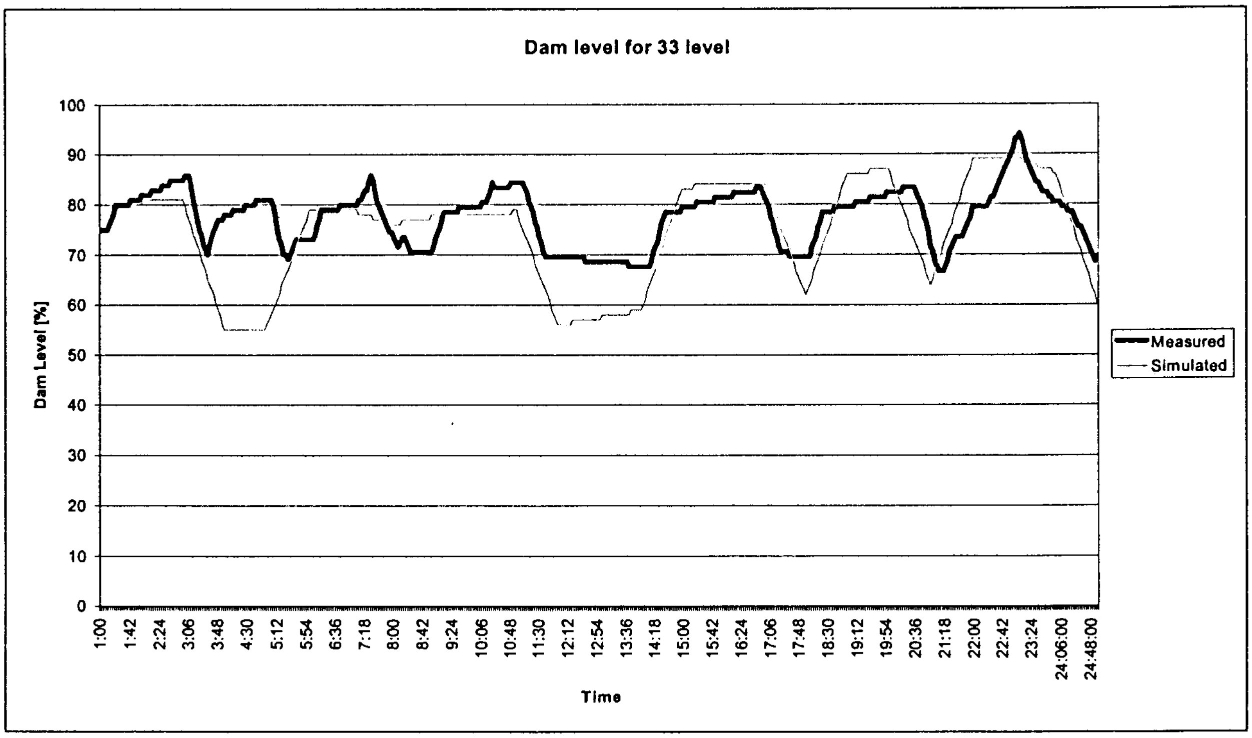

Figure 3-13: Dam level for 33Level dam

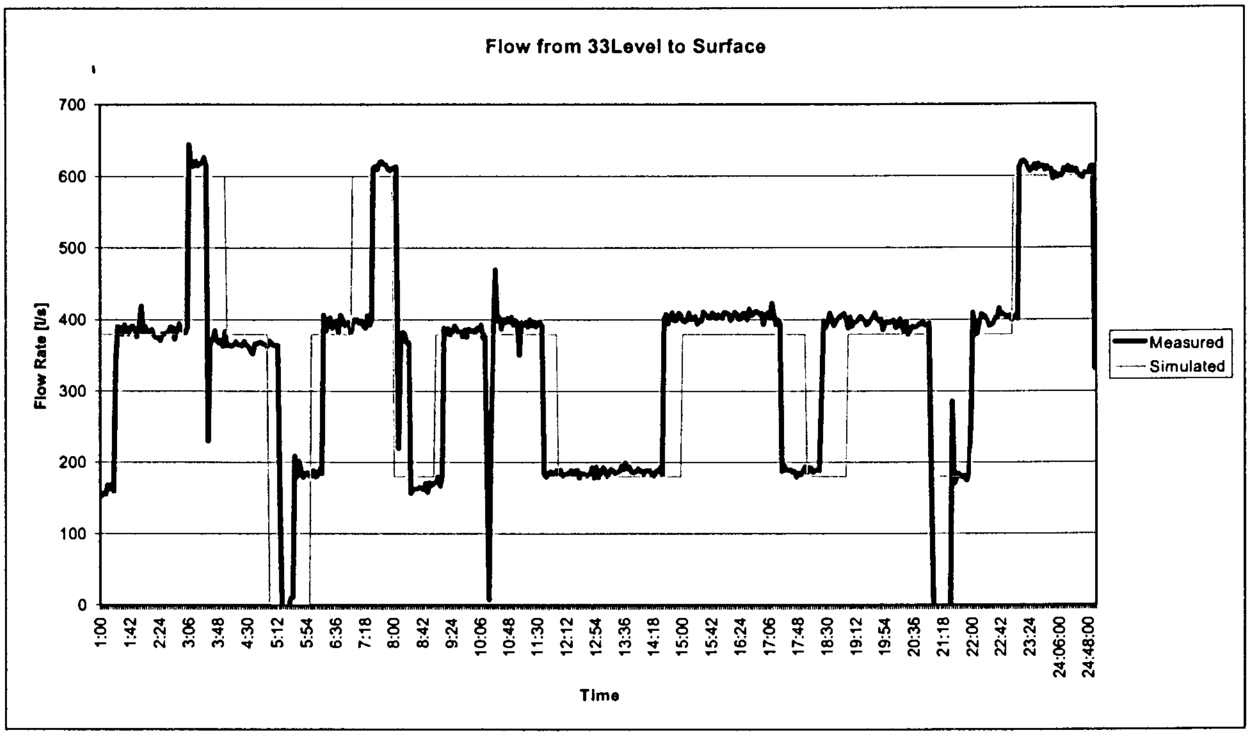

Figure 3-14: Flow from 33Level dam to Mine Water dam

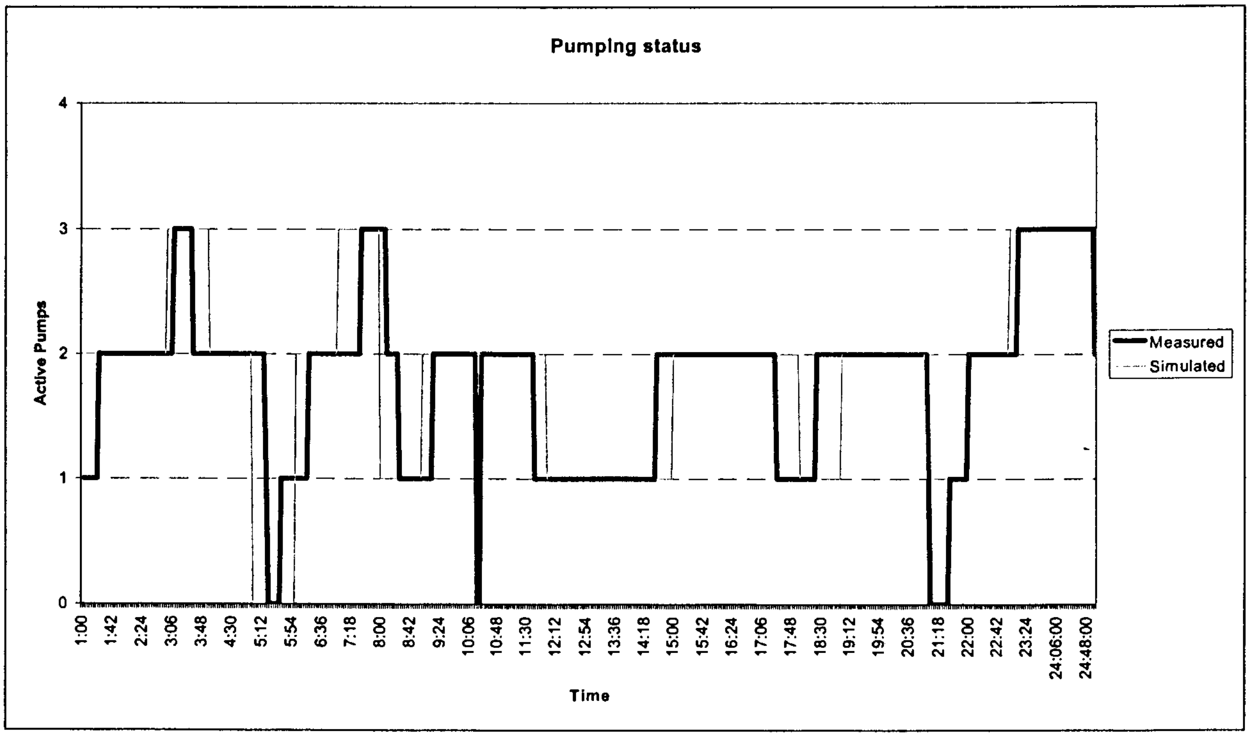

Figure 3-15: Status of the pumps on 33Level

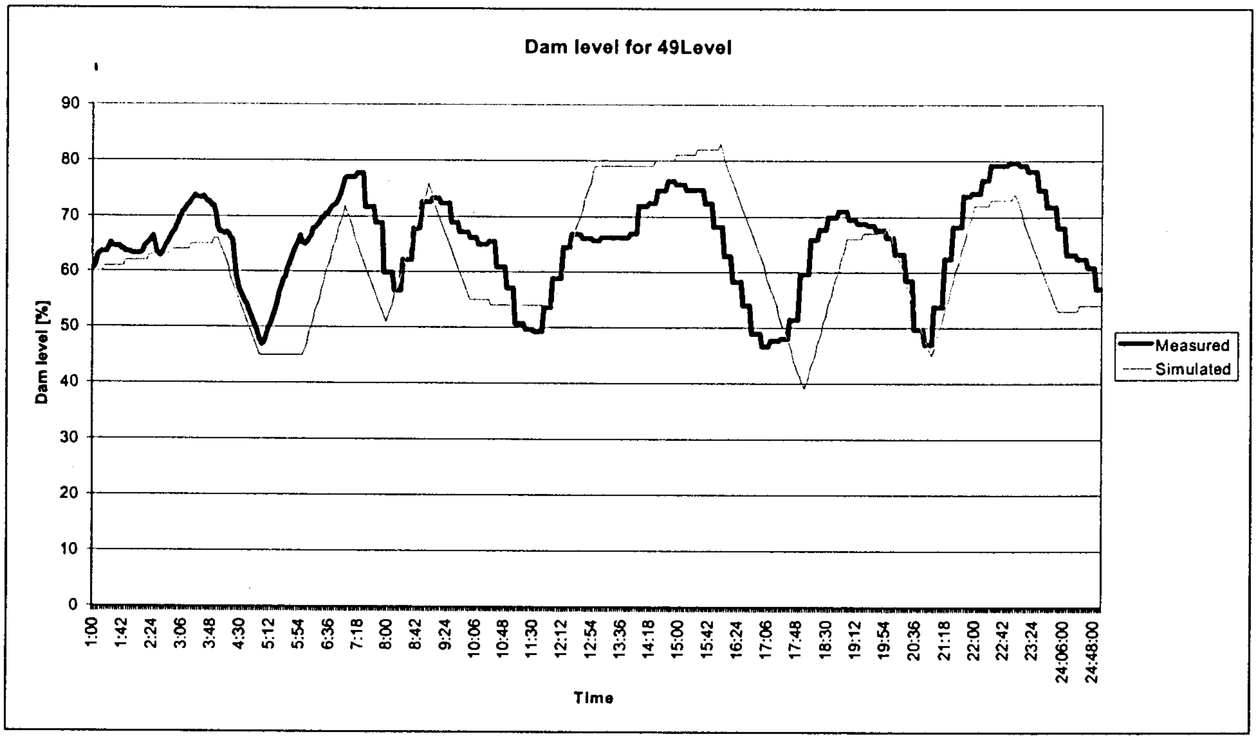

Figure 3-16: Dam level for 49Level dam

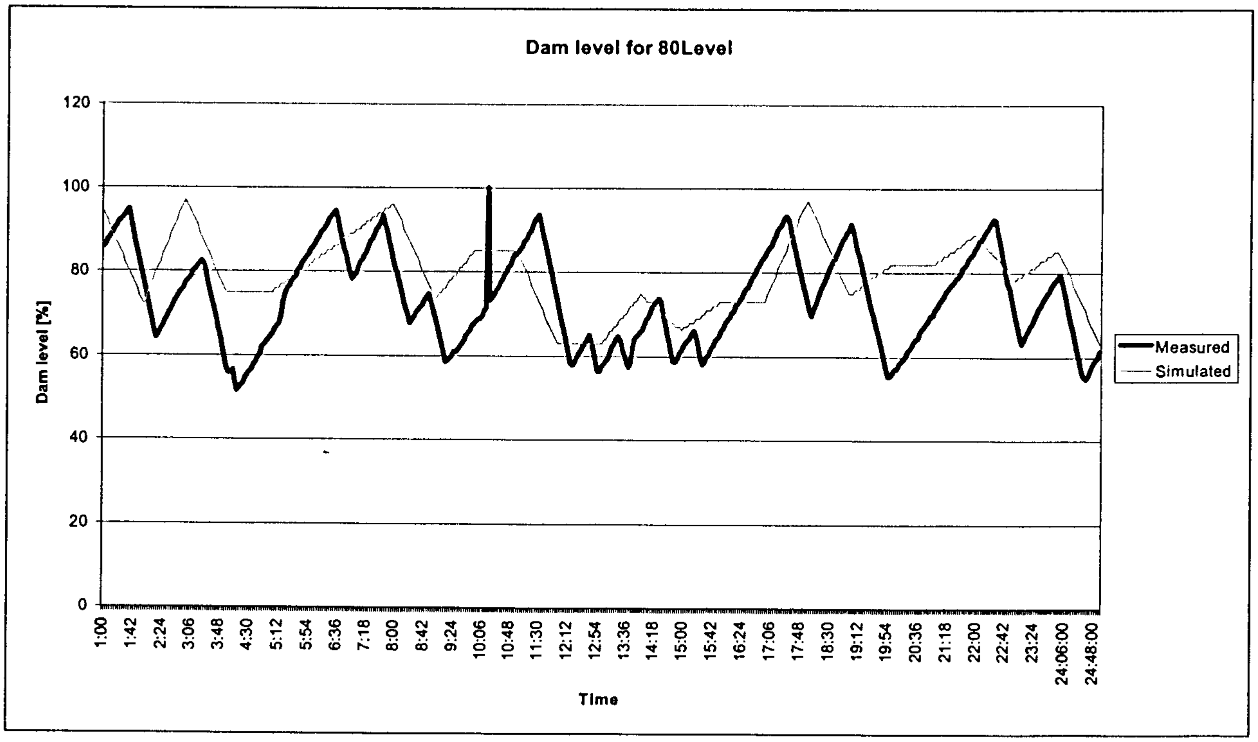

Figure 3-17: Dam level for 80Level dam (One of the dams)

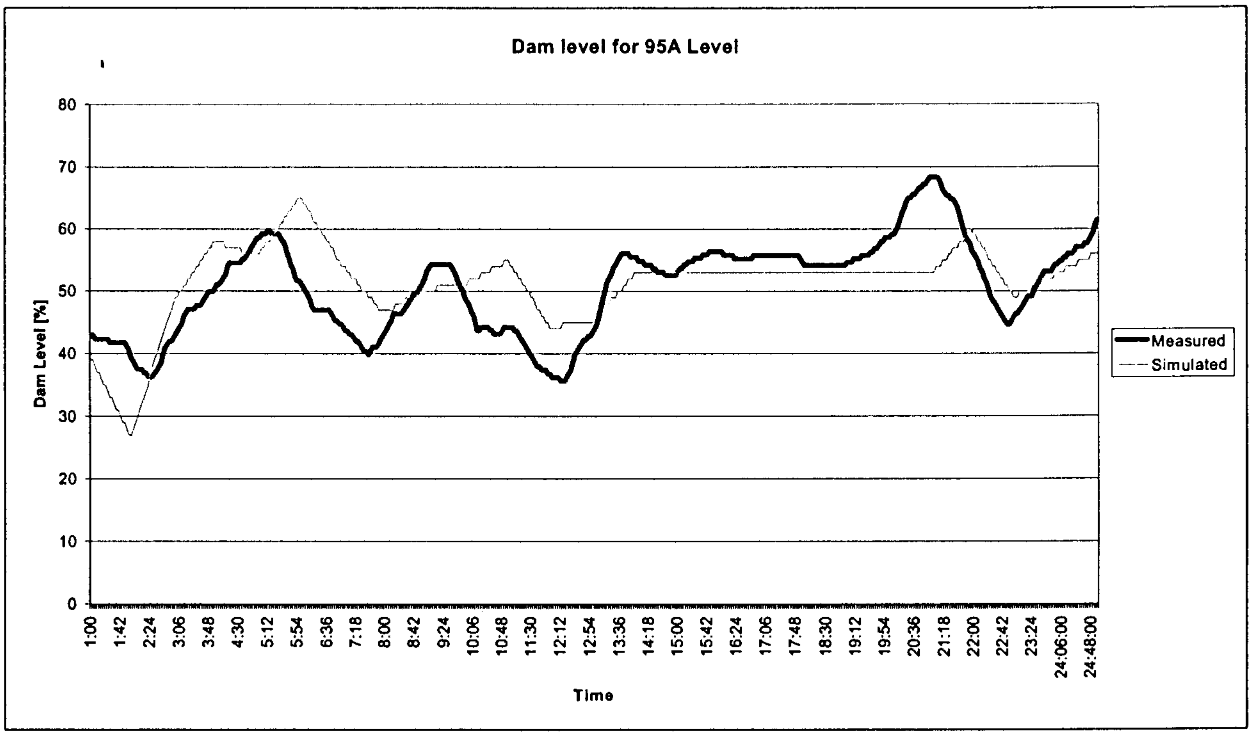

Figure 3-18: Dam level for 95Alevel

Component	Within 10% (%)	Within 20% (%)
33Lvl Dam Level	75	94
33Lvl Flow Out	72	74
49Lvl Dam Level	53	82
80Lvl Dam Level	44	73
95ALvel Dam Level	60	79

Table 3-2: Summary of dam level and certain flows verification results

The margin of error for the dam levels are quite acceptable for the purpose of determining the potential for load shifting. The final results of the study will be relative and not absolute which makes these results sufficient.

3.6Verification of energy usage

The power consumed by the different components was determined by measuring the current flowing through the equipment, taking the voltage as fixed and using the power-factor and efficiency from the manufacturers. These verification results for the power usage can be seen in the following two sections.

- **Surface plant**

In Figure 3-19 to Figure 3-27 the results are shown for various pumps in the system, the chiller compressor power and the cooling tower fan. Figure 3-19 shows the power verification of the pre-cooling tower fan. The measured result shows that the fan is continuously running, while the simulation shows that the fan is switched off at times. The model used assumes that when there is no flow through the cooling tower, the fan is switched off.

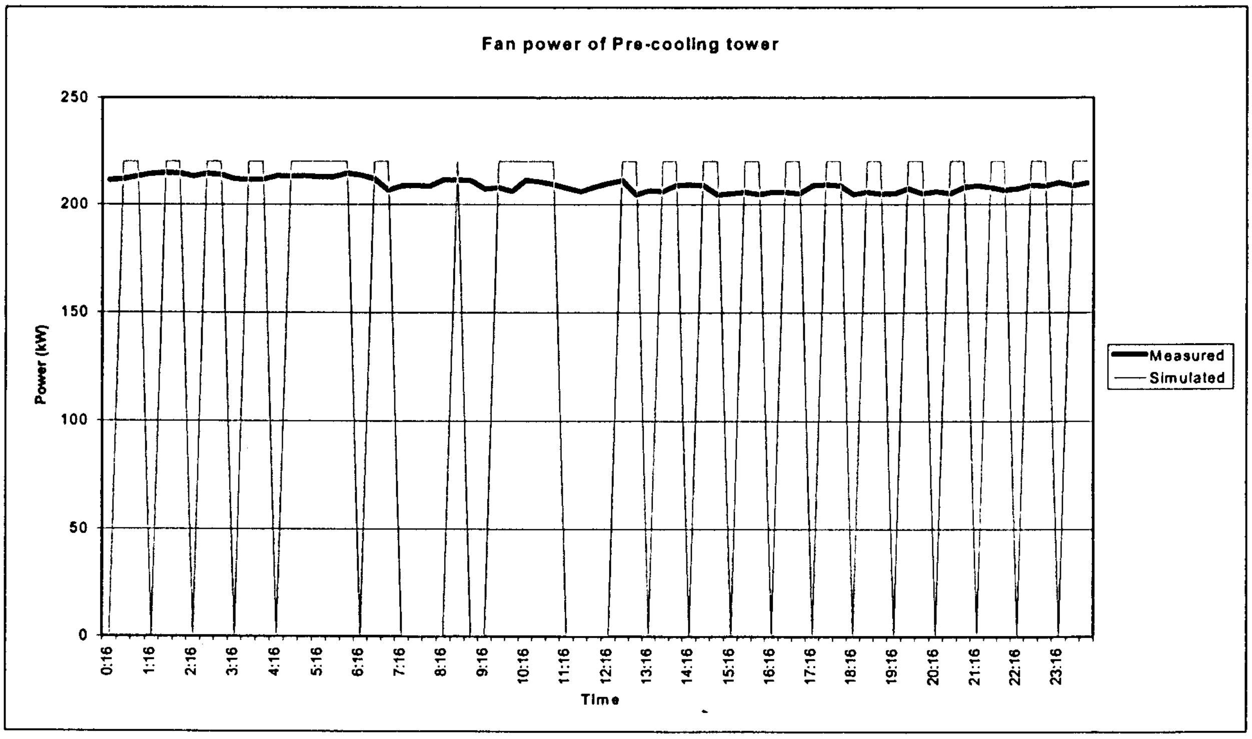

Figure 3-19: Pre-cooling tower fan power verification result

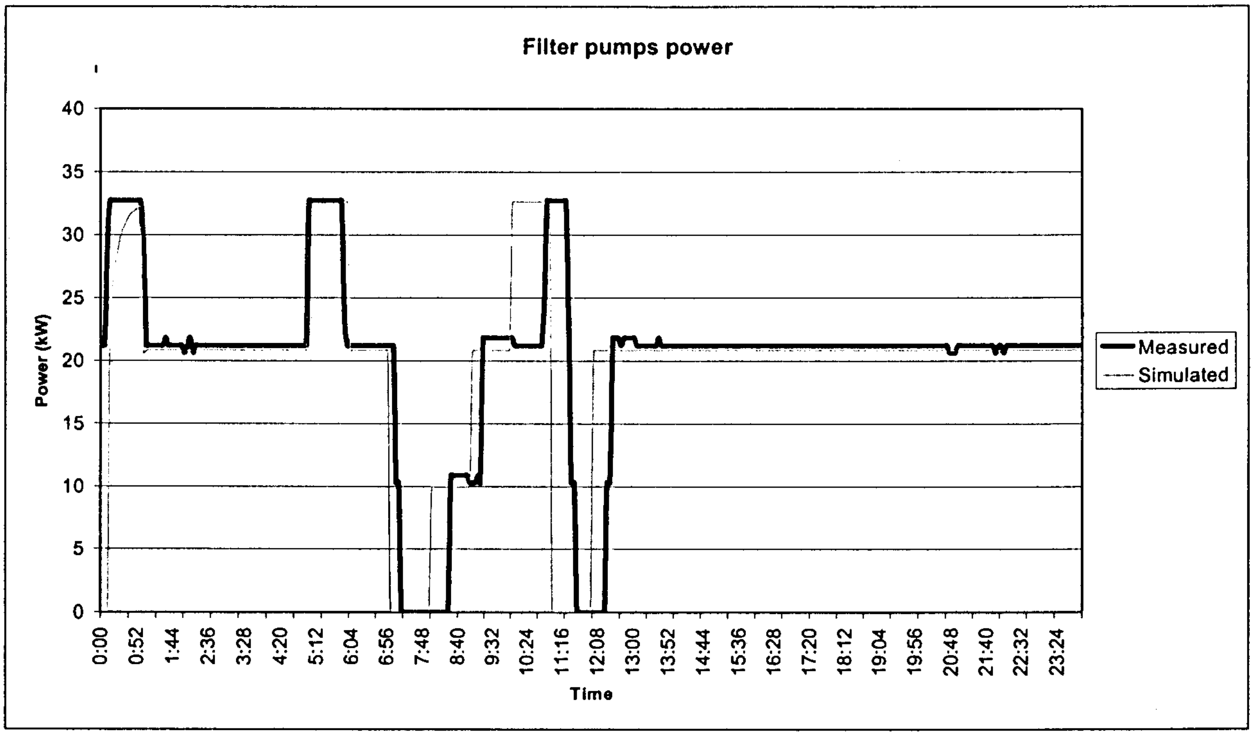

Figure 3-20: Filter pumps power verification results

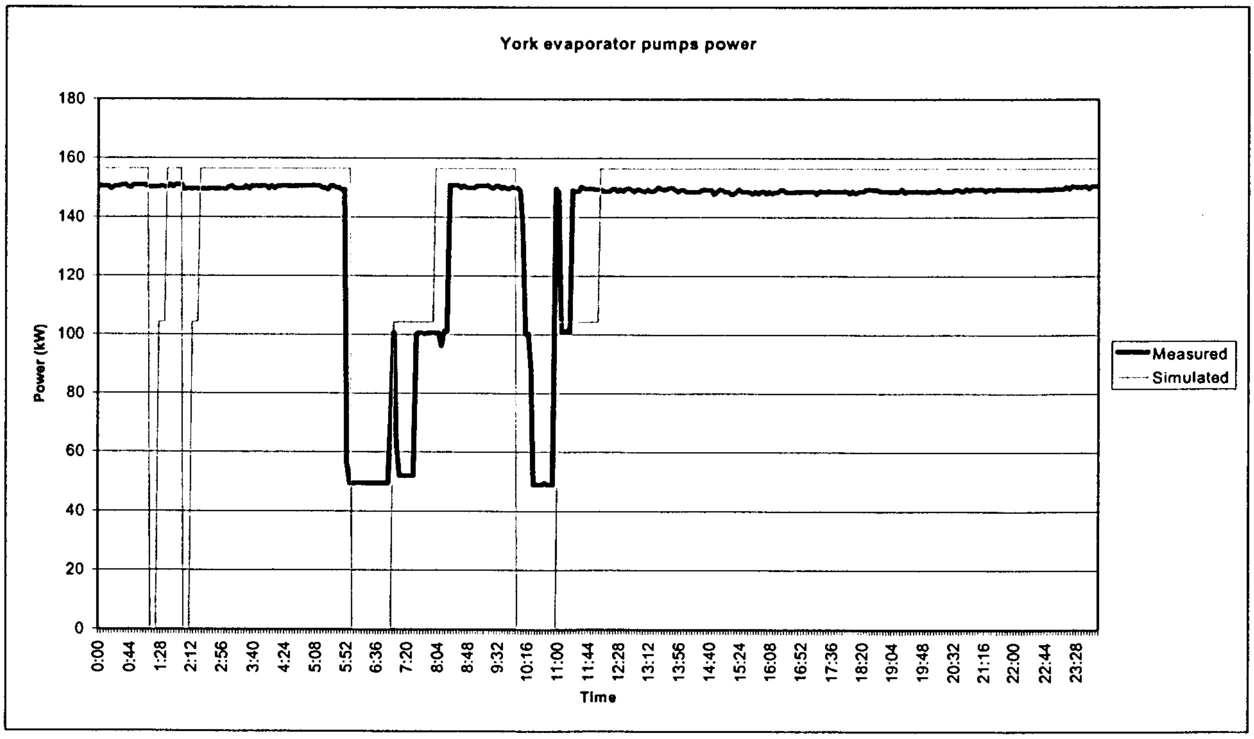

Figure 3-21: York evaporator pumps power verification results

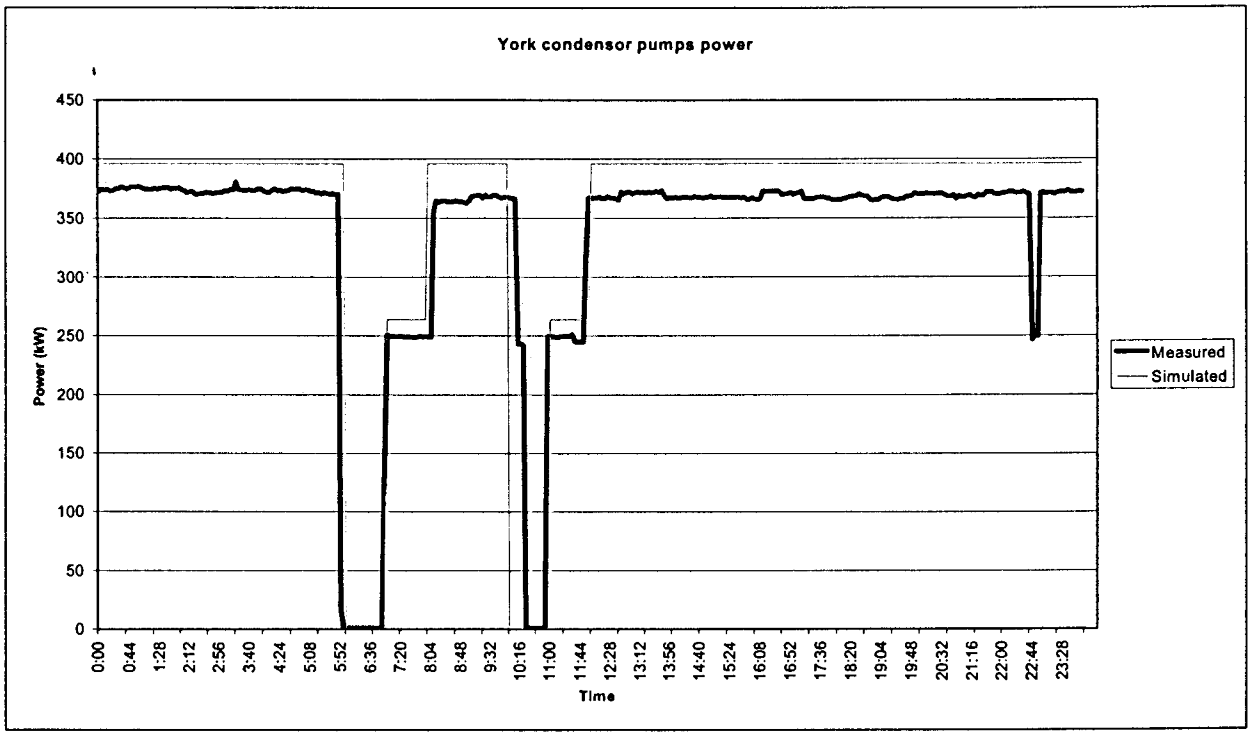

Figure 3-22: York condenser pumps power verification results

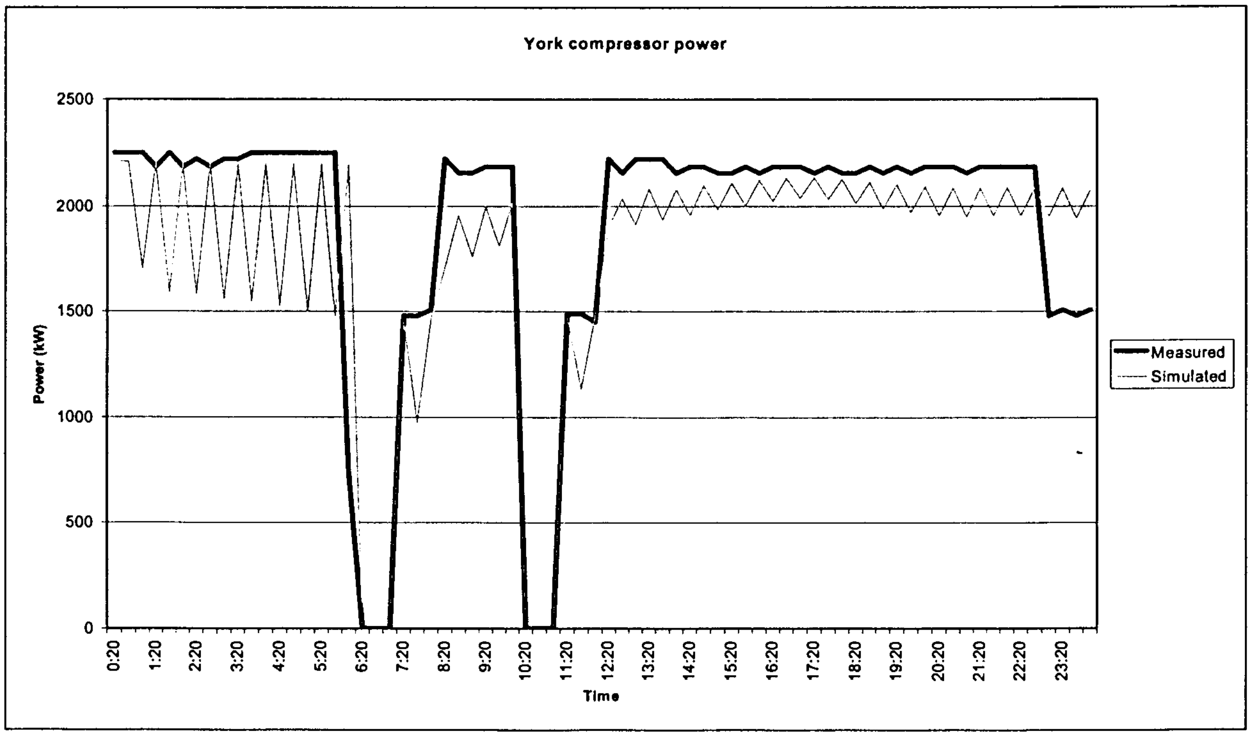

Figure 3-23: York chiller compressor power verification results

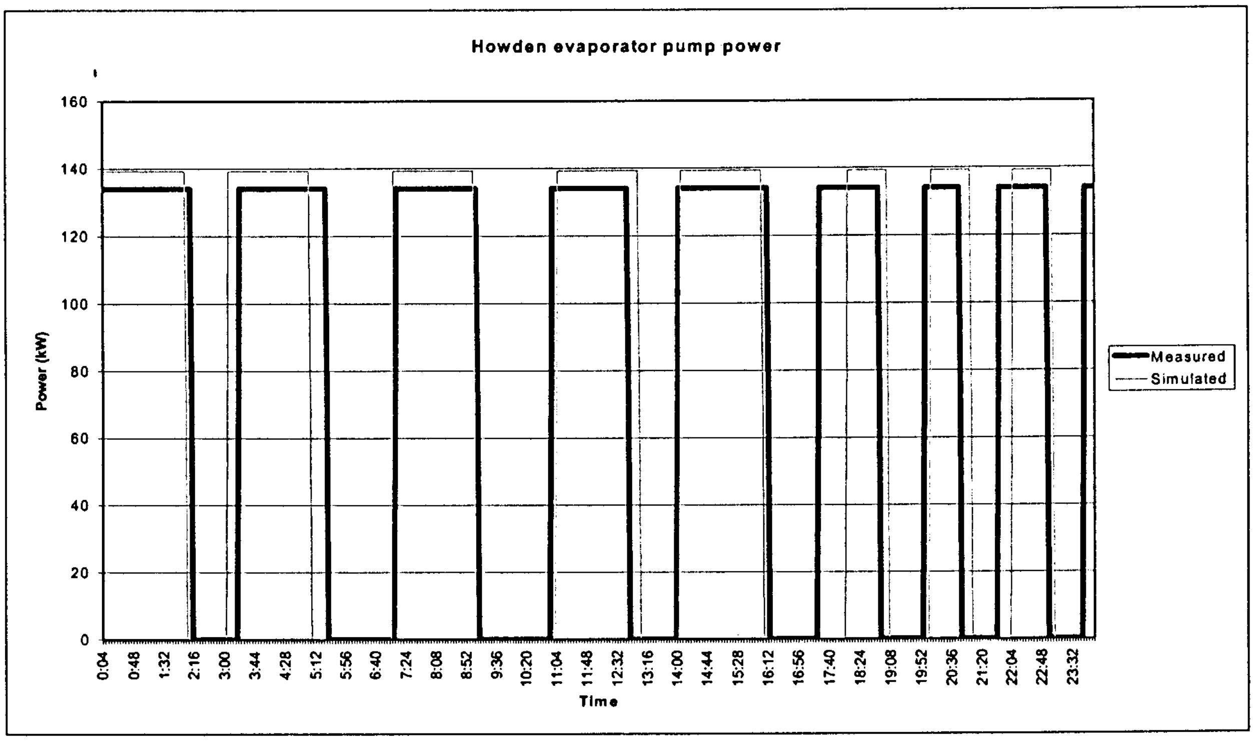

Figure 3-24: Howden evaporator pump power verification results

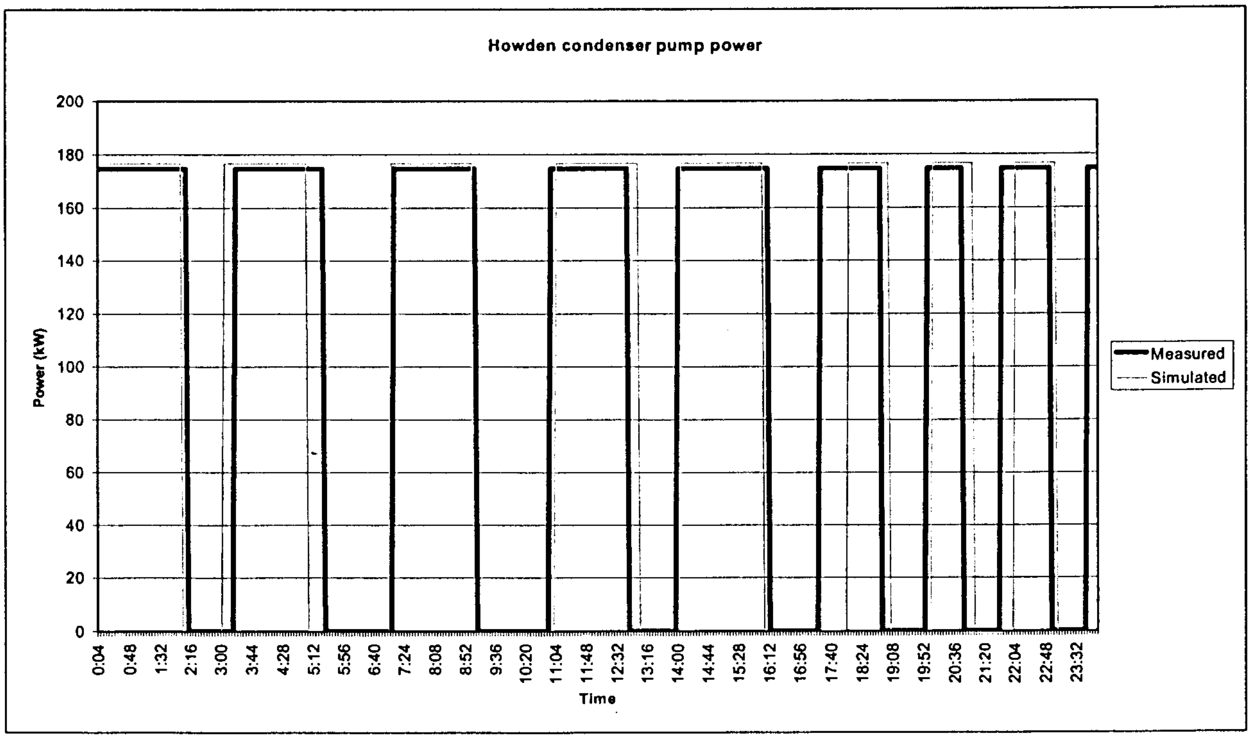

Figure 3-25: Howden condenser pump power verification results

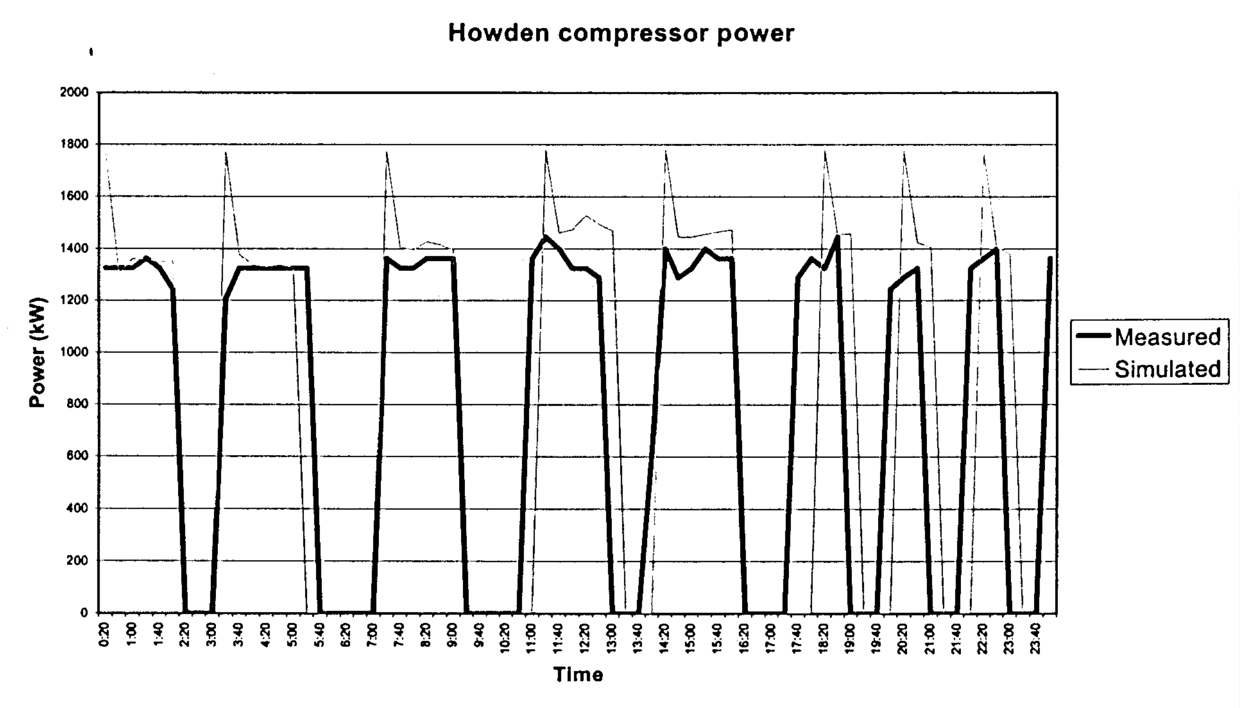

Figure 3-26: Howden compressor power verification results

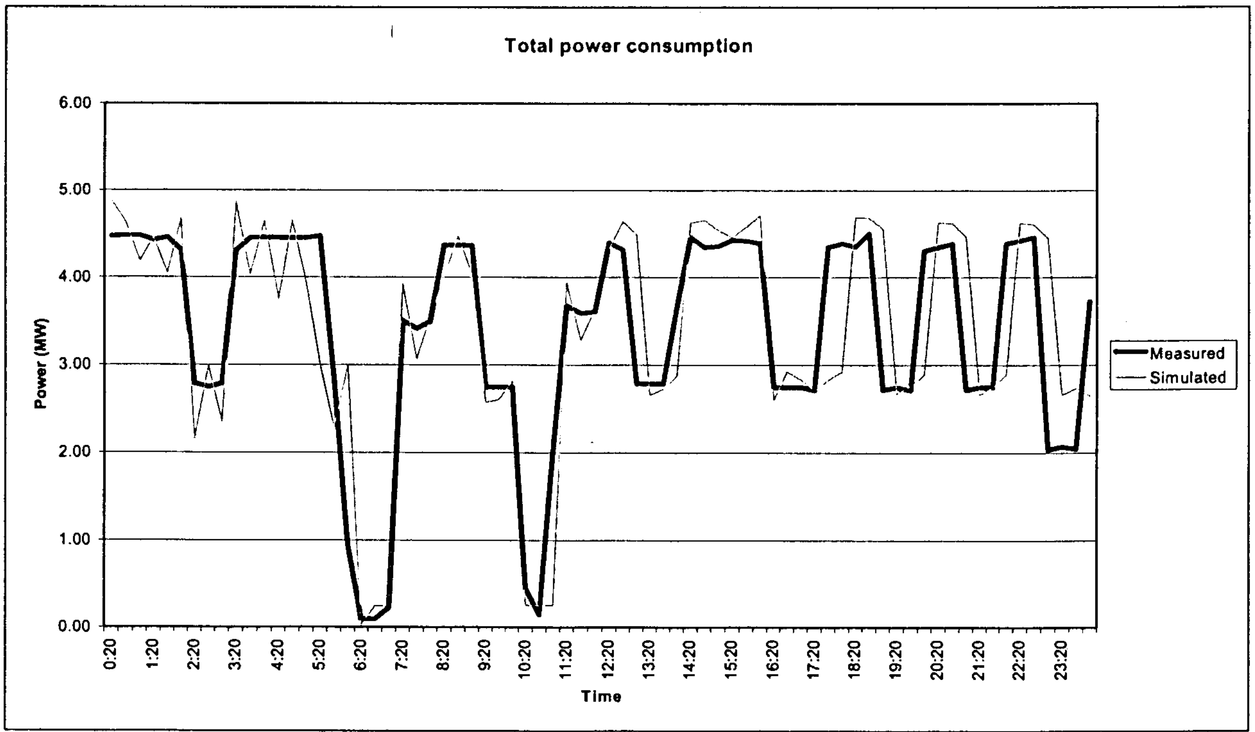

Figure 3-27: Total power consumption verification results

Figure 3-27 shows the total power usage of the surface cooling system from the Hot water dam to the water going down to the shaft. A summary of the results can be seen in Table 3-3.

Component	Within 10% (%)	kWh Error over 24 hours (%)
Pre-cool tower fan	62.5	34.26
Filter pumps	88.1	1.92
York evaporator pumps	84.72	0.83
York condenser pumps	88.89	5.92
York compressor	68.66	6.96
Howden evaporator pump	85.28	4.44
Howden condenser pump	85.28	6.99
Howden compressor	72.22	1.95
Total power	62.5	0.05

Table 3-3: Summary of power consumption

- **Underground pumping stations**

Limited information was available on the energy usage of the underground pumping stations. Furthermore, it was difficult to log the electricity usage of these pumps for it meant that the electrical loggers would have to be set up below ground. This was difficult for special permission was needed.

The only information available was the total daily energy usage of the underground pumps per pumping station. To be able to use this, the correct scheduling of the pumps were needed. It was needed to control the system just like the people would control it. This was done by using the verified dam levels and controlling the system accordingly. The scheduling of the pumps were verified, seen in Figure 3-15, and used to verify the energy usage.

The results per pumping station and the total can be seen in Table 3-4.

Pumping Station	Measured (kWh)	Simulated (kWh)	Error (%)
33Lvl	113683	121513.2	7
49Lvl	61894	58605.32	5.3
70Lvl	21383	26029.08	21.7
80Lvl	118923	85876.83	27.8
95ALvl	49970	54153.79	8.4
Total	**365853**	**346178.2**	**5.4**

Table 3-4: Summary of Underground Pumping Stations energy usage

3.7 Conclusions and recommendations for future work

Verification of the simulation temperatures, flows, dam levels and energy consumption was conducted. Fifteen to twenty time steps per hour were needed to simulate the dynamics of the cooling and pumping system with its controls.

Satisfactory results were obtained from the verification study in all the components. The temperatures were within 2°C for 79% of the time, except for the cooling tower. The energy consumption of the components was acceptable for the purpose of the study.

The predicted power consumption of the surface equipment over a period of 24 hours is accurate within 7% for all but one of the components. The most important result, for the purpose of the study was the less than 1% error of the total energy consumption of the total system over 24 hours. This successfully demonstrates the value of the simulation tool for energy studies.

The new models work well enough but the building software* was rather difficult to use for mining applications. The only practical option for future studies would be to develop a mine specific program. The new models published in this thesis could help when developing such a new tool.

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* Building Software, QUICKcontrol, was used with the owners, TEMMI's, permission

CHAPTER 4

NEW CONTROL STRATEGIES

With the simulations properly verified for the existing cooling cycle, it is necessary to investigate options for strategies to shift load. The most important aspect to keep in mind is that the workers work within a safe and reasonably comfortable environment. To do this, the current system and control needs to be properly understood. The major energy consumers in the system need to be identified. From that point new strategies and control can be investigated. These new controls are tested in the simulation model to test feasibility and comfort.

4.1 Introduction

Nearly 25% of the electricity used by the mining sector goes to the VC system of the mine to maintain the comfort and safety of the workers. Of this percentage certain equipment causes a big part of the load. To investigate the potential for load shifting it is important to establish the representative impact of each of these larger equipment components.

When the energy usage contributions of the different equipment have been established there can be focussed on these big energy users like the chiller compressors and underground pumps. The current control also needs to be established for better understanding of the system. This information can then be used to optimize or control the right equipment to accomplish the better energy usage and load shifting by implementing retrofits.

To effectively perform retrofits to establish load shifts, it is necessary to do year simulations. This is done to evaluate the system's performance over a period of time, including the full variation of climatic changes. Giving the annual savings and load profile is more understandable and usable. It also gives a comparison between the different retrofit strategies.

4.2 Comfort and energy audit

To achieve the maximum efficiency and productivity of the workers it is important that the workers are comfortable in their working environment. A well-controlled working environment is also important for safety aspects to prevent accidents caused by excessive exposure to heat.

In Table 4.1 an indication can be seen of the maximum wet bulb temperature at which men can be expected to work, at different metabolic rates, with a reasonable factor of safety. The air velocity is at about 2.5 m/s [1].

Metabolic rate of work (W/m^2)	**Maximum wet bulb temperature for acclimated men (°C)**
Hard work – 240 W	32.5
Moderate work – 180 W	33.0
Light work – 115 W	34.0

Table 4-1: Maximum air temperatures for various work rates

The average unacclimatised person can work at these metabolic rates at 2.5°C lower than an acclimatised person can for about four hours. More exposure than this could cause heatstroke. It is therefore important to acclimatise a person before they enter such an area at those temperatures.

To prevent or lessen acclimatisation time mines control the working area temperature at a temperature lower than the above stated maximum temperatures. This temperature will have to be lower than 30°C for minimum acclimatisation time. PDWAJV controls their working area temperature at about 27.5°C [2]. Above this temperature special heat-stress management programs are run.

The temperature of the working area is dependant on the depth of the area below the surface. This is due to the rising virgin rock temperatures and adiabatic compression of air. The best available information indicates that a thermal step of 83 m per degree Celsius can be expected and that the virgin rock temperature varies with depth according to the expression (18 + 12d)°C, where d is the vertical depth in kilometers. For platinum mines this expression is closer to (20 + 21d)°C due to higher virgin rock temperatures and different rock formation[3]. This can be seen in Figure 4-1, which shows some of the South African mines.

It is therefore important to control this working area's climate. This control of the working climate can only be achieved in deeper mines by proper ventilation and cooling. Most mines use bulk-air coolers to achieve the desired climate. PDWAJV tries to send chilled water between 1°C and 3°C down the shaft to the bulk-air cooler.

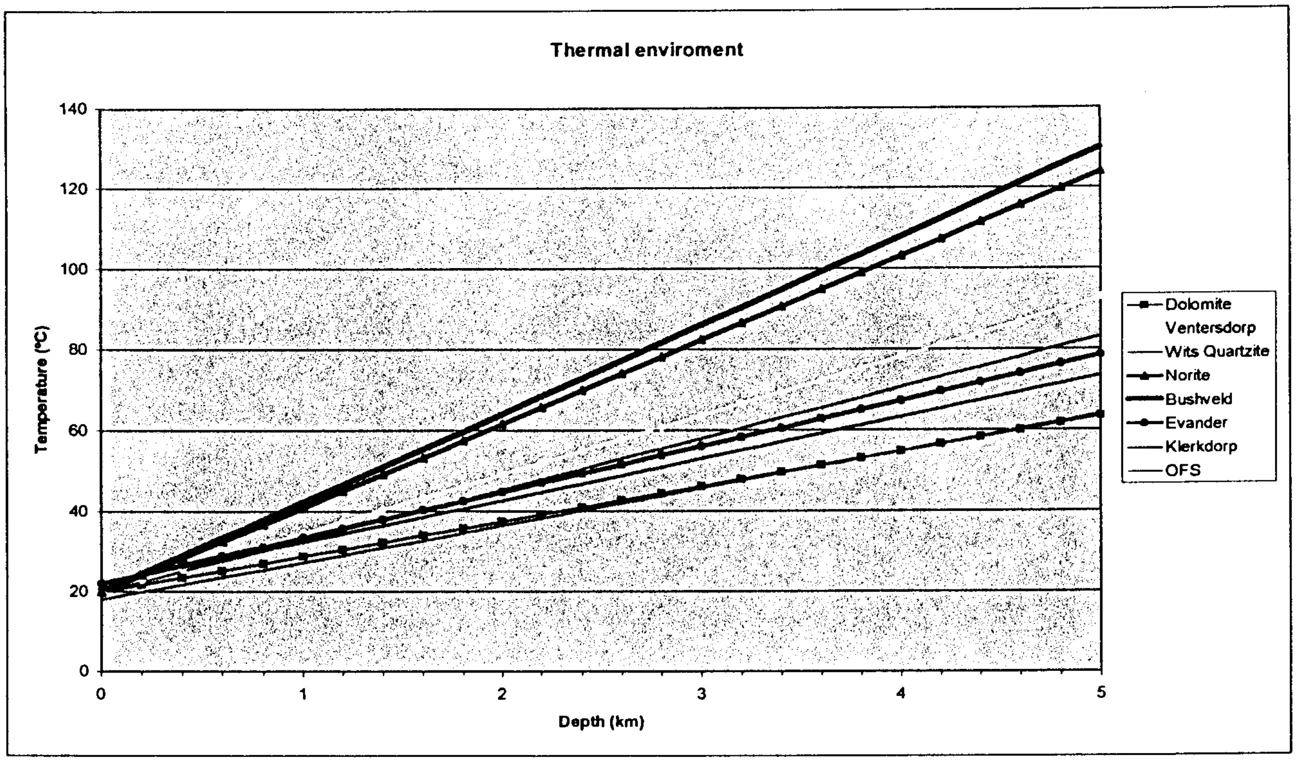


Figure 4-1: Thermal environments for different mines

Large equipment is needed to maintain the water temperature going down the shaft. This equipment uses different amounts of energy and to shift the load it is needed to investigate the influence of the different equipment. Figure 4-2 shows a breakdown of the different surface plant equipment energy usage.

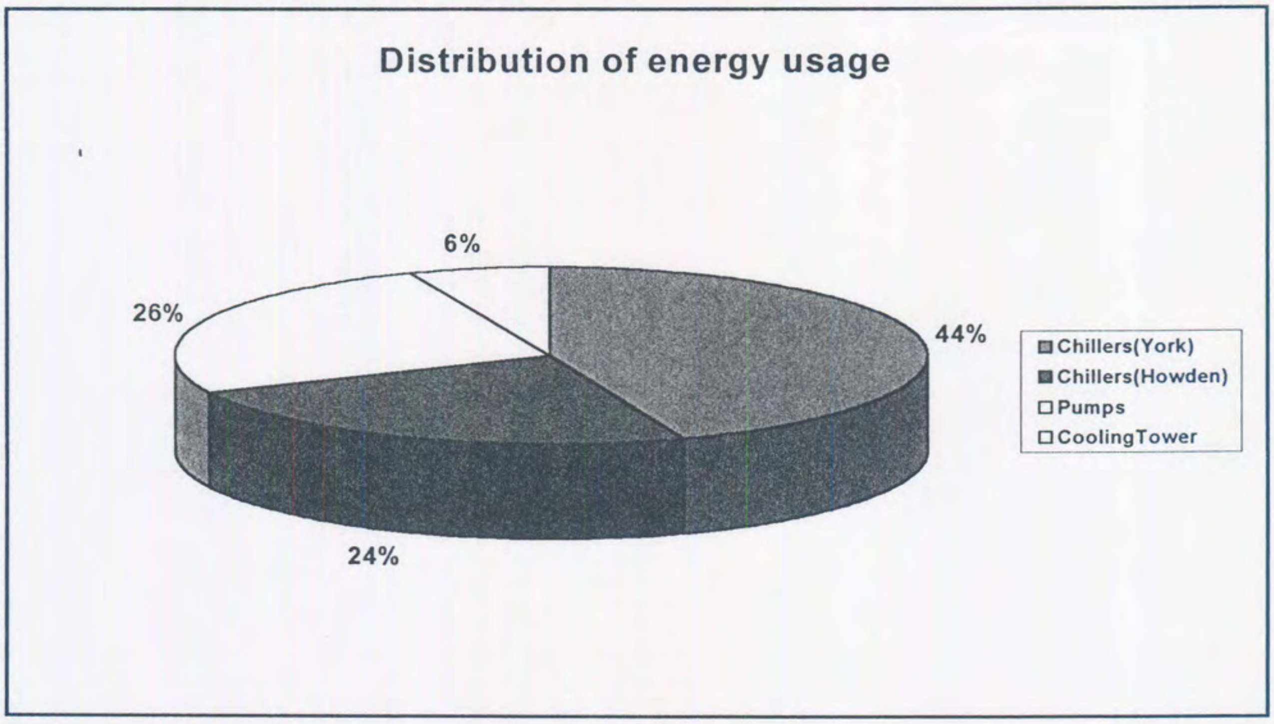


Figure 4-2: Energy usage of different surface plant equipment

It can be clearly seen that the compressors from the chillers use the most energy of the surface plant equipment. The chilled water of the chillers is currently being stored in thermal storage dams. Any retrofit strategy would firstly have to look at the load caused by the chillers for load shifting and savings and then the possibility of utilising the dams for optimum storage.

Another interesting point to investigate is the comparison between the energy usage of the Surface cooling plant and the Underground Pumping stations. The comparative percentages of energy usage are shown in Figure 4-3.

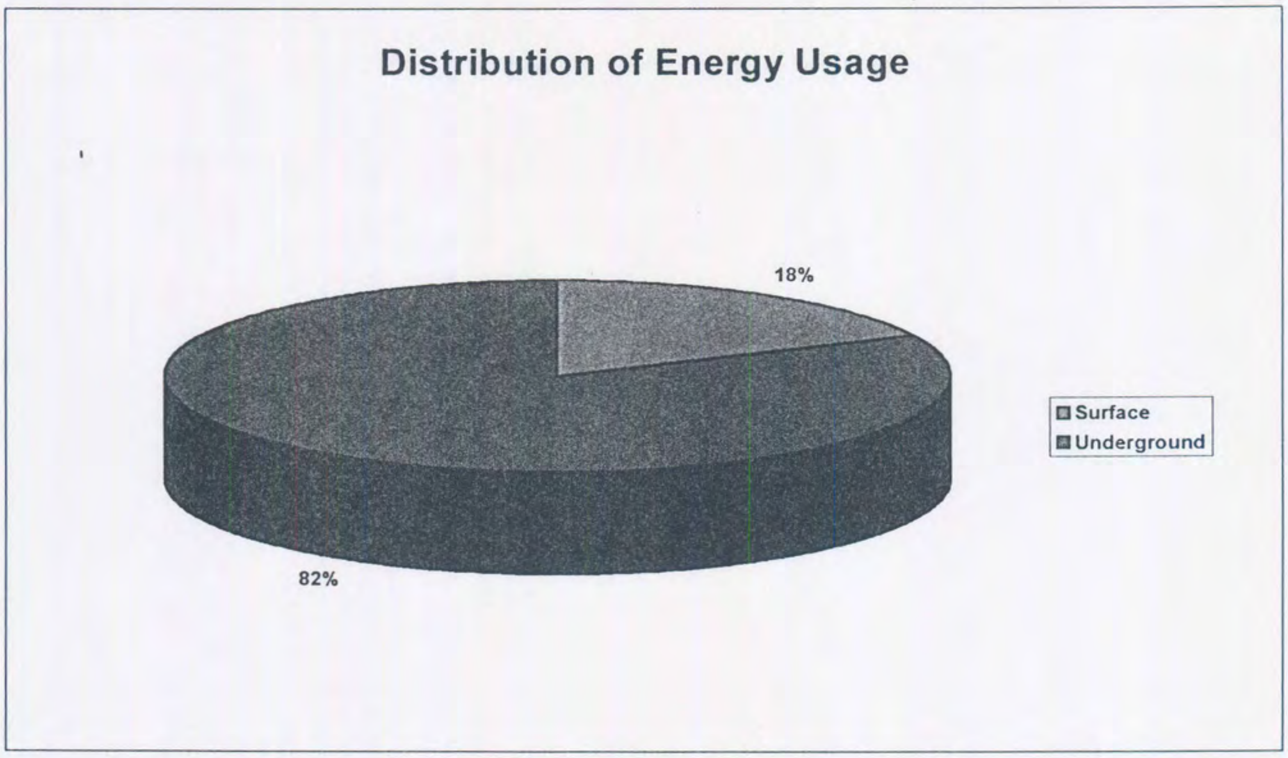


Figure 4-3: Energy usage of the surface and underground plants

4.3 Current control

- **Surface plant**

A detailed schematic view of the system with the currently controlled equipment can be seen in Figure 4-4. The current system uses ultrasonic level measuring equipment on the dams. The signal is sent to the control room where operators control the system manually. The operators decide on the appropriate level for the dams, usually between 80% to 100% of the volume of the dam.

The levels of the dams of the pre-cooling towers control the flow to the towers from the Hot Water dam through variable flow valves. The level of the Cool Water dam controls the flow from the filter pumps, that work in steps, and the level of the Chill Water dams control the flow through the chillers. If the Chill Water dam levels drop below the set parameters the operators manually switch on the chillers.

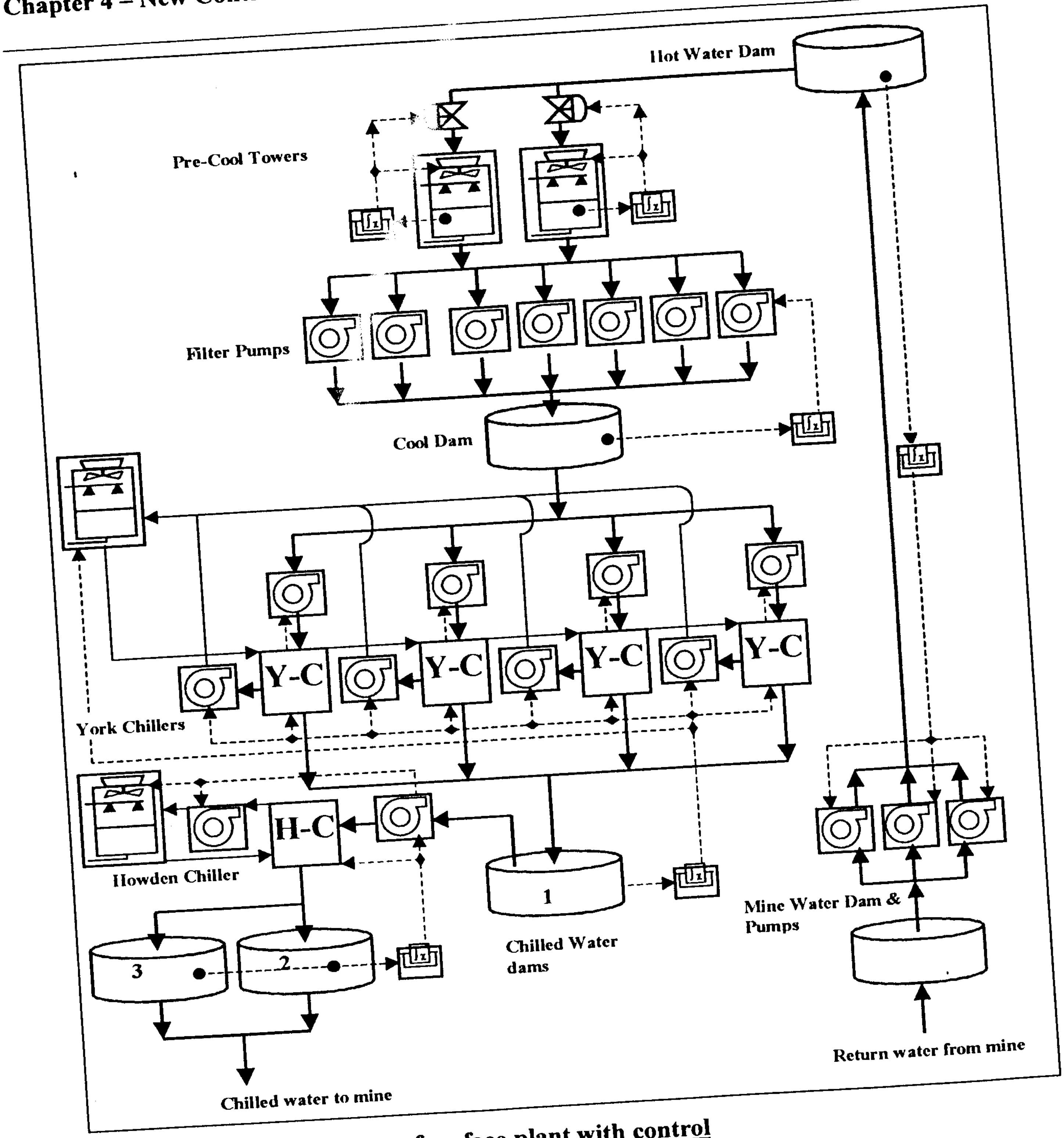
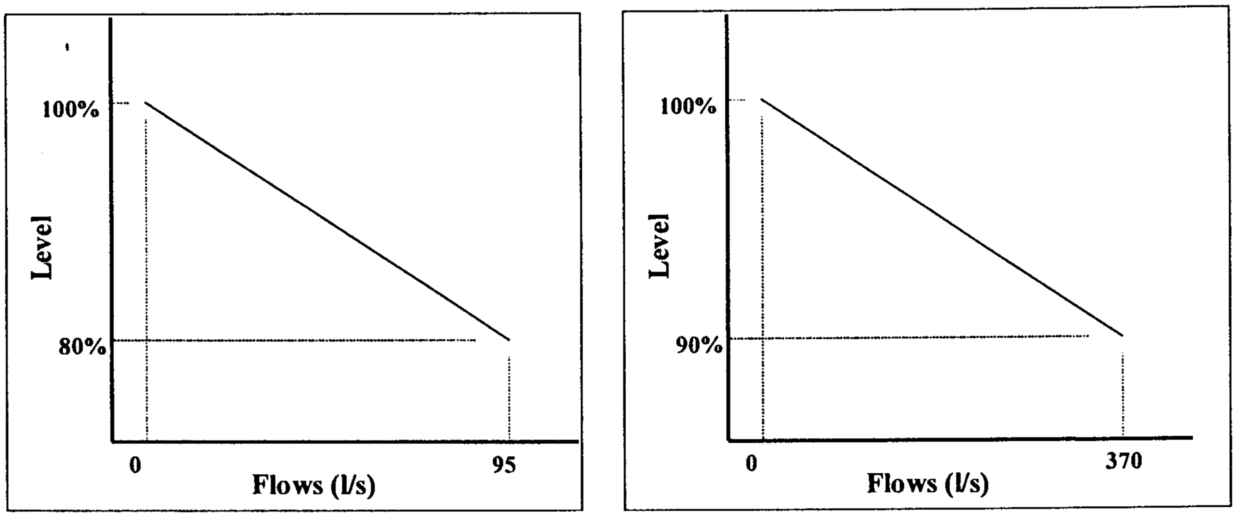


Figure 4-4: Schematic layout of surface plant with control

The current manual control parameters for the Chill Dam1 are set as seen in Figure 4-5 (a) for a single York chiller. When the dam is full, there is no flow and when the level falls below 80%, the chillers are switched on. The number of York chillers being switched on is dependent on the flow out of the dam, caused by the Howden chiller.



(a) *(b)*

Figure 4-5: Manual control parameters on Chill Dams

The control on the Chill Dams 2&3 can be seen in Figure 4-5 (b). The dam levels are controlled by the Howden chiller and serves as the supply storage to the mine. The water in these dams are controlled to a temperature of between 1.5 – 2°C. To maintain this exact temperature, the water is recycled to mix with the water entering the Howden, but this control is not relevant to the study.

- **Underground pump stations**

A detailed schematic view of the system with the currently controlled equipment can be seen in Figure 4-6. The current system uses ultrasonic level measuring equipment on the dams. The signal is sent to the control room where operators control the system manually. The operators decide on the appropriate level for the dams, usually between 80% to 100% of the volume of the dam. The operators manually control all the dams.

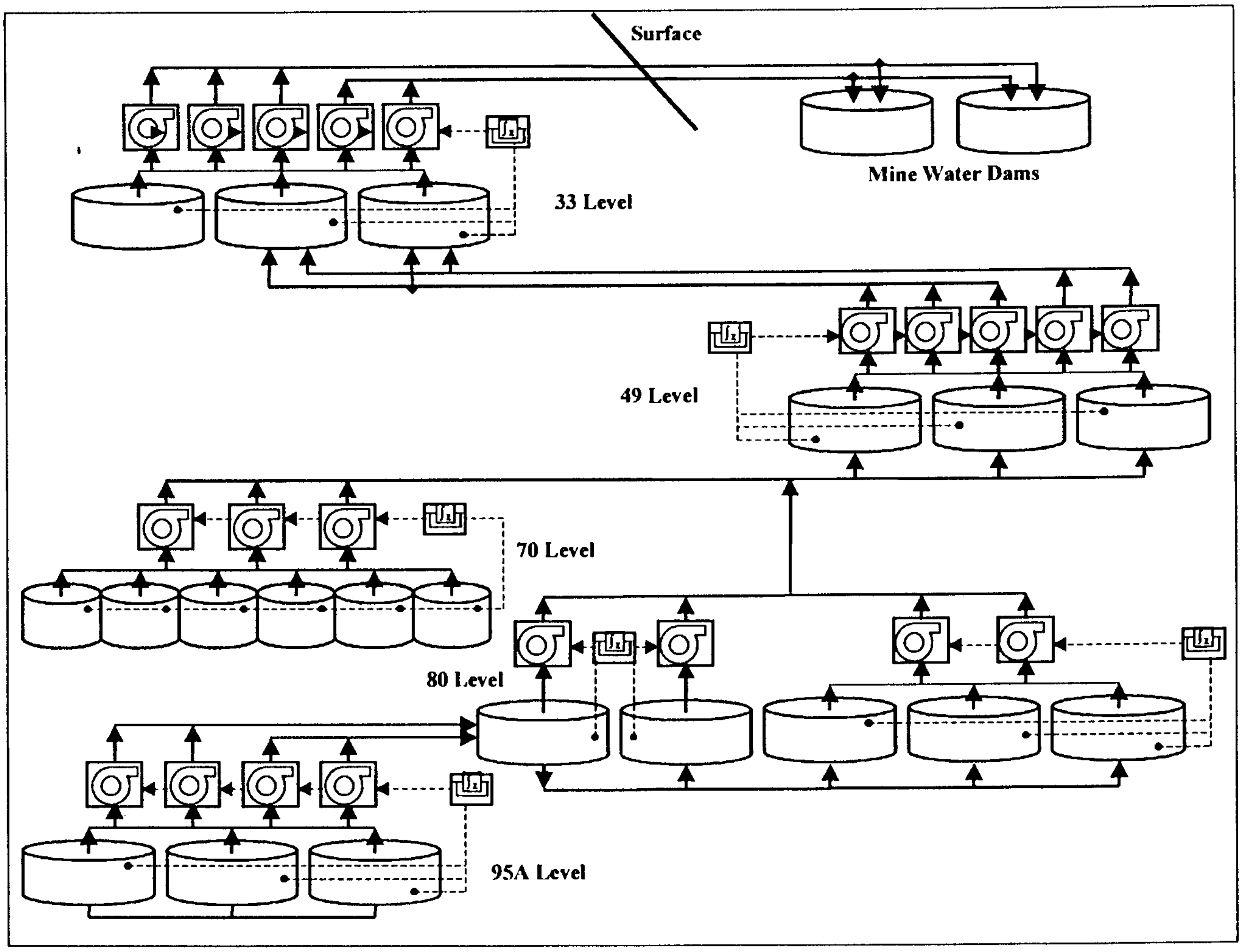


Figure 4-6: Schematic layout of underground pumping stations with control

4.4 New control for load shifting

- **Surface plant**

The first step in the new control strategy it to install step control on the pumps and chillers, receiving their signal from the already installed level sensors on the dams. This will allow for automatic controlling of the pumps and chillers. The dam levels can be monitored more closely and the set points of the control can be set lower, utilizing the storage capacity of the dams more effectively.

Each of the Cool and Chill dams have a two hour storage capability, containing 2700m^3. To fully utilize the capacity of the dams, the three chill dams are put into parallel, meaning that the three dams basically form one big dam. This is an existing scheme, Scheme A, seen in Figure 3-2 in Chapter3. The only difference being the ability to use Chill Dam1 along with the other two dams. The new control strategy can be seen in Figure 4-7 with controls and dam configuration.

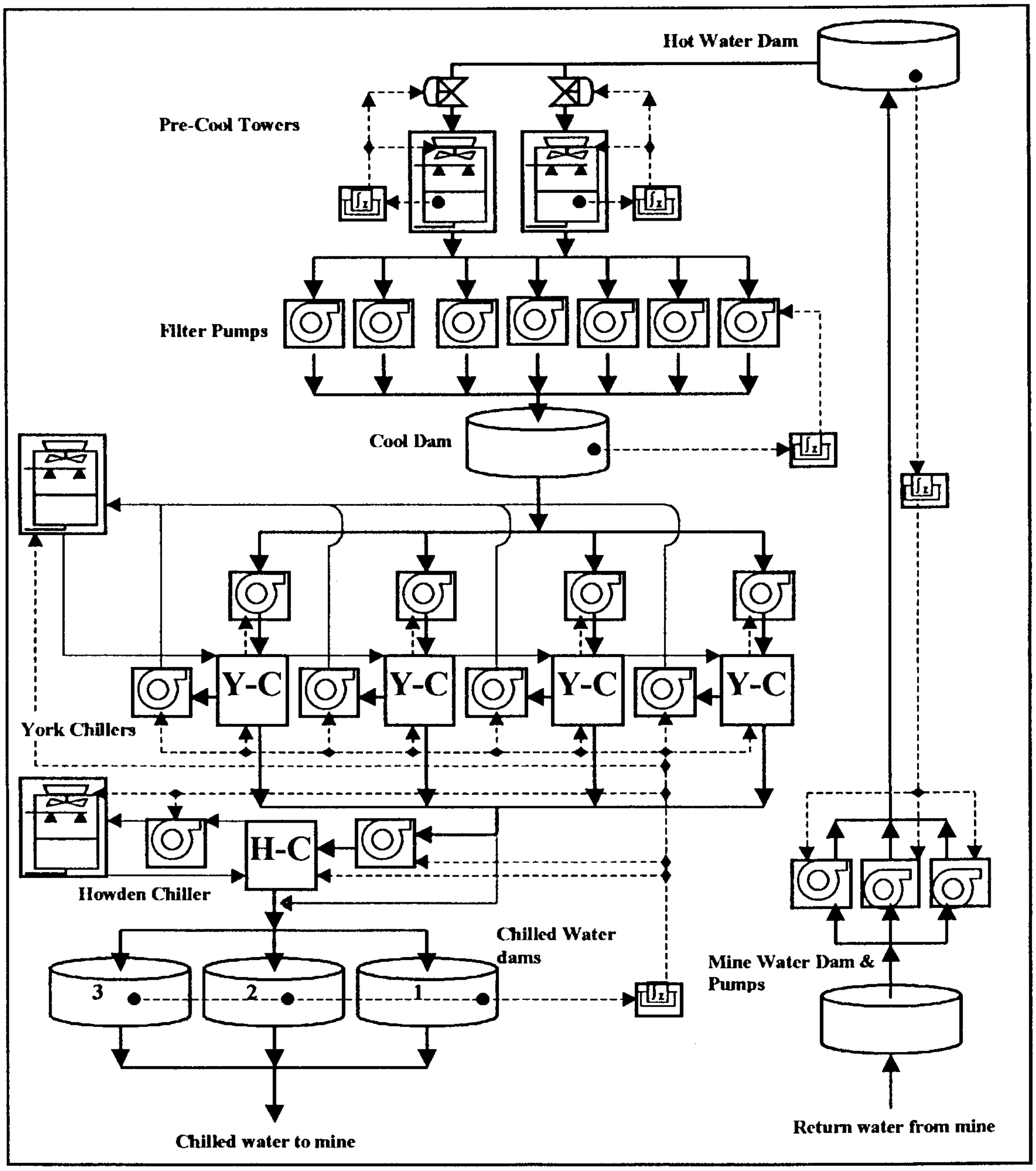
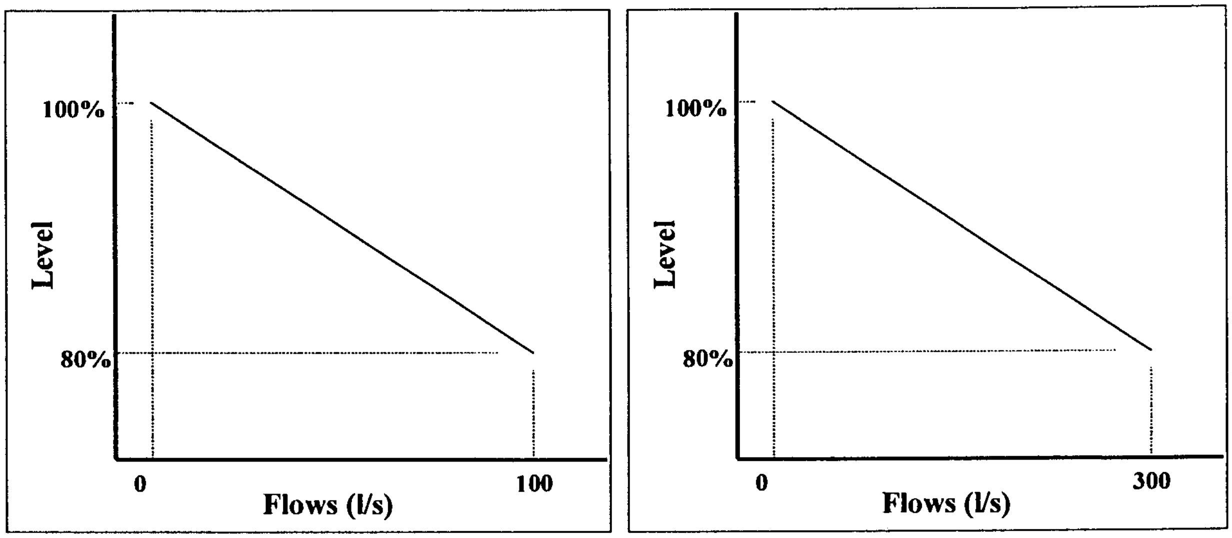


Figure 4-7: New control and configuration

The control parameters for the three dams in parallel can be seen in Figure 4-8 (a), which will control the York and Howden chillers in series.



(a) (b)

Figure 4-8: New control parameters for chillers

- **Underground pump stations**

The current system has some well installed equipment, including the valves and actuators, for controlling the dam levels and flows. As mentioned earlier, the entire system is manually controlled. The new control strategy, for the underground pumping stations, can be done by simply automating the control on the system.

The pumps and valves are already electronically controlled, but the switches are manually activated. To achieve the goal of automatic control, relays can by used to electronically switch on, or off, the pumps and valves. The new control on the valves and the pumps can be seen in Figure 4-9.

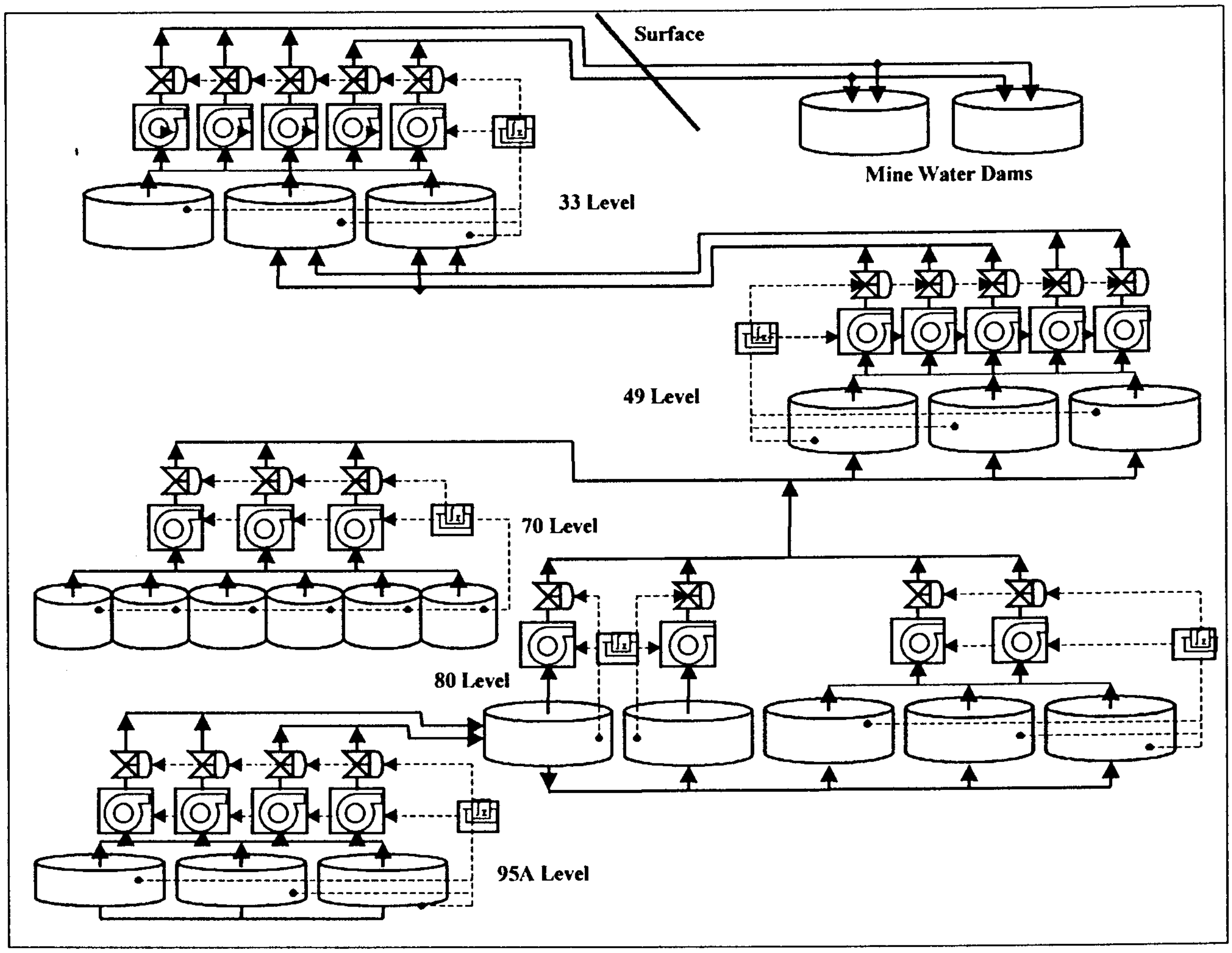


Figure 4-9: New control on pumps and valves

All these new control parameters and strategies are tested continuously in the simulation to ensure the maintaining of the safe and comfortable environment. This is done for the surface plant by comparing the simulated temperature with the required temperature of the water sent down the shaft. For the underground pumping stations it is important to make sure that the dams do not overflow.

4.5 Conclusions

From the energy usage distribution it is clear that the chillers use the most energy of the surface cooling plant. Furthermore, the underground pumping stations use approximately four to five times the energy of the surface plant.

The best way to shift the load caused by the energy usage of the plants is to use thermal storage. This can be achieved by new control strategies on the current systems. There does exist some installed capacity, which can be better utilized by the new control strategies. By implementing this new control the load will be shifted. This is discussed in Chapter 5 in further detail.

Again it was rather difficult to do the control simulations for the mines. The need for an application specific software tool for the mines is obvious.

4.6 References

[1] Le Roux, W. L., Le Roux's notes on Mine Environmental Control, Fourth edition, pp. 100 – 107, 1990.

[2] Placer Dome Western Areas Joint Venture, Annual report on Health and Safety, http://www.westernareas.co.za/, 1998, Contact details: Tel: 27 11 688 5000, PO BOX 61719, Marshalltown, 2107.

[3] Patterson, A.M., Ventilation and Refrigeration Considerations in the Design of a Deep, Hot Gold Mine Using Trackless Operations, Technical Challenges in Deep-Level Mining, (1990), 1323-1332.

CHAPTER 5

RESULTS AND POTENTIAL

The main objection of the study was to find the potential of load shifting for use by the mining industry and ESKOM for strategic planning of energy usage and pricing. The load shifting capabilities of PDWAJV was determined for the cooling cycle and the influence on the total energy usage of the mine. This was then extrapolated for the national mine energy usage and its potential for shifting load.

Chapter 5 – Results and potential

5.1 Introduction

From Chapter 1 it has become apparent that there is need to find possibilities to use Real Time Pricing or other pricing structures from ESKOM. This implies the shifting of load at certain times when electricity peaks are charged at a maximum price. This has widespread implications and benefits nationwide for the mining industry, ESKOM and consulting engineers. One of the most effective ways to achieve this goal is to use integrated, dynamic simulations.

From the standard installed system the current control parameters were established and new control strategies were investigated, using retrofits on the system. The results of these retrofits, using new control and different configurations of the dams, are discussed in this chapter. The potential shifting load on the PDWAJV gold was established. Using this potential and then extrapolating it, with a certain margin of error, the potential for shifting load for the whole South African mining industry was calculated.

5.2 Load shift for surface plant

In Chapter 4 the current and new control strategies were discussed extensively. These new control parameters and strategies were used with the new simulation of the system and the results were compared to the current system for a typical day. These results can be seen in Figure 5-1. This figure shows an average potential of shifting 4 MWh for a period of five hours on the surface cooling plant in a 24-hour cycle.

It was also important to ensure that the dam levels do not drop to below their minimum level. This was achieved and is shown in Figure 5-2 for the three Chill Water dams. Before the load shift the dam is filled to capacity and during the shift the level doesn't drop below 30%.

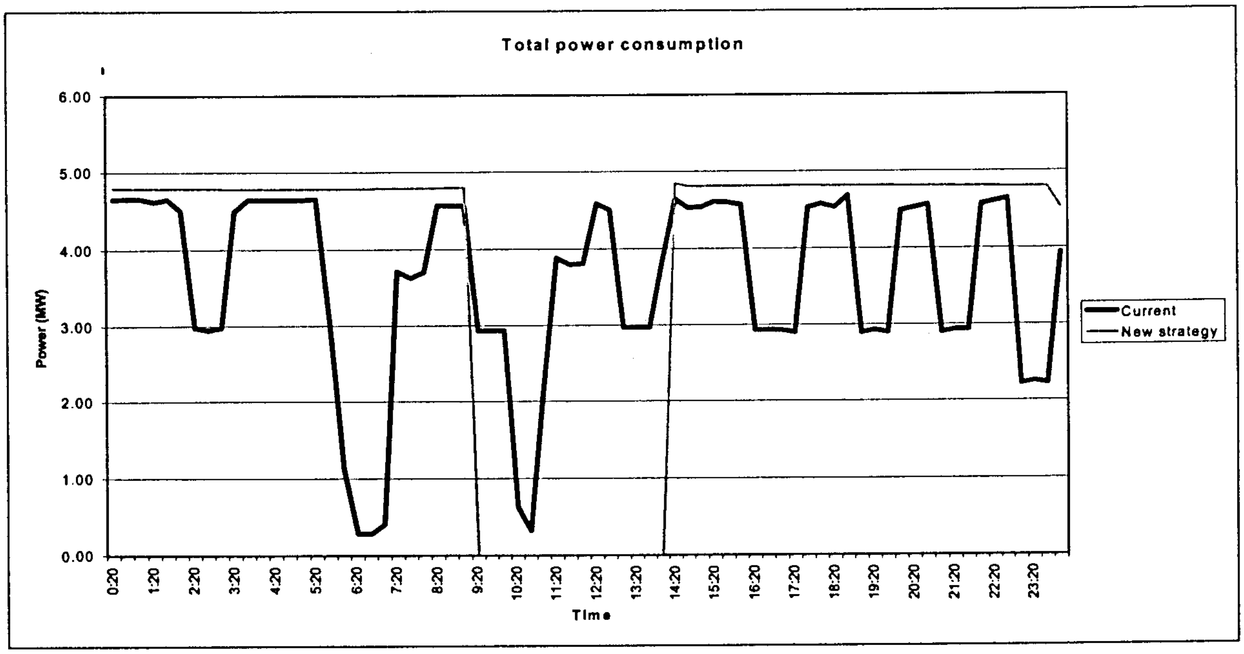


Figure 5-1: The potential load shift of surface plant

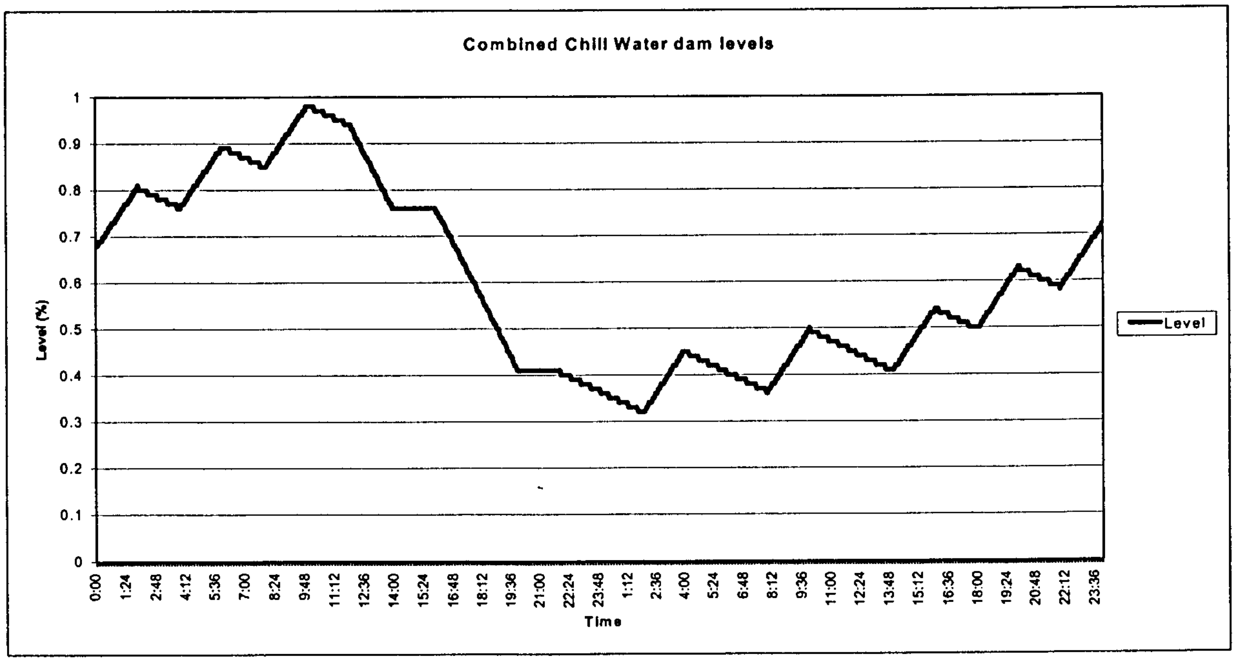


Figure 5-2: The combined dam levels for the Chilled Water dams

The maximum energy used by the mine is higher than the typical day's energy usage. This can be attributed to the harder work that some of the equipment, e.g. the chillers, had to do to ensure the dams are as full as possible for when the load shift needed to occur. This can correspond to the RTP for that specific day. It is important to note that, with this strategy, the total amount of energy used remains the same for the chilled water demand per day is constant.

5.3 Load shift for underground pumping stations

The verification study in Chapter 3 provided the necessary evidence of the accuracy of the new models. To determine the load shifting possibilities of the underground pumping stations, these verified models were used. To ensure the feasibility of the options the dam levels were carefully monitored to ensure that the dams do not exceed their maximum capacity, for that would be a dangerous situation.

The investigations showed that it was possible to shift the load for a maximum period of five consecutive hours per day. The control strategy used in the simulation model was the de-activation of all the pumps of the entire system for five consecutive hours. The total active pumps and the dam level for Level 95A is shown in the Figures 5-3 and 5-4 respectively.

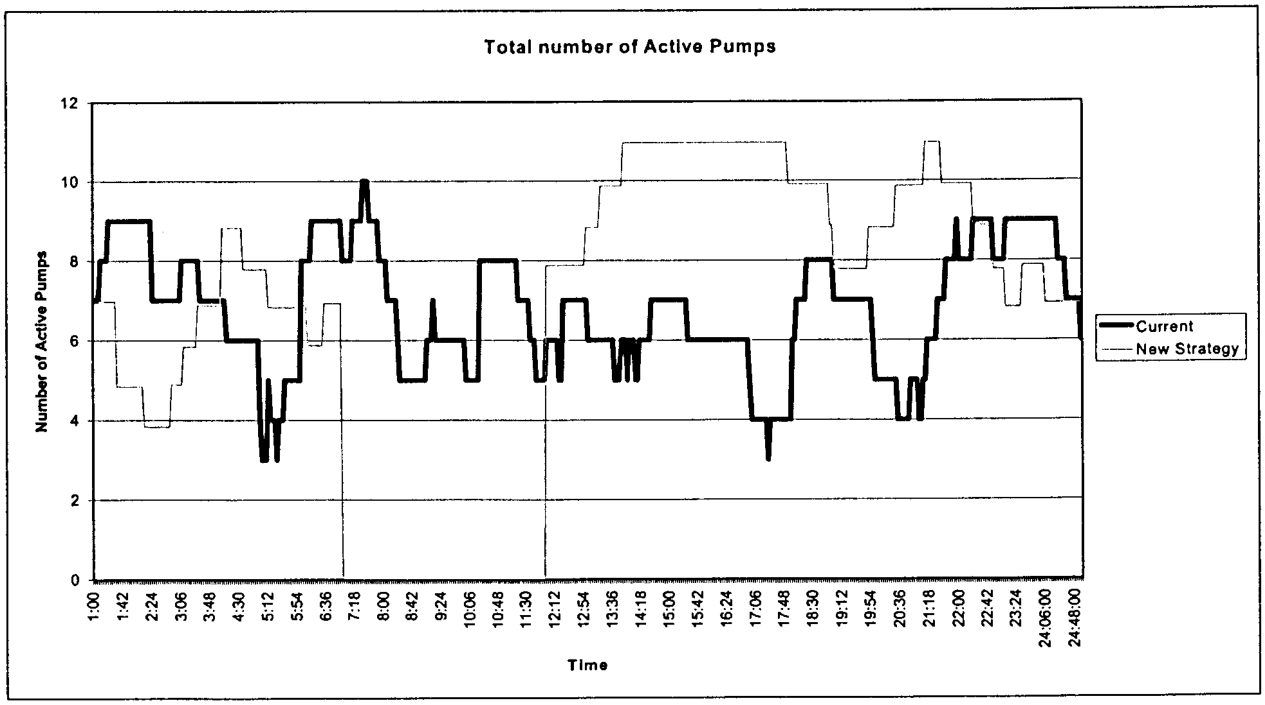


Figure 5-3: The potential load shift for Underground Pumping Stations

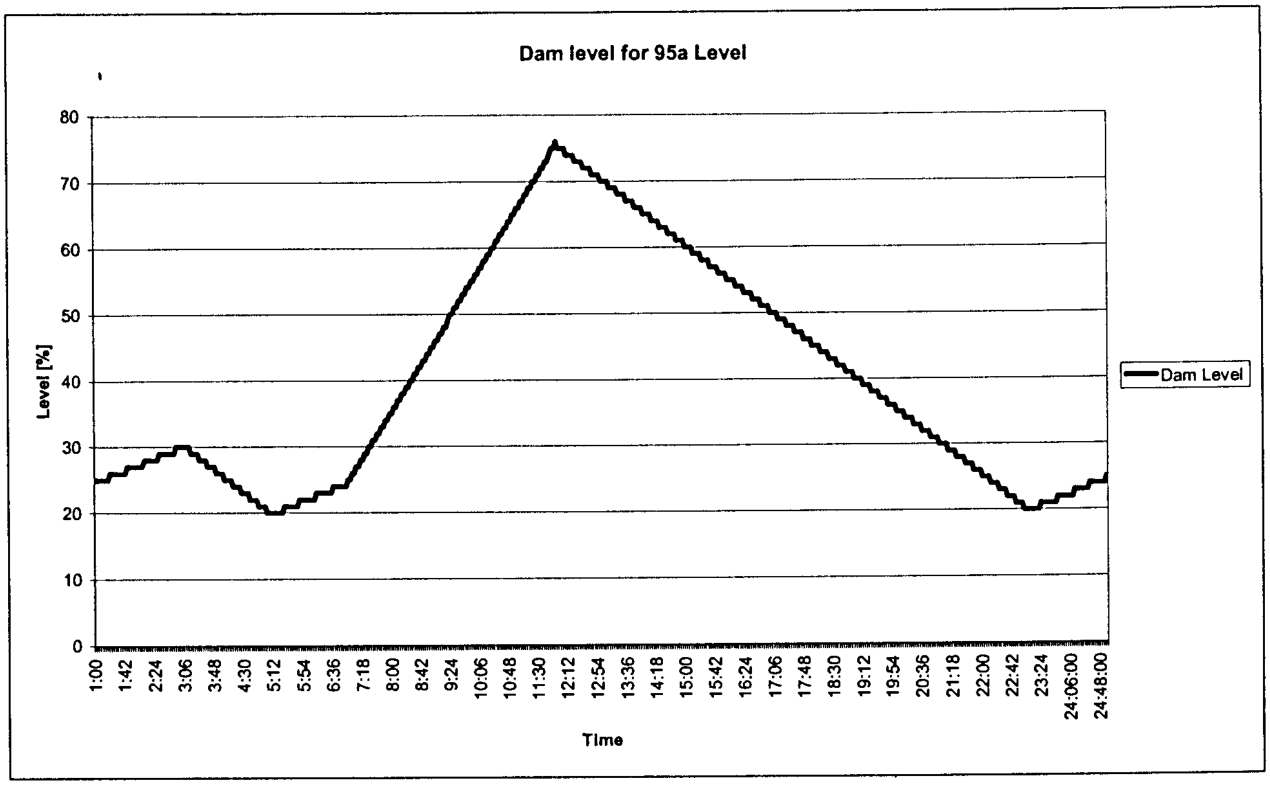


Figure 5-4: The dam level for 95A Level storage dam

From Figure 5-4 it can be seen that the dam never rises above 80% of its maximum capacity. The idea is to keep the dam levels to a minimum before the load shift and then to keep the levels below full capacity during the load shift period.

From Figure 5-3 it can be seen that the maximum number of pumps used is higher than for the normal running number of pumps. This is due to the increased demand to bring the dam levels to a lower percentage. This method does increase the maximum load on the system by 4MWh, but it also shifts a load of 15 MWh for five hours on average for a 24-hour cycle and a recovery time of five to six hours. This can be used for strategic planning of the energy usage of the mine.

It is important to note that the amount of water that needs to be pumped to the surface must remain the same. This means that the energy used in the system also remains the same and that it has only been shifted to different time periods. Table 5-1 shows a summary of the total flow and energy usage for a 24-hour period.

	Measured	Simulated	Error (%)
Flow (m^3)	30508	30448	0.21
Energy (kWh)	365853	346955	5.45

Table 5-1: Summary of flows and energy usage for 24-hours

5.4 Total load shift and National Potential

Having achieved the goal of simulating the various components of PDWAJV gold mine, with verified results and new control strategies, and determining the load shift potential, it is now necessary to determine the national potential. This is done to determine the total potential for ESKOM to supply electricity to other users that can't shift load, for a specific period of time, while the mining industry uses less energy at that time.

From the two previous sections it can be seen that both the surface plant and the underground pumping stations can shift their load for up to five hours. The combined load shift is almost 19MWh for a time period of five hours for a peak demand increase of 4,5 MWh over 24 hours with a recovery time of five to six hours. The water that needs to be moved stayed the same as well as the energy used. The load shift does not save energy; it just presents the possibility to use energy elsewhere in the system for a certain period of time.

PDWAJV uses about 125,5 GWh per year or approximately 15 MWh for the underground pumping stations. It further uses 29 GWh per year or approximately 4 MWh in its Surface cooling plant. The combined energy usage of the cooling cycle, on average, is 154 MWh per year or an average of 19 MWh.

The mine has a total energy usage of 400 GWh per year or 45.7 MWh. Of this load the cooling cycle, surface plant and underground pumping, attributes 39.8 % of the average load. The impact of the load shift can be seen in Figure 5-5. This shows the average current load versus the shifted load. The maximum load is higher due to the fact that the cooling cycle had to work at higher or fuller capacities to fill the surface dams and empty the underground dams.

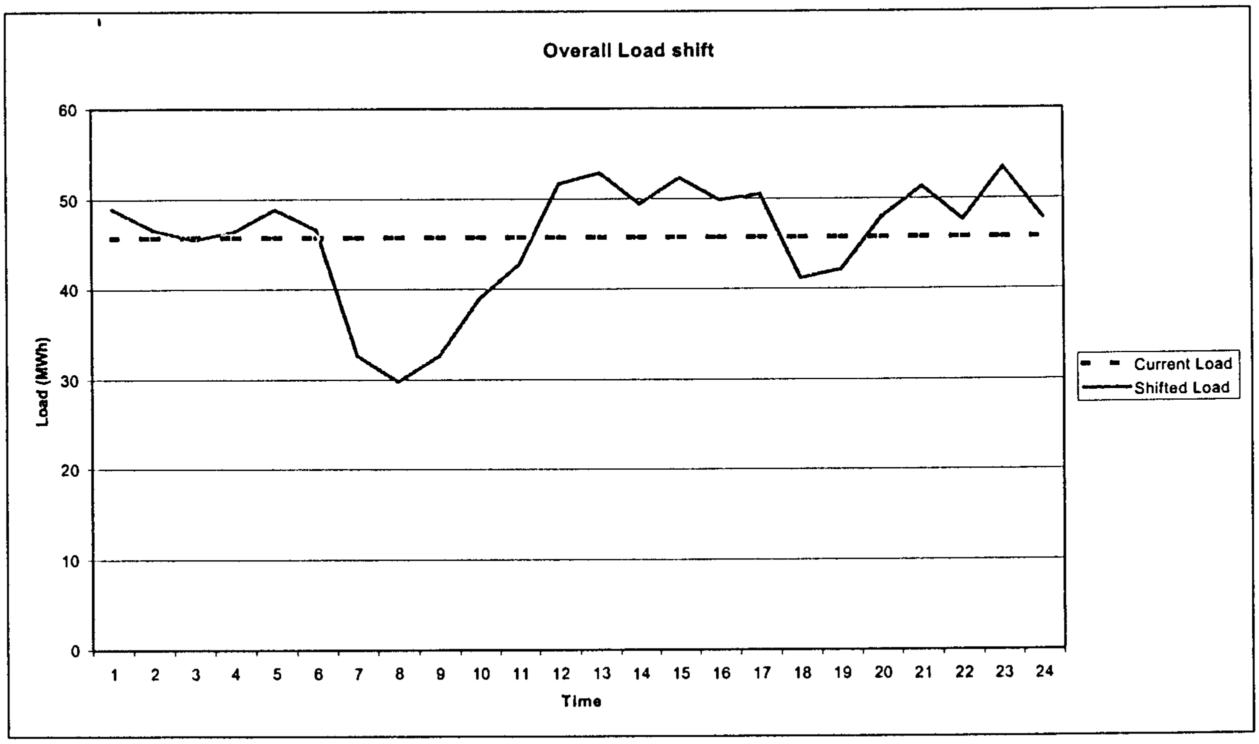


Figure 5-5: The overall load shift impact

In 1997 the energy consumption of the mining industry in South Africa was 109,405.23 TJ per year or an average consumption of 3,47 GWh [1]. In 1999 the energy consumption of the mining industry in South Africa was 114 325.2 TJ or 31.757 TWh per year at an average consumption of 3.63 GWh. This constitutes 18.4% of the country's total energy consumption for 1999 [2]. PDWAJV, with its average consumption of 45,7 MWh, accounts for 1,2 % of the consumption in South Africa.

If all the rest of the mines were able to shift their load in the same way and the same percentage of the energy is used by the cooling cycle, 1.35 GWh could be shifted for a period of time. This energy could then be used in different sectors where load shifting is not so readily possible. More realistically would be that the rest of the mines in South Africa could only shift half the percentage load that PDWAJV could shift. This would correspond to a shift of 676 MWh for a certain period of time.

5.5 Conclusions and recommendations for future work

The mining industry is a big consumer of ESKOM's electricity sales. It is therefore important that the mining industry and ESKOM work together to find ways to optimise the consumption of energy on a national level. One such way is to use ESKOM's pricing structures, available for mines, discussed in Chapter 1. All of these structures work best if the mine has the ability to shift some of its load during a specific part of the day (MegaFlex and NightSave) or according to a specific price for a specific time (Real Time Pricing).

The main purpose of this study was to investigate the potential load shift in the Ventilation and Cooling cycle on a mine and then give an estimate for the national potential. This could only be done using dynamic simulations, to investigate the effect of various load shift options. Such software is not available in the mining industry. In this study an attempt was made to use such software from the building industry. With great effort some of the useful results were produced.

These results were verified using measured data. Chapter 3 discusses the verification procedure and it shows the results for the mine used. PDWAJV, or South Deep of late, was an ideal gold mine for it had a very typical VC system and a well installed measuring and controlling system.

The only way to achieve the goal of load shifting was to use automated control, as the current system is predominantly manual. Manual overrides would need to be included. Chapter 4 showed the control strategies, current and new, to achieve the goal of load shifting.

The final step is to use the simulations to determine the potential load shift in the mine's VC system and then the overall load shift on the mine. Because of the depth of the mine, the underground pumping stations use almost a third of the energy used in the entire system. Along with the load shift of the cooling plant a total shift of 19MWh was achieved for a period of five hours with an increase of 4,5 MWh on the peak demand over a 24-hour period.

If this could be replicated on all the mines in South Africa, a total load shift of 1,35 GWh could be achieved. But not all mines are that deep and therefore the influence of the cooling cycle might not be so great. If only half the potential load could be shifted it could still cause a load shift of 676 MWh for the South African network for a potential period of five hours.

It can be clearly seen that there is a great potential for load shifting in the South African mining sector. This can be well used in the strategic planning of mines concerning their pricing structures. ESKOM can further use it to plan their possible implementation of their pricing structures and possible new strategies.

For this study only one mine was used and from the results obtained from this one mine a figure for the national potential for shifting load was extrapolated. To obtain a more accurate figure more mines need to be studied, including most of the various mining types in South Africa.

To be able to achieve this goal, the simulation software needs to be fully adapted for mining applications. The current study was done by using QUICKcontrol* in conjunction with new models. It was however very difficult to implement the new models and the physical use of the software was very hard and time consuming. The software was very unstable during the investigation.

QUICKcontrol is therefore not suited for mine applications, and a new tool with a different simulation engine and platform will have to be developed. This will be necessary for fast, efficient and accurate simulations.

5.6 References

[1] DME, Energy balances, http://www.dme.gov.za/energy/, Energy balance for 1997. Contact details: Tel: +27 12 317 9000, Private Bag X59, PRETORIA, 0001.

[2] Boeije W, Senior Manager IRP, National Electricity Regulator (NER), Contact Details: Tel: +27 11 884 0118, National Electricity Regulator, PO Box 785080, Sandton, 2146, South Africa.

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* Software developed by TEMM International (Pty) Ltd and used with special permission

APPENDIX A

EQUIPMENT SPECIFICATIONS

This section displays the equipment specifications for the equipment used in the mines ventilation and cooling system. There are also more graphical representations of the VC system.

Appendix A – Equipment specifications

1. SURFACE EQUIPMENT

A more detailed look at the pre-cool towers and the surface cooling plant can be seen in Figure A-1 and Figure A-2. Scheme A is shown in Figure A-2.

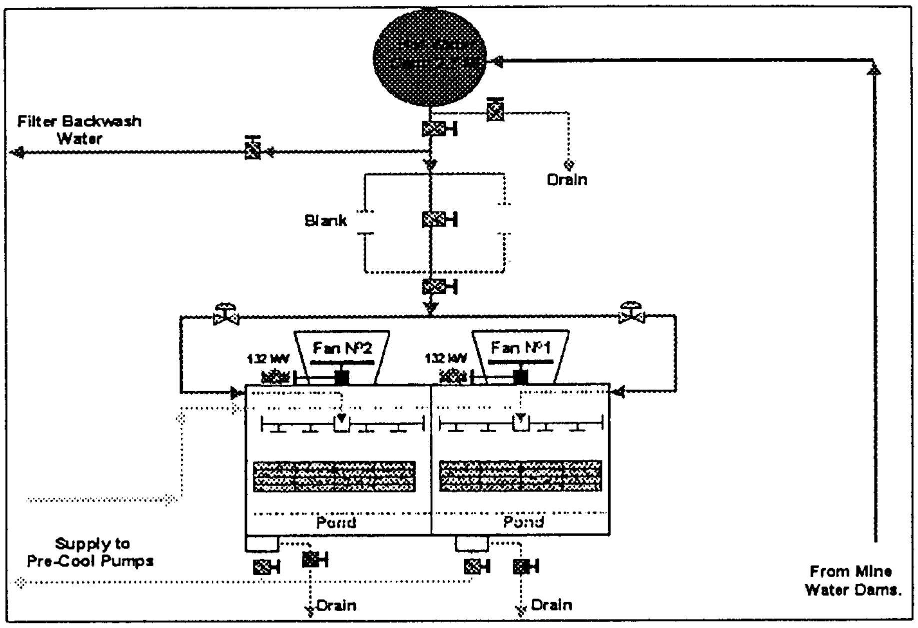

Figure A-1: Pre-cooling tower configuration

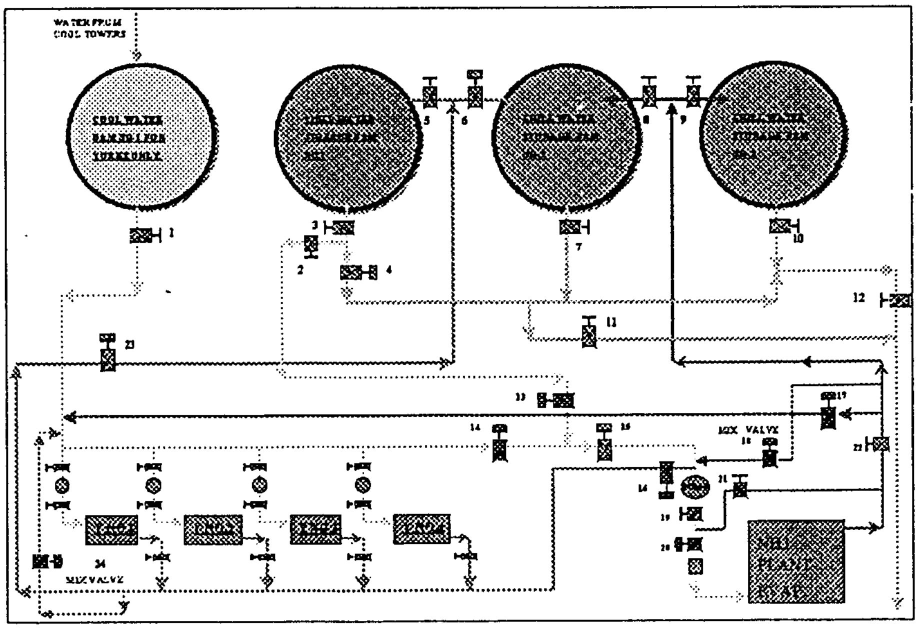

Figure A-2: Surface cooling plant

Appendix A – Equipment specifications

A.1 Dams

Dam	Purpose	Volume [m^3]	Open/ Closed	Controlled by
Mine Water	Collect water from mine	3817.7	Open	-
Hot Water	Hot water pumped from Mine water dam	2709	Open	Level
Pre-Cool	Collect water from Pre-cool Towers	318.1	Open	Level
Cool Water	Store water after Pre-cool Towers	2709	Closed	Level
Chill 1	Store water after York chillers	2709	Closed	Level
Chill 2	Store water after York or Howden chillers	2709	Closed	Level
Chill 3	Store water after Howden chiller	2709	Closed	Level

Table A-1: Summary of dam

A.2 Pumps

Table A-2 presents a summary of the pumps used in the surface cooling cycle. The various pump curves are shown in the following pages.

Pump description	Pump (Type)	Impeller diameter (m)	Flow [l/s]	Power [kw]	Cotrolled by:
Mine Water	KSB ETA 250/50	0.41	300	200	Hot dam level
Filter pumps - A	Sulzer AZS 200/250	0.25	75	15	Cool dam Level
Filter pumps - B	Allis-Chalmer	0.3	120	30	Cool dam Level
York Evaporator	Salweir SDB 200/250	0.32	114	55	Chill 1 dam Level
York Condensor	Salweir SDB 10/12	0.36	280	132	Chill 1 dam Level
Howden Evap	Salweir SDB 350/450	0.415	420	160	Chill 2&3 dam Level
Howden Cond	Salweir SDB 350/450	0.475	420	185	Chill 2&3 dam Level

Table A-2: Summary of pump specifications

A.3 Cooling towers

There are basically two sets of cooling towers. Firstly is the Pre-cooling tower used to cool the water from the Hot water dam. Secondly, there are the cooling towers on the condenser sides of the chillers. The two types are almost the same, therefore only one tower, the Pre-cooling tower, will be discussed. Table A-3 shows all the data of the Pre-cooling tower.

Performance Data	
Inlet Water Temp. (°C)	28
Outlet Water Temp. (°C)	18.5
Inlet WB Air Temp. (°C)	16
Outlet WB Air Temp. (°C)	23.3
Pressure (kPa)	85
Losses (%)	1.63
Water Flow (m^3/h)	1728
Per Cell (m^3/h)	864
Air flow/cell (m^3/s)	525.8
Static Pressure drop (Pa)	136.8
Heat Exchanged (MW)	19.06

Fan Details	
Diameter (m)	7.315
RPM	161
Number of blades	6
Pitch of blades (°)	16.3
Manufacturer	Howden
Type	ENF

Motor Details	
Power per motor (kW)	132
RPM	1480
Absorbed power (kW)	117.4
Manufacturer	ZEST/WEG

Construction Details	
Number of cells	2
Total Plot area (m^2)	14.85x28.75
Fill Area (m^2)	14.34x14
Induced draught	
Air opening (m^2)	80
Pitch of fill (m)	0.25
Fill Depth (m)	3.25
Height to bottom of fill (m)	3

Table A-3: Specifications for Pre-cooling Tower

A.4 Chillers

The specifications for the York chillers are shown in Table A-4 and for the Howden in Table A-5.

Design Details

Voltage (V)	11000
Amps (A)	85.5
Bearing Temp. - DE (°C)	60
Bearing Temp. - NDE (°C)	60
Stator Temperature - Phase1	100
Stator Temperature - Phase2	100
Stator Temperature - Phase3	100
Barometric Pressure (kPa)	84
% Vane opening	100
Oil Level	Halftop
Oil Temp. (°C)	60
Oil Press. (kPa)	450
Differantial oil Press. (kPa)	210
Suction Temp. (°C)	2
Suction Press. - Gauge (kPa)	240
Suction Press. - Absolute (kPa)	324
Corresponding Temp. (°C)	1.62
Suction Superheat (°C)	0.4
Discharge Temp. (°C)	50.5
Condenser Press.-Gauge (kPa)	670
Condenser Press.-Absolute(kPa)	754
Corresponding Temp. (°C)	30.52
Discharge superheat (°C)	20.5
High Pressure Liquid Temp. (°C)	30
Degrees system Air	0.5

Chilled water inlet Temp. (°C)	14.5
Chilled water outlet Temp. (°C)	4
Chilled water Delta T (°C)	10.5
Chilled water flow (l/s)	114
Evaporator duty (kW)	5012
Condenser water outlet Temp.(°C)	27.5
Condenser water inlet Temp. (°C)	22
Condenser water Delta T (°C)	5.5
Condenser water flow (l/s)	270
Condenser duty (kW)	6217
Compressor shaft power (kW)	1264
Coeffiesient of performance	3.96
Carnot COP	9.5
Cycle efficiency (%)	41.71
Power to cooling Ratio	0.25
LMTD Condenser	4.73
LMTD Evaporator	6.21

Table A-4: Specifications for York Chillers

Appendix A – Equipment specifications

Design Details - Normal running

Voltage (V)	11000	Evap. Ammonia Inlet Temp. (°C)	1
Amps (A)	160	Evap. Ammonia Outlet Temp. (°C)	10
Bearing Temp. - DE (°C)	45	Evap. Water Inlet Temp. (°C)	11
Bearing Temp. - NDE (°C)	34	Evap. Water Outlet Temp. (°C)	5
Stator Temperature - Phase1	59	Chilled water Delta T (°C)	5.5
Stator Temperature - Phase2	63	Chilled water flow (l/s)	420
Stator Temperature - Phase3	60	Evaporator duty (kW)	8300
Barometric Pressure (kPa)	84	Cond. Ammonia Inlet Temp. (°C)	40
% Vane opening	100	Cond.Ammonia Outlet Temp.(°C)	28
Oil Level	Halftop	Cond. water outlet Temp.(°C)	30
Oil Temp. in Seperator (°C)	40	Cond. water inlet Temp. (°C)	21
Oil Temp. in Manifold (°C)	40	Cond. water Delta T (°C)	9
Oil Filter Diff. Press. (kPa)	10	Cond. water flow (l/s)	350
Differantial oil Press. (kPa)	440	Cond. duty (kW)	11340
Suction Temp. (°C)	3	Compressor shaft power (kW)	1462
Surge drum Press. (kPa)	417	Coeffiesient of performance	5.7
Surge drum Level (%)	7	Carnot COP	13.434
Discharge Temp. (°C)	40-50	Cycle efficiency (%)	42.3
Discharge Press. (kPa)	1230	Power to cooling Ratio	0.1761

Table A-5: Specifications for Howden Chiller

2. UNDERGROUND EQUIPMENT

The schematic layout of the Underground Pumping Stations can be seen in Figure A-2. This shows the pumps' mass flow capacity and the dams' storage capacity.

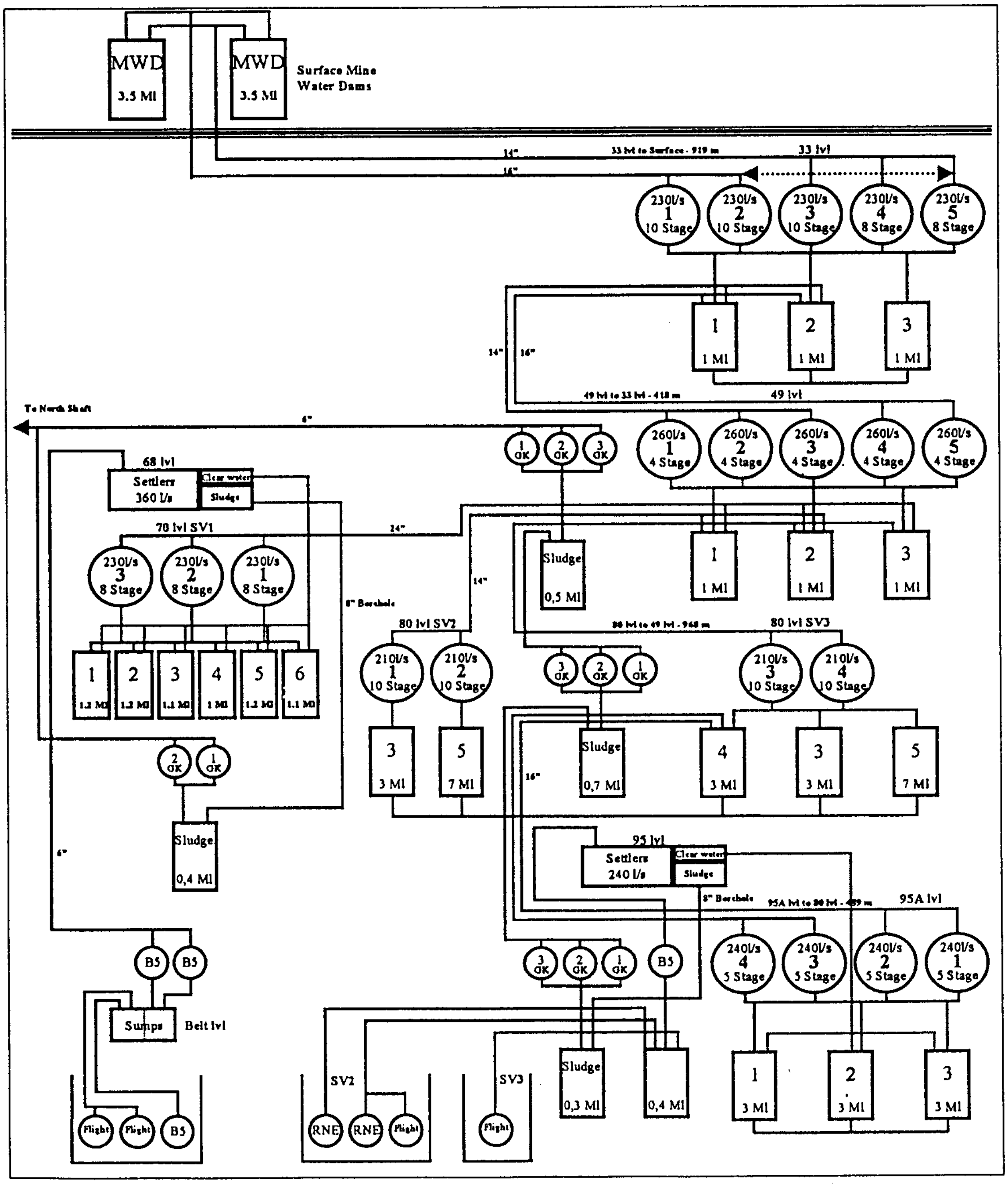

Figure A-2: Schematic layout of Underground Pumping Stations

A.5 Dams

Level	Depth [m]	Number of Dams	Total Capacity [m^3]
Surface	0	2	7000
33	919	3	3000
49	1337	3	3000
70	2000	6	6800
80	2305	5	23000
95A	2794	3	9000

Table A-6: Specifications of Underground Dams

A.6 Pumps

Level	Pumps details	Quantity	Flow [l/s]	Power [kW]	Controlled by:
33	GRIFO 10-Stage, GHP 53-29	5	230	3000	Dam level
49	GRIFO 4-Stage, GHP 58-29	5	260	1160	Dam level
70	GRIFO 8-Stage, GHP 53-29	3	230	2200	Dam level
80	GRIFO 10-Stage, GHP 53-29	4	210	3000	Dam level
95A	GRIFO 5-Stage, GHP 58-29	4	240	1600	Dam level

Table A-7: Specifications of Underground Pumps

APPENDIX B

MEASURED DATA

This section shows thew measured results of the mine's VC system over a period of time. These results were used for the verification of the simulations.

1. SURFACE PLANT

The various measured data is shown graphically in this section. These measurements are from the installed and self-measured equipment for the verification day of 20 February 2000.

B.1 Temperatures

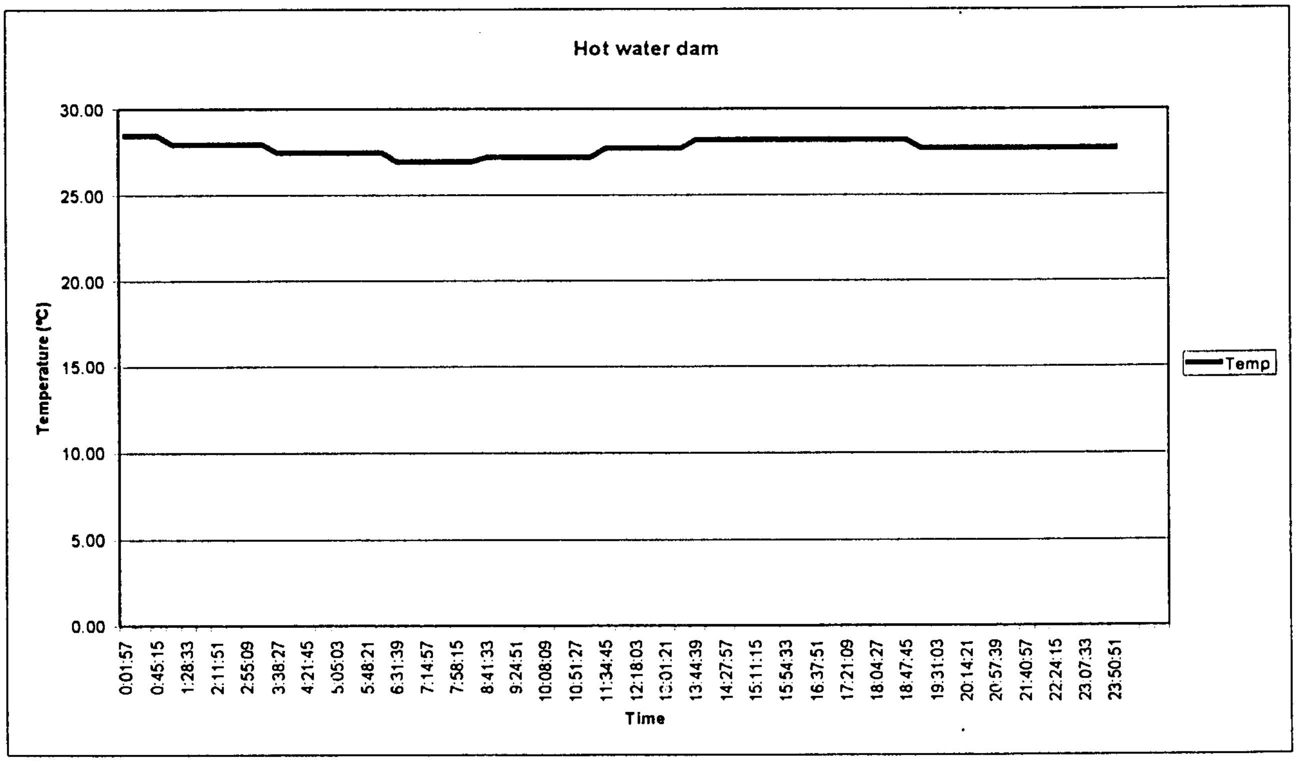

Figure B-1: Hot water dam temperature

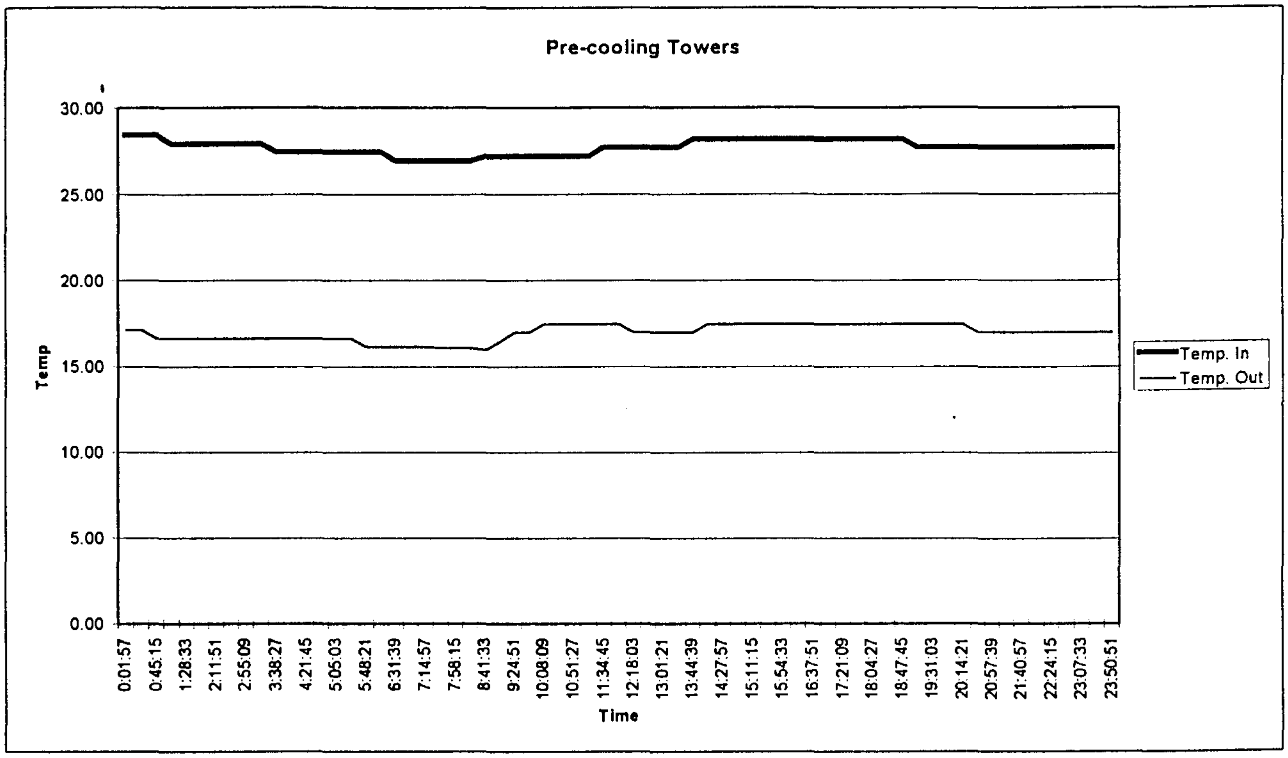

Figure B-2: Pre-cooling Towers temperature

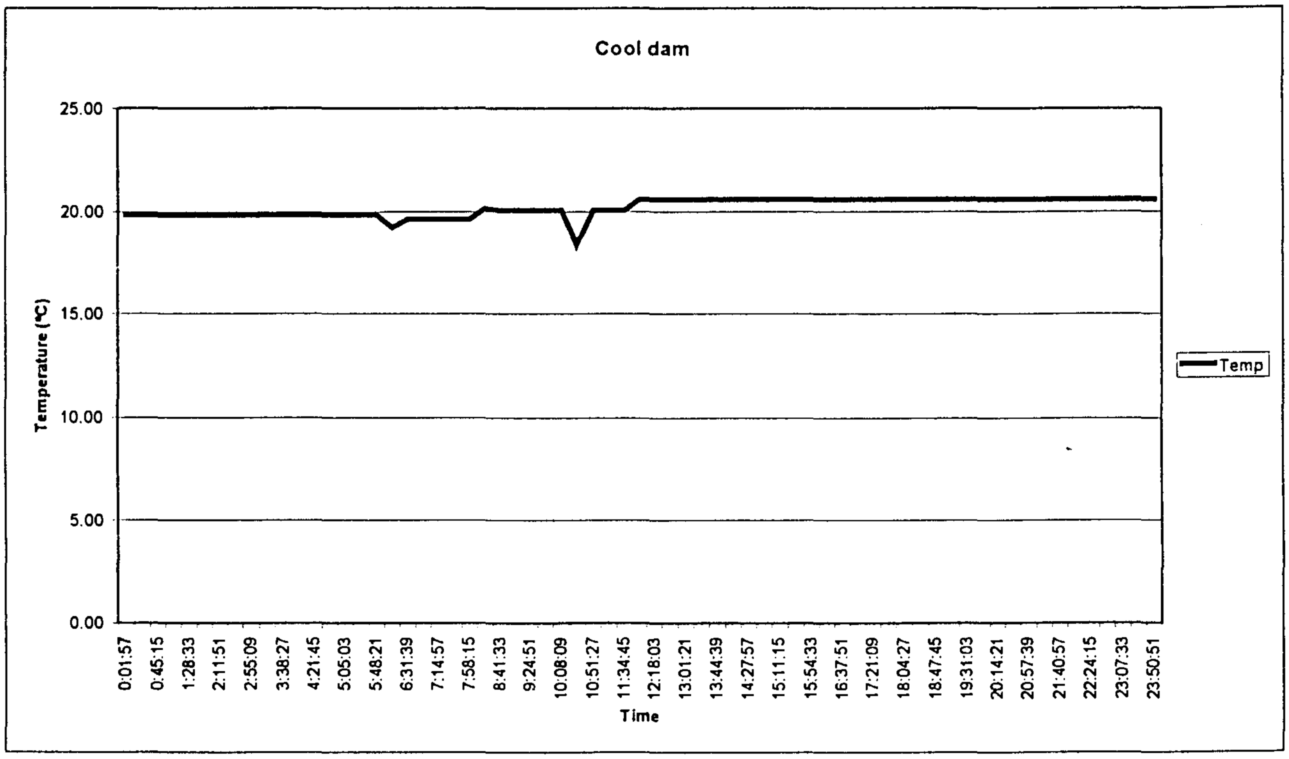

Figure B-3: Cool dam temperature

Appendix B – Measured data

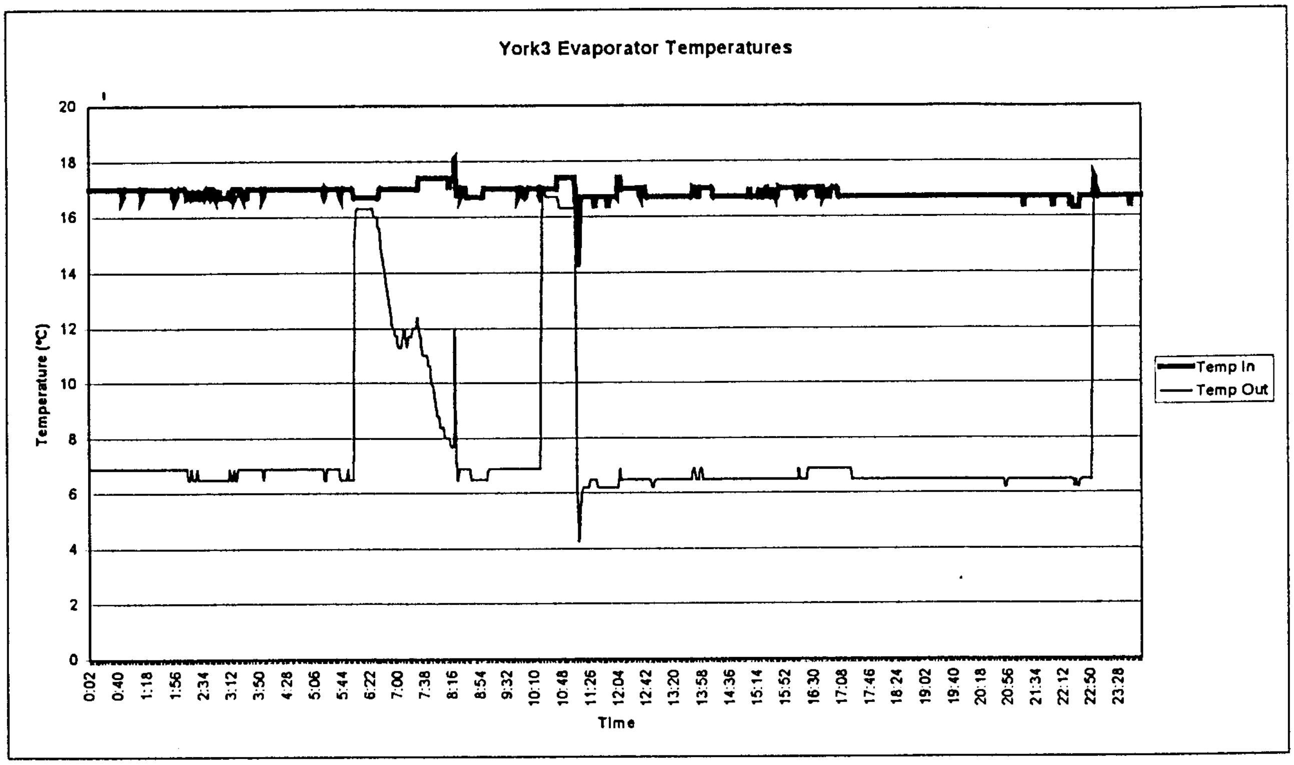

Figure B-4: York3 Evaporator Temperatures

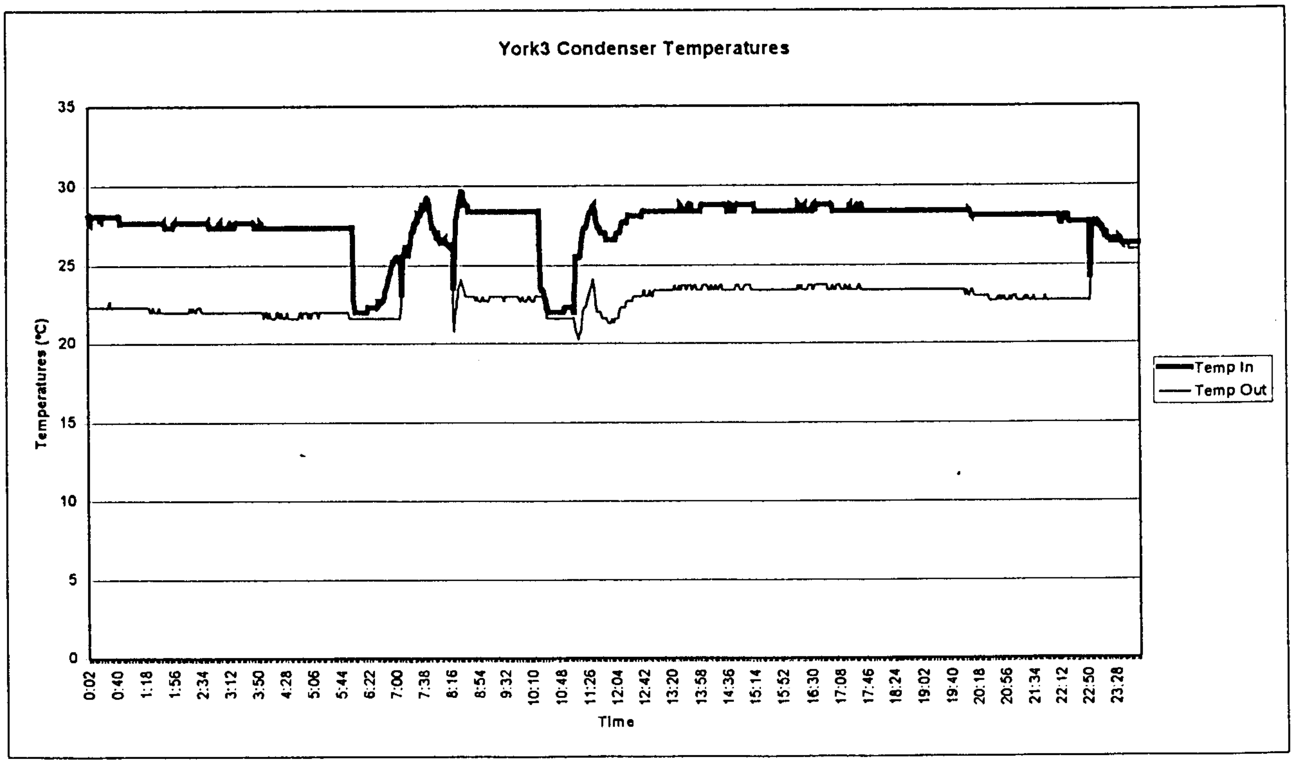

Figure B-5: York3 Condenser Temperatures

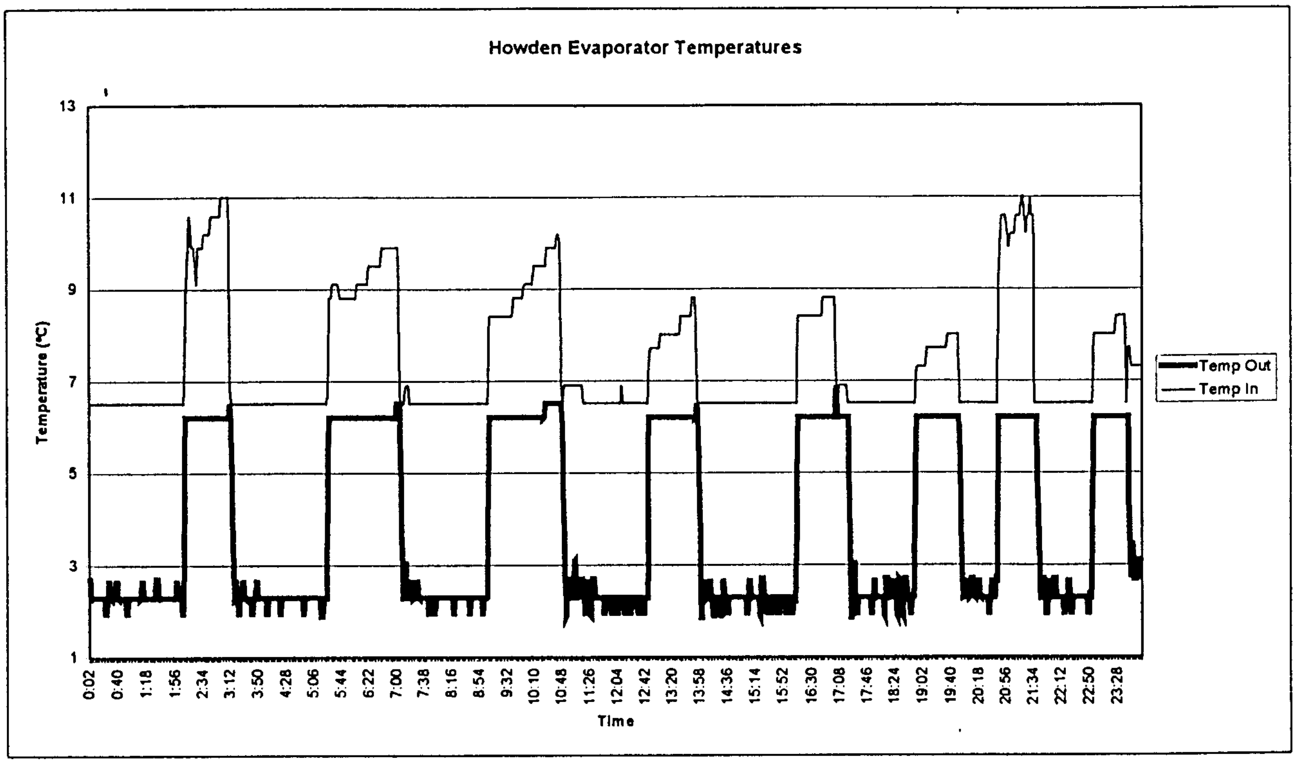

Figure B-6: Howden Evaporator Temperatures

The temperature out is the same as the temperature going down the shaft.

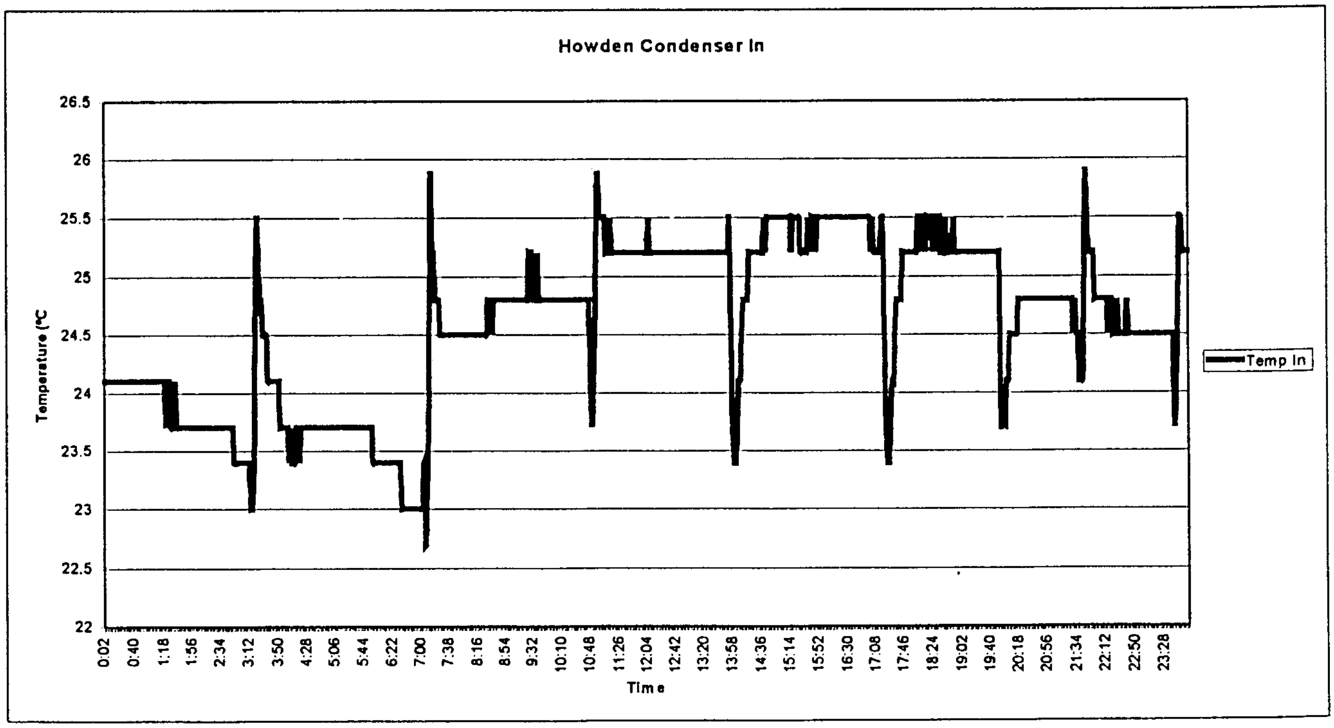

Figure B-7: Howden Condenser Temperatures

B.2 Flows

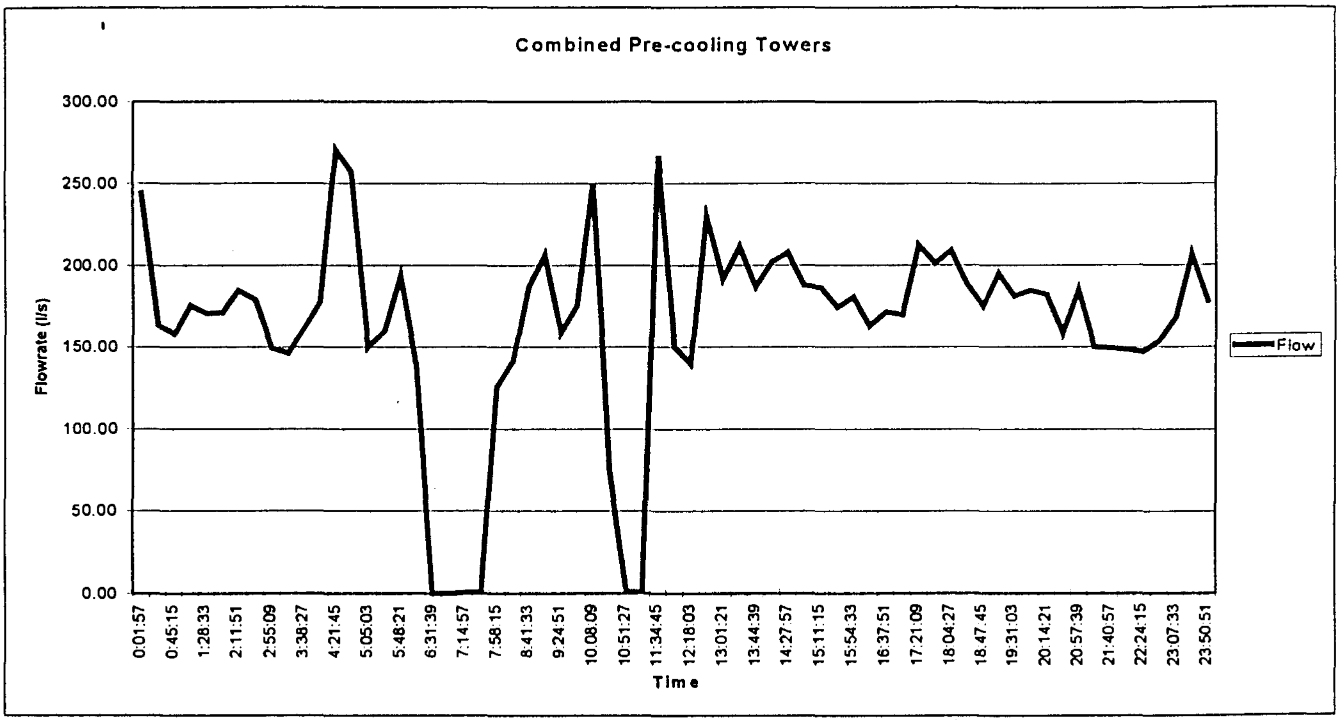

Figure B-8: Flows through Pre-cooling Towers

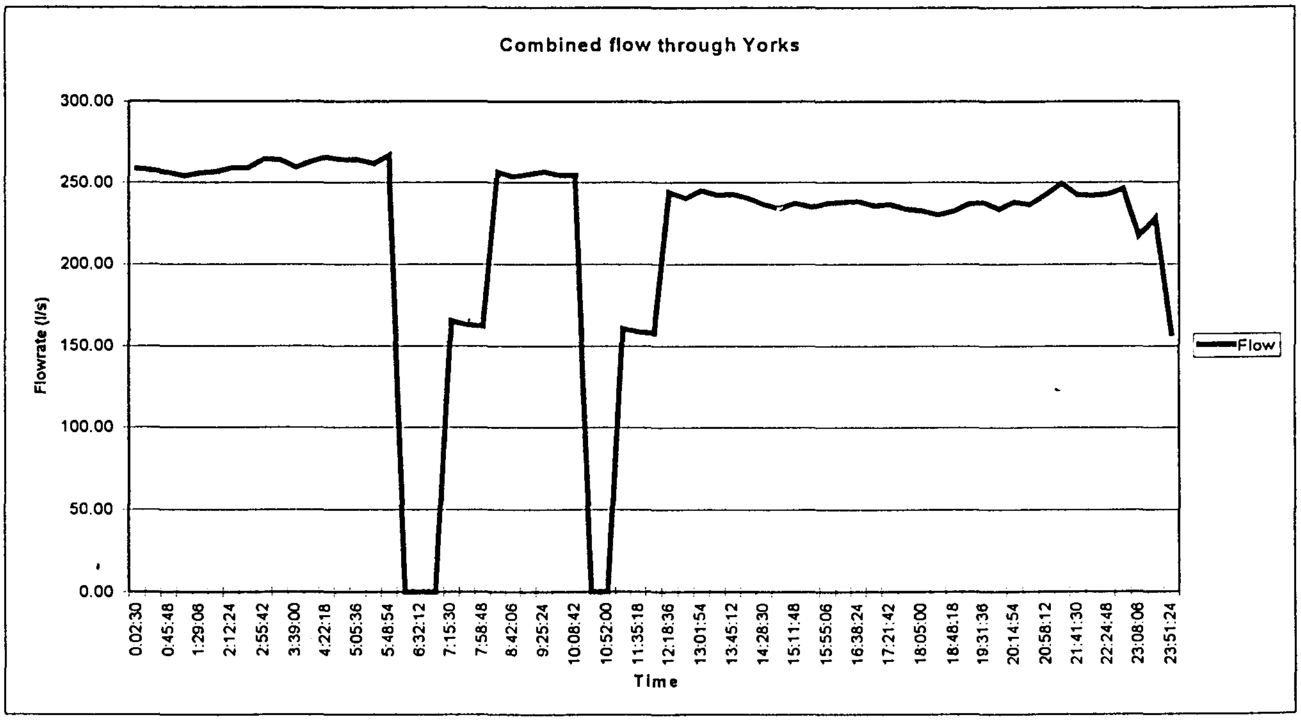

Figure B-9: Flows through York chillers

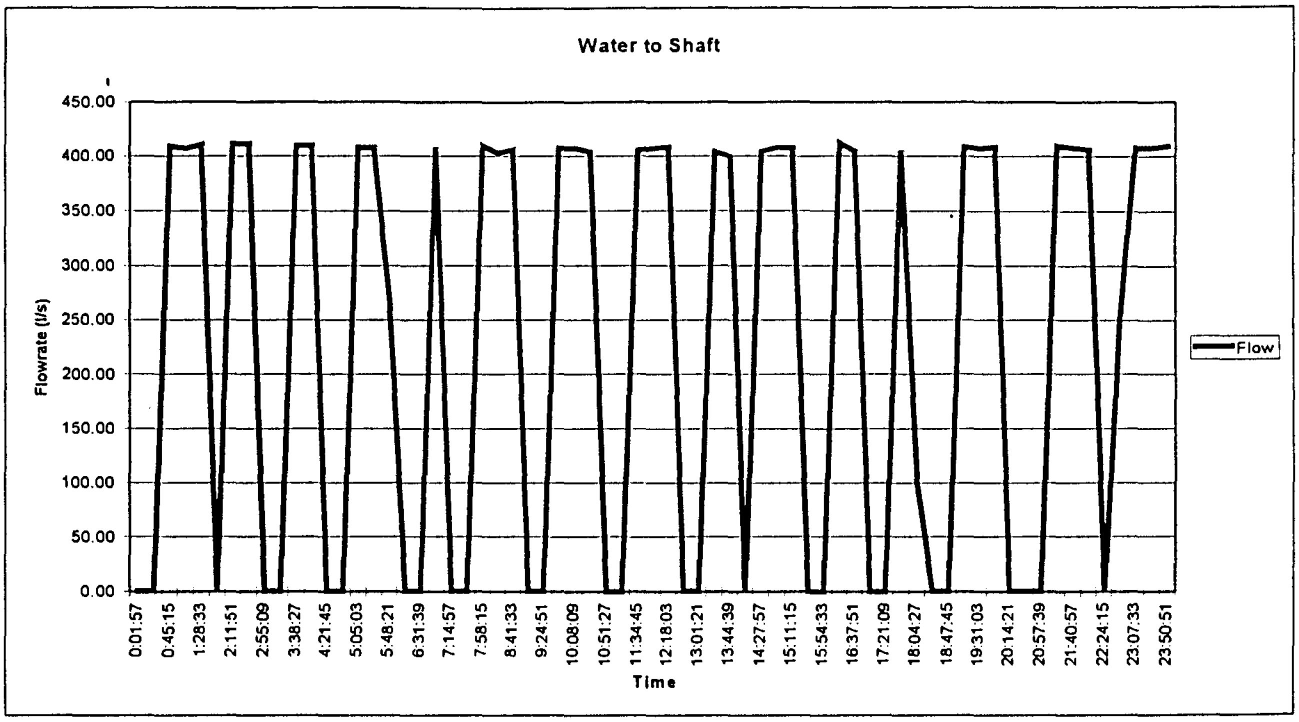

Figure B-10: Flows down shaft

B.3 Levels

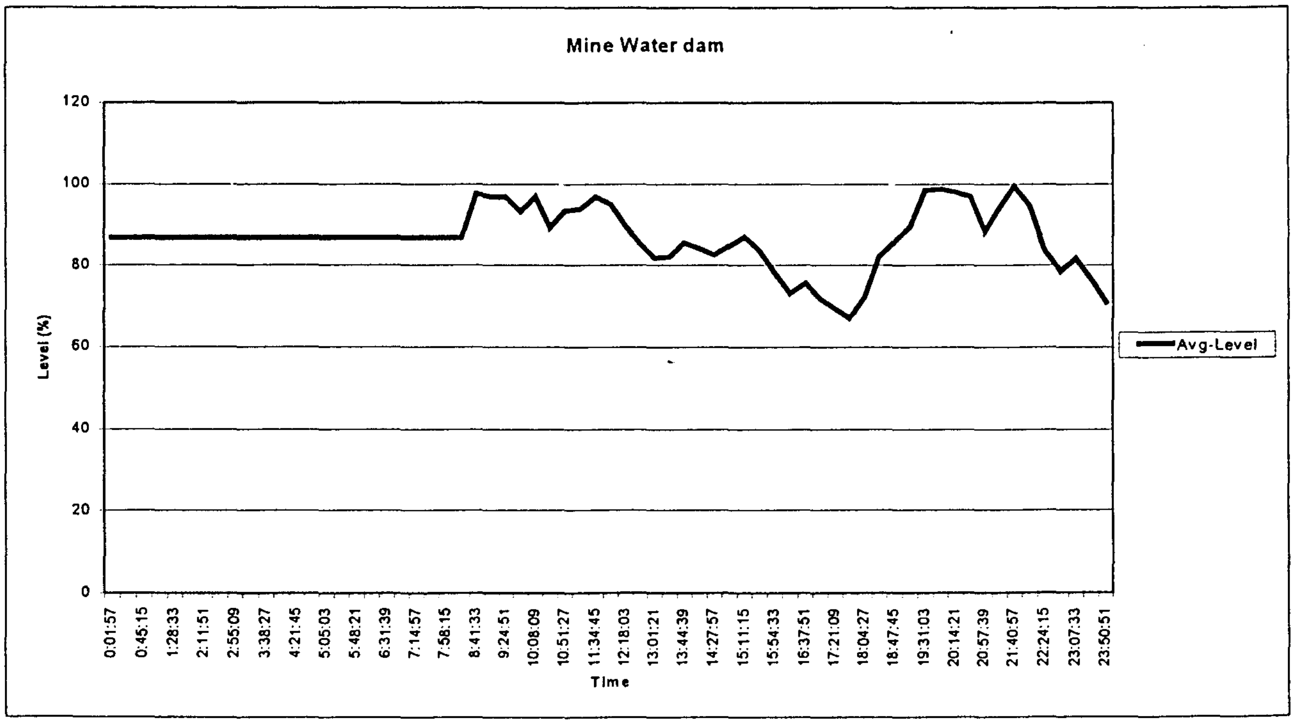

Figure B-11: Mine Water dam level

Appendix B – Measured data

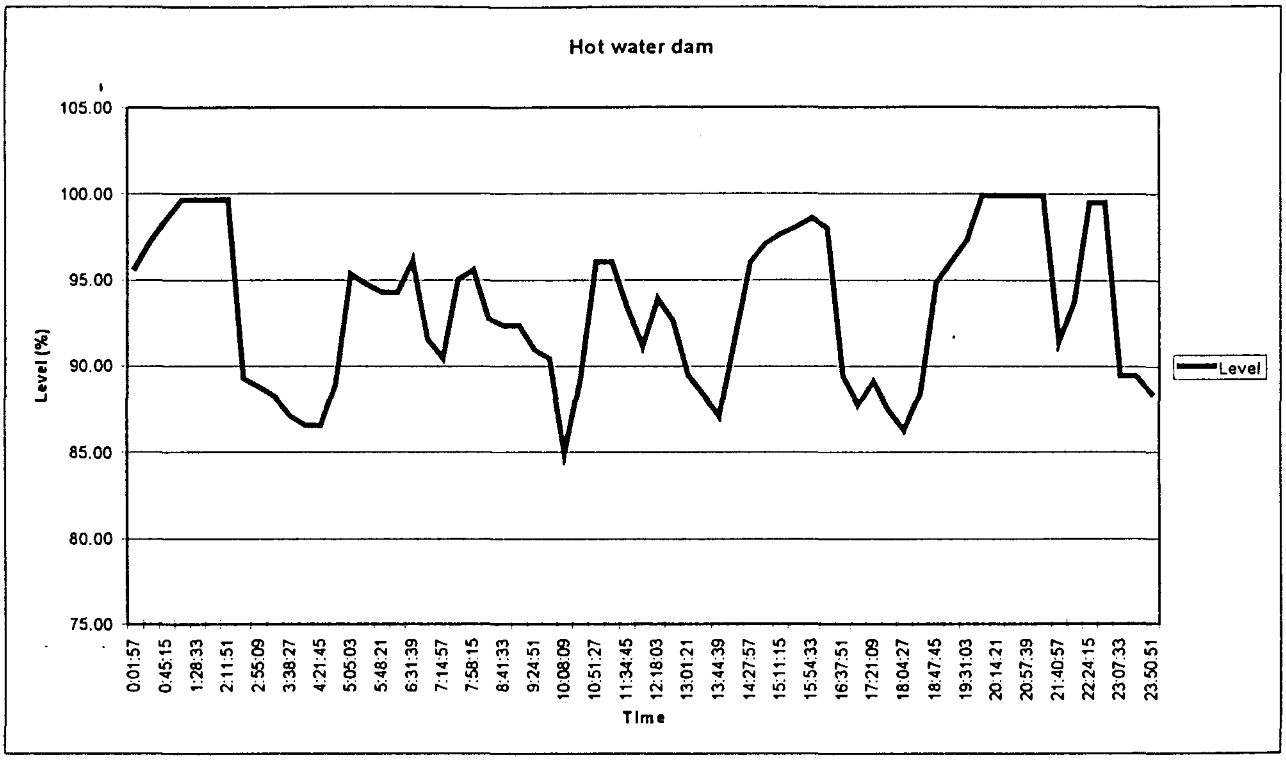

Figure B-12: Hot water dam level

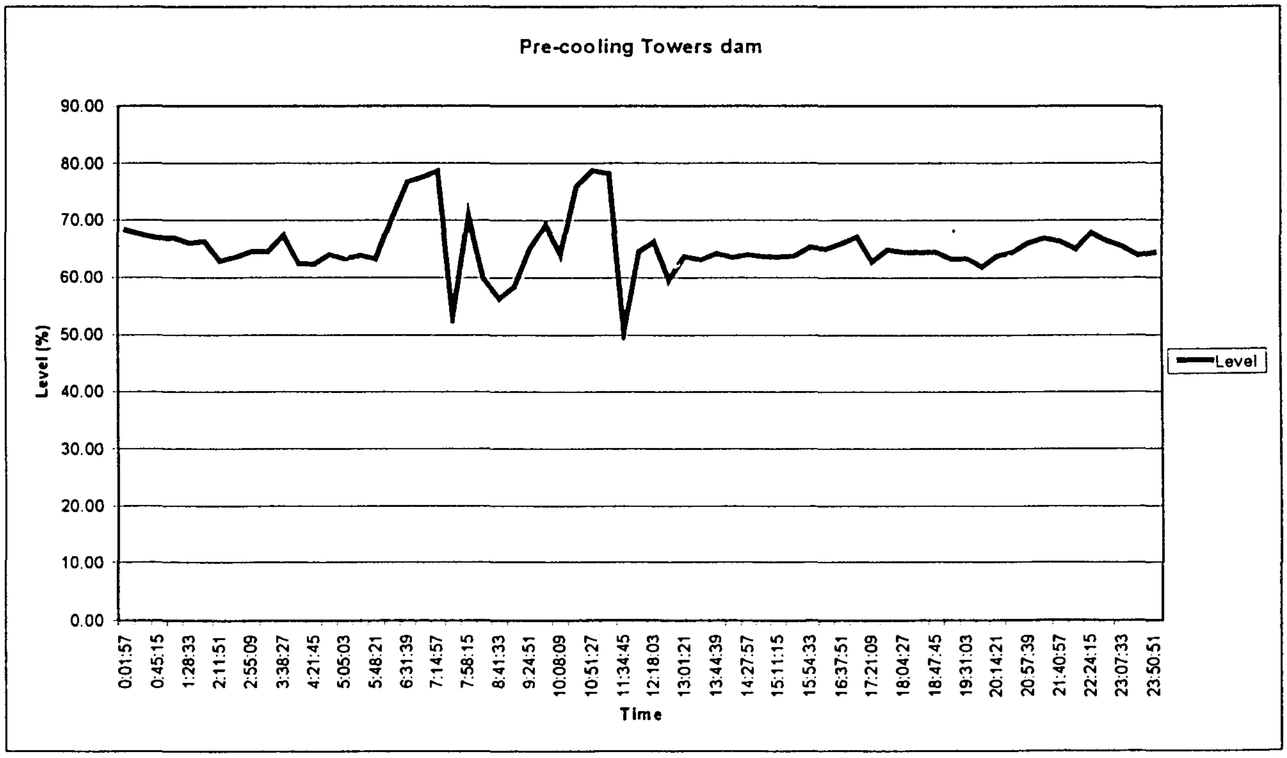

Figure B-13: Pre-cooling Towers dam level

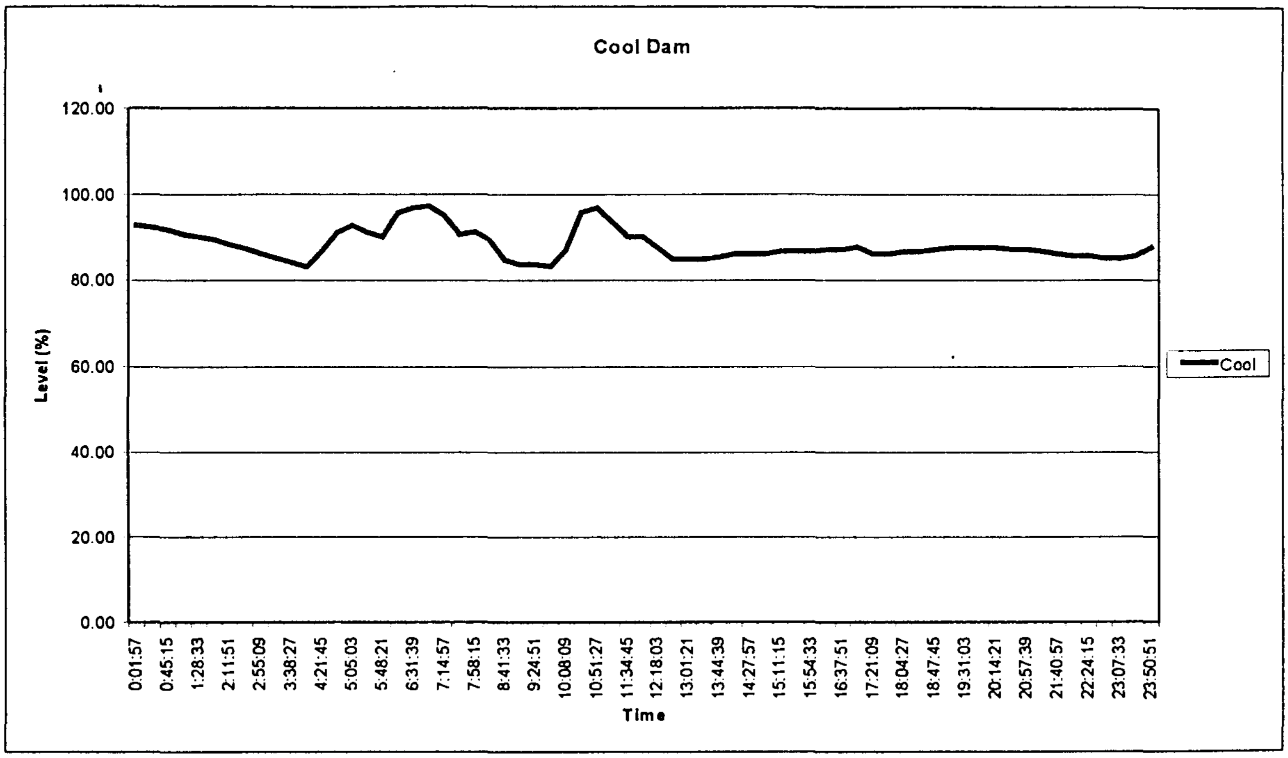

Figure B-14: Cool dam level

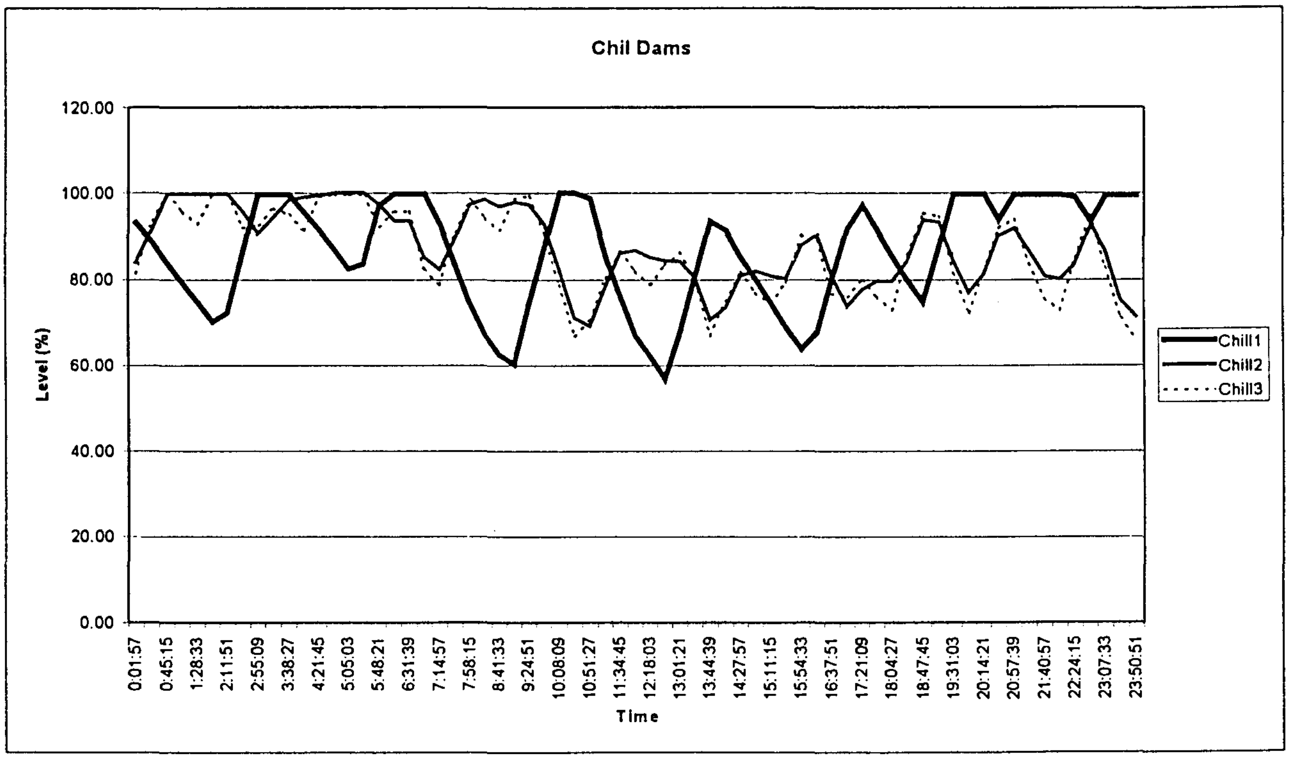

Figure B-15: Chill dam levels

B.4 Power

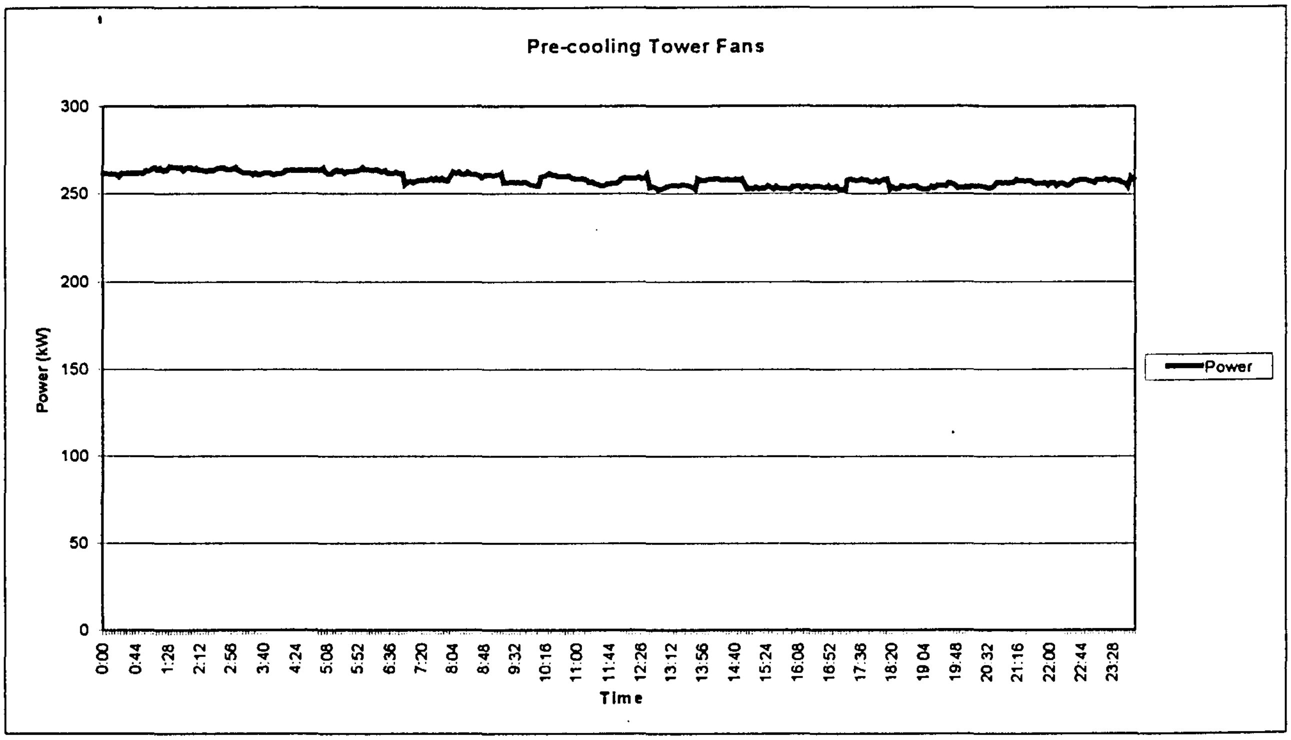

Figure B-16: Pre-cooling tower fans

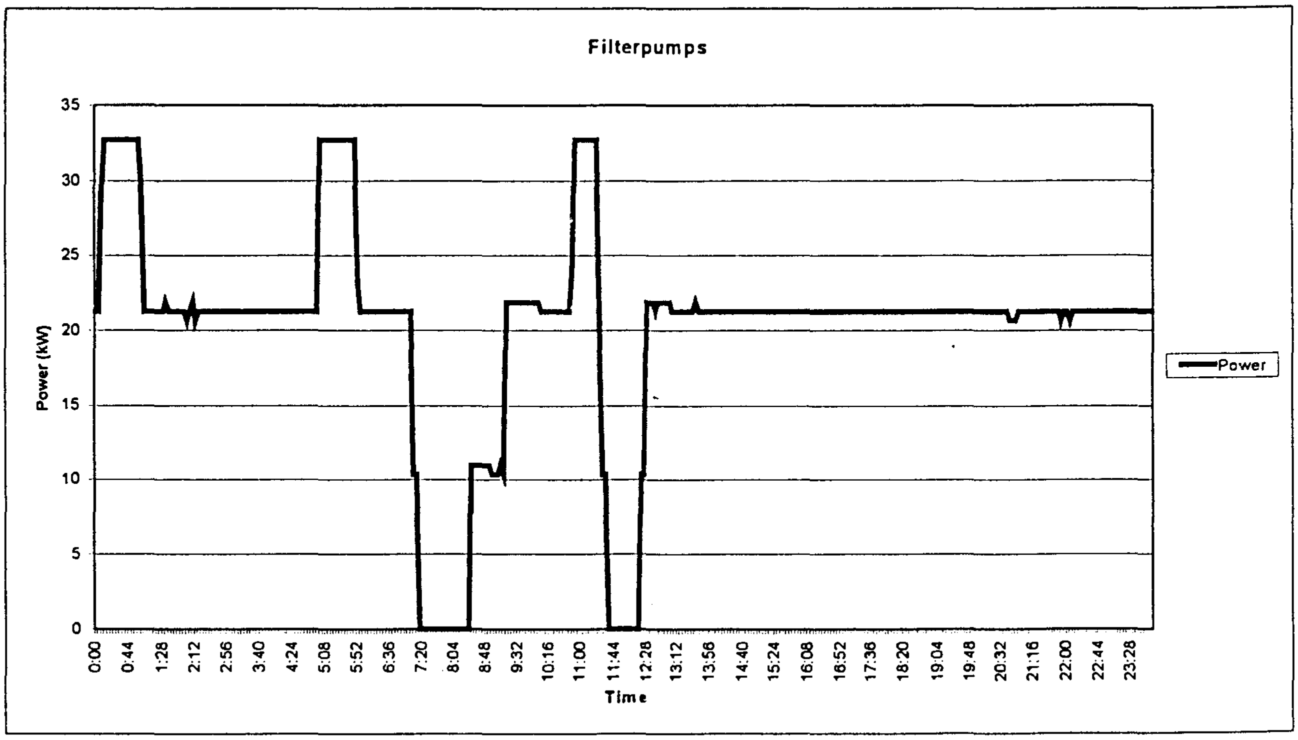

Figure B-17: Filter pumps

Appendix B – Measured data

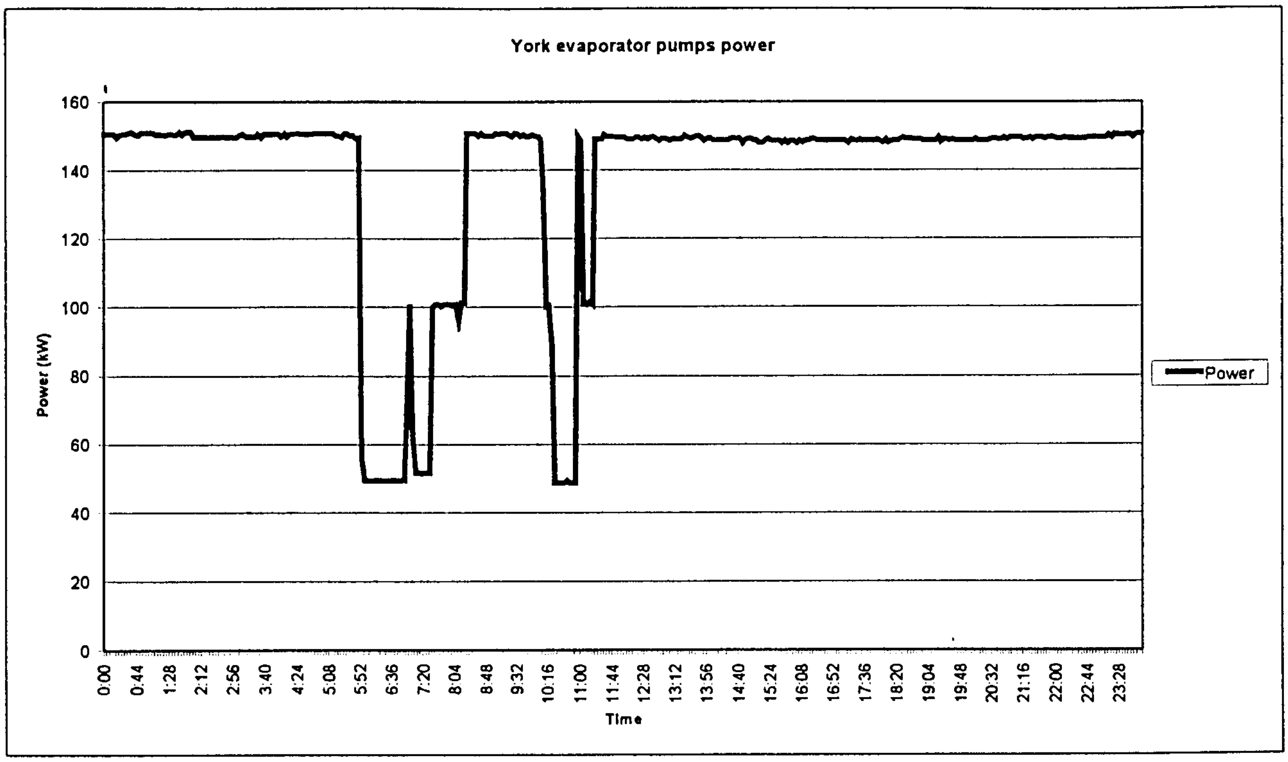

Figure B-18: Combined York Evaporator pumps

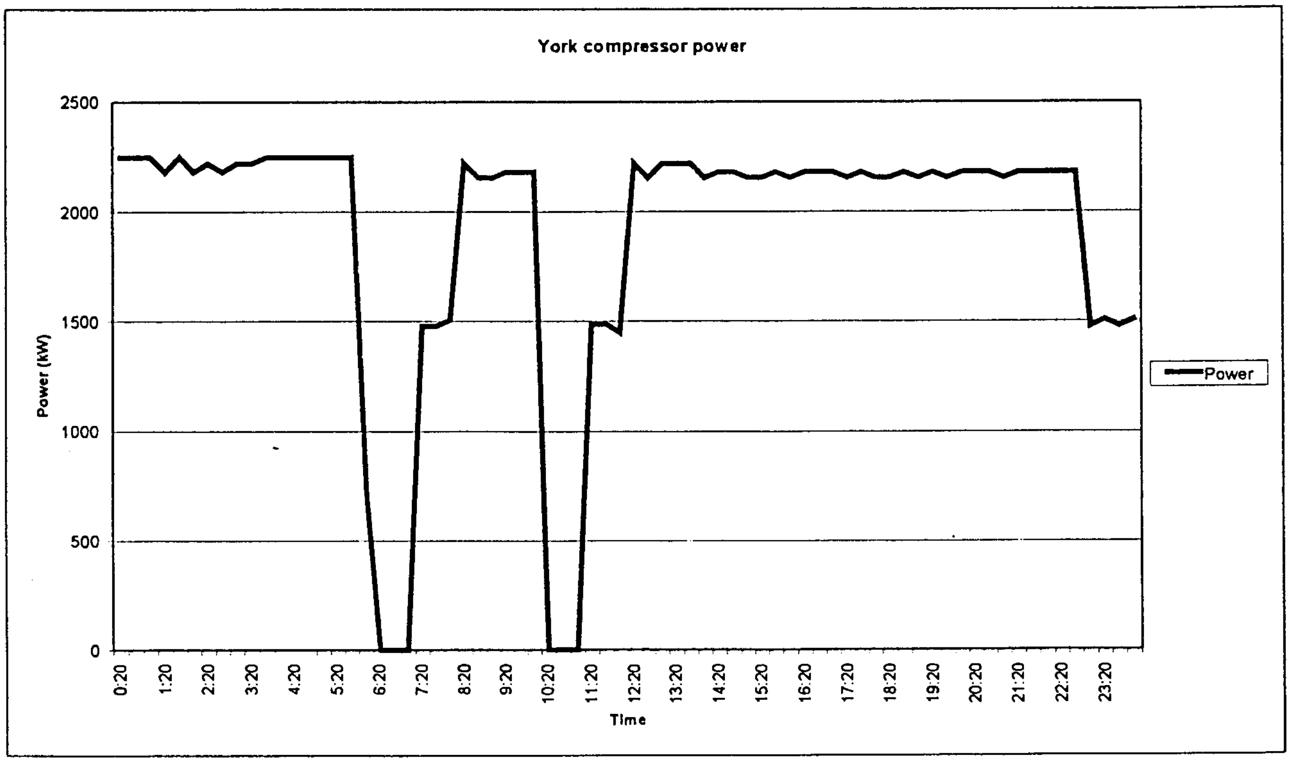

Figure B19: Combined York Compressors

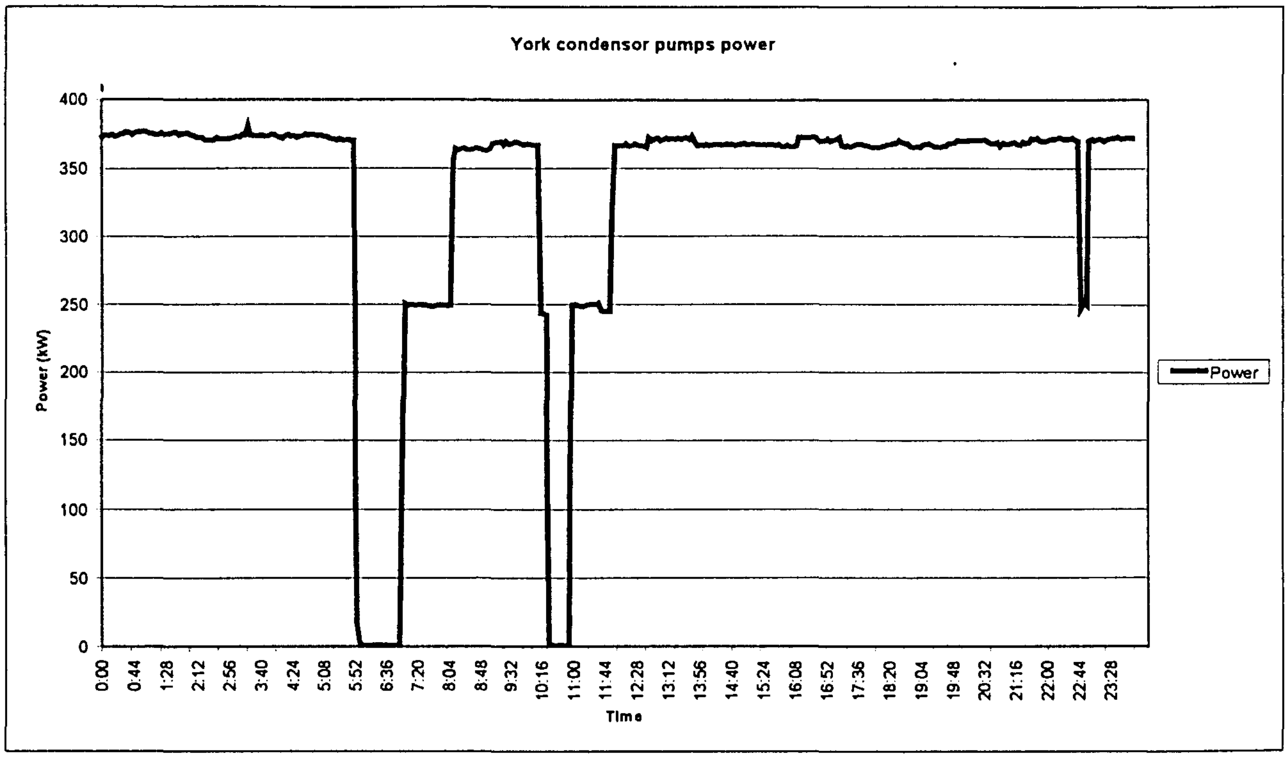

Figure B-20: Combined York Condenser pumps

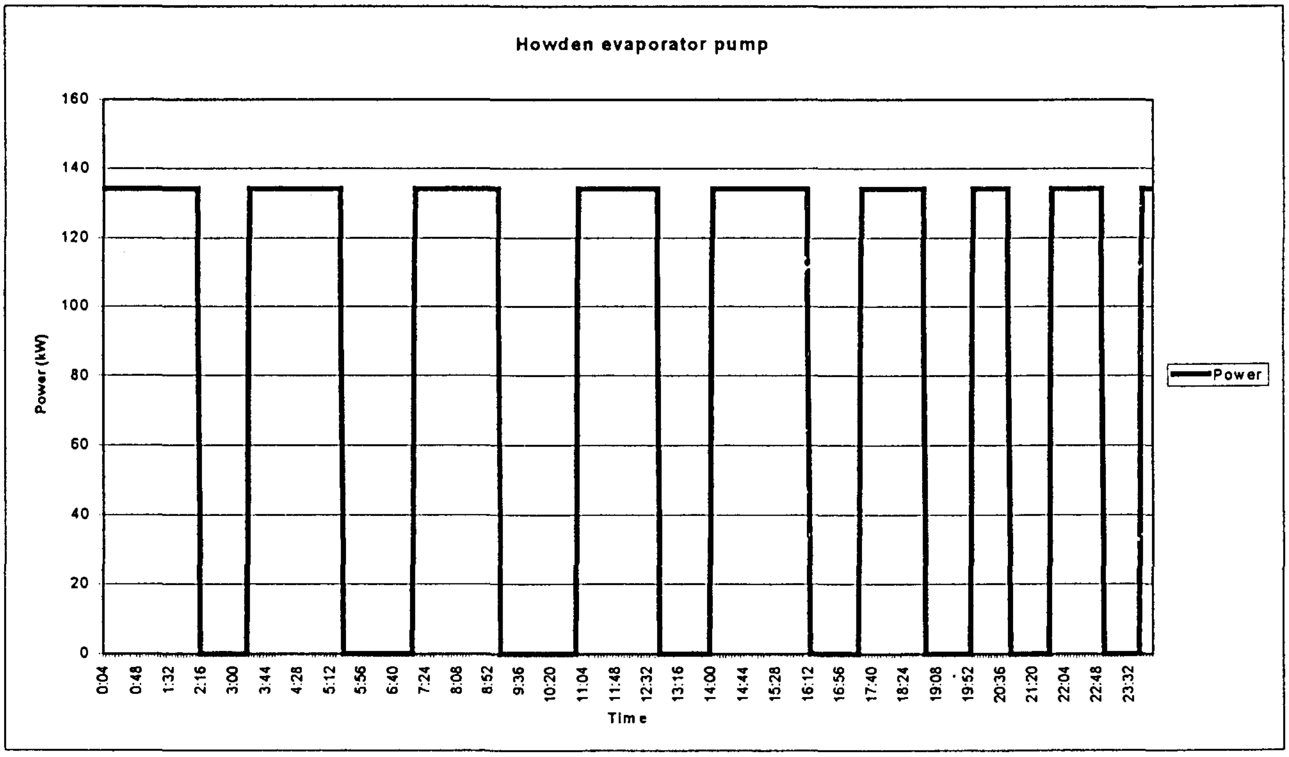

Figure B-21: Howden Evaporator pump

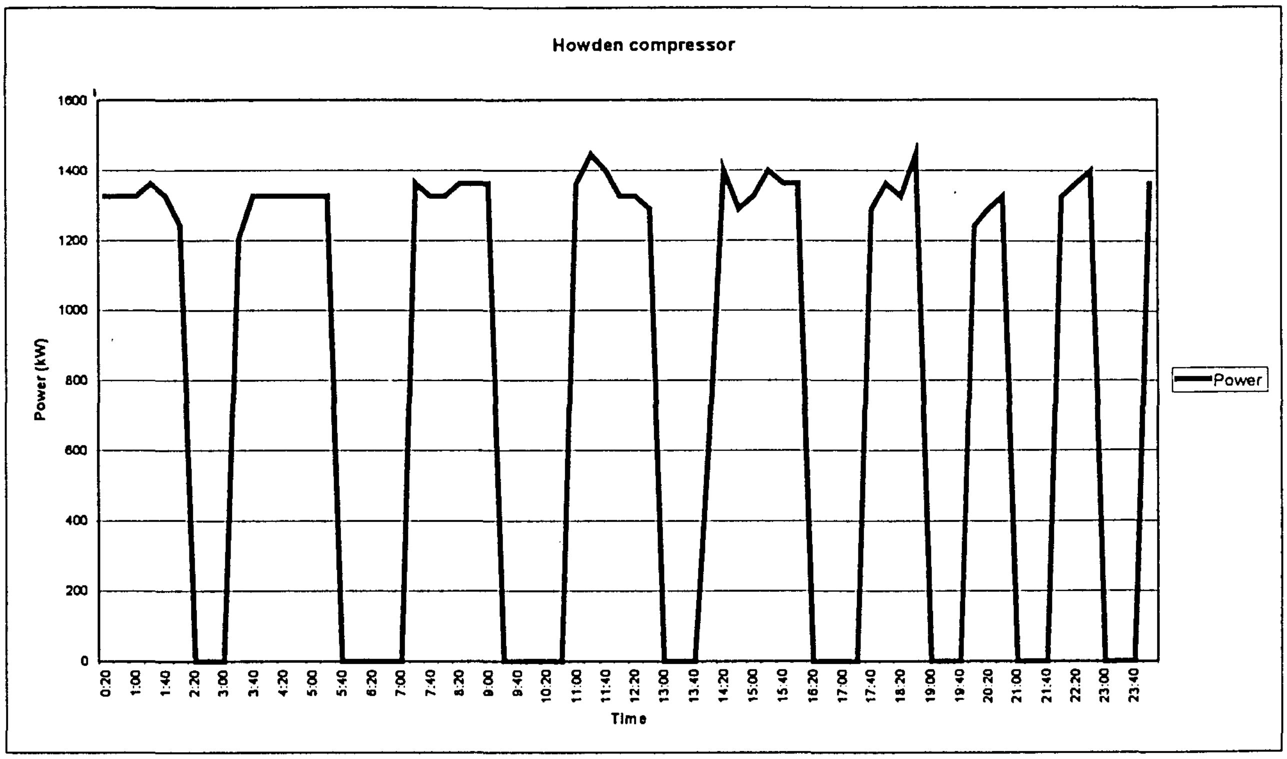

Figure B-22: Howden Compressor

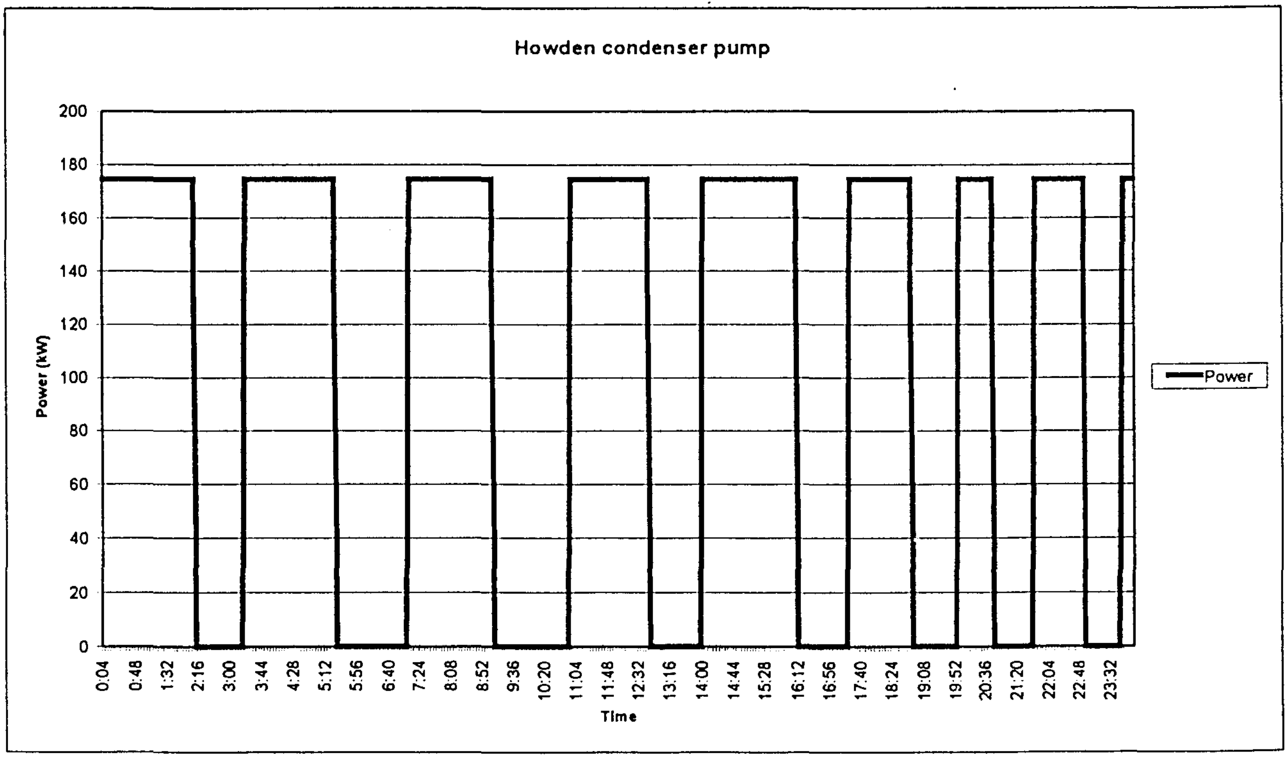

Figure B-23: Howden Condenser pump

Appendix B – Measured data

2. UNDERGROUND PUMPS

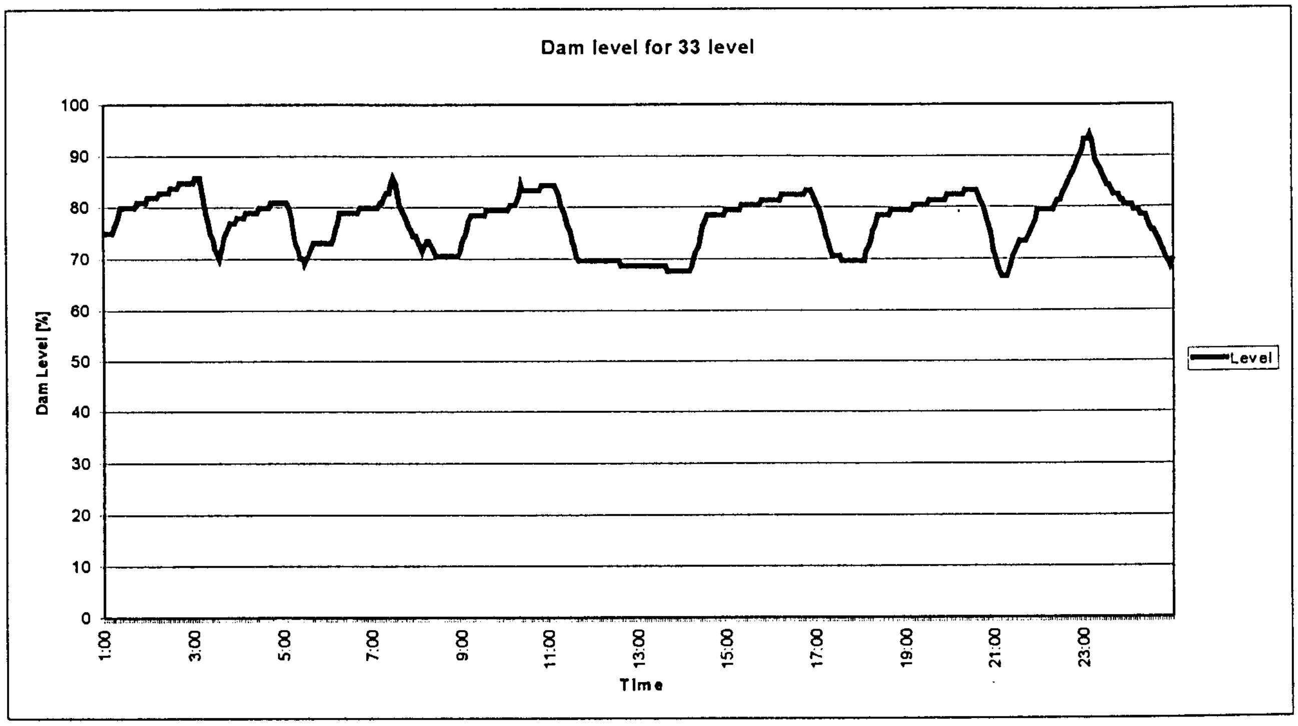

Figure B-24: Level 33 dam level

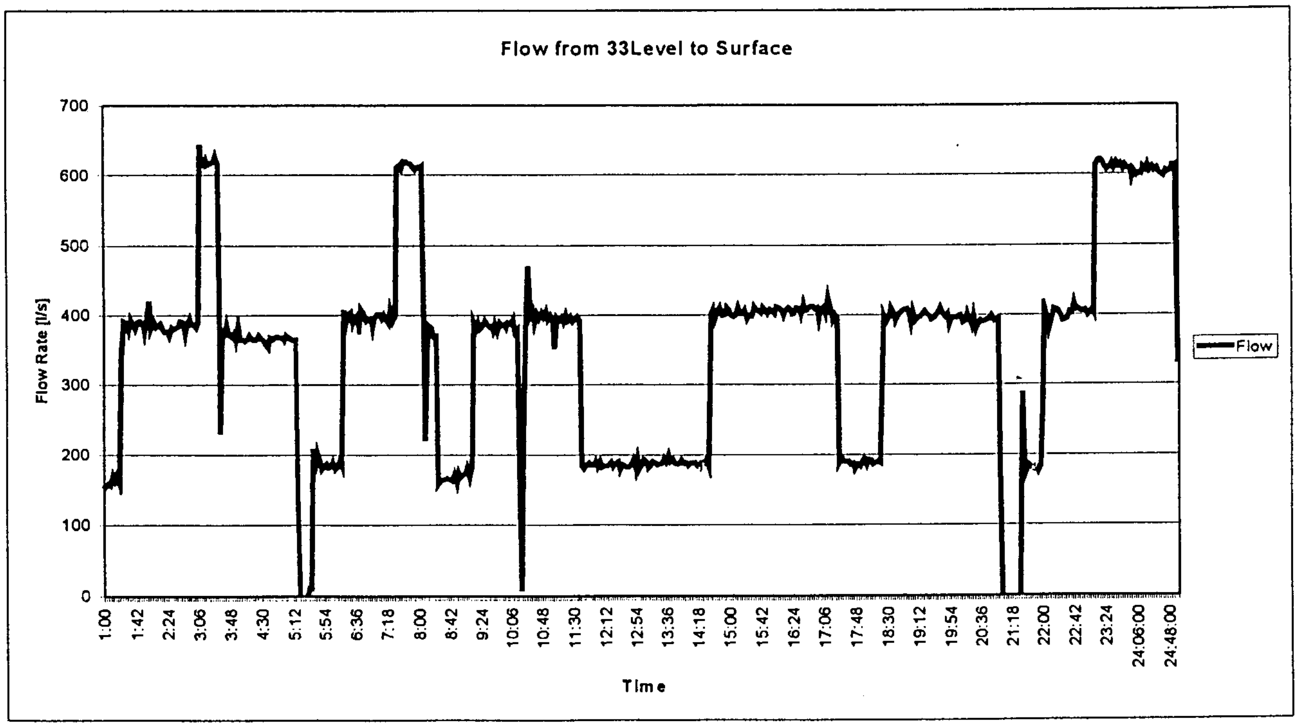

Figure B-25: Flow from 33Level dam to surface

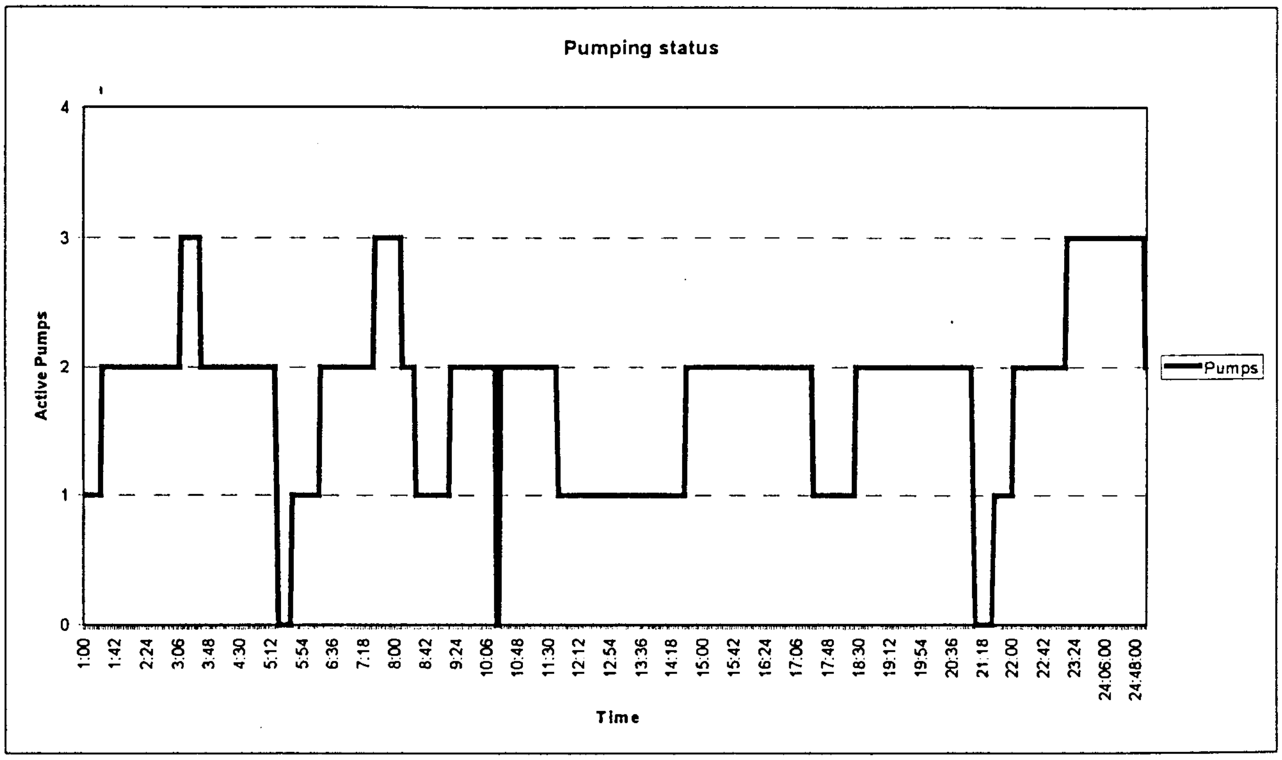

Figure B-26: Pumping status for 33Level pumps

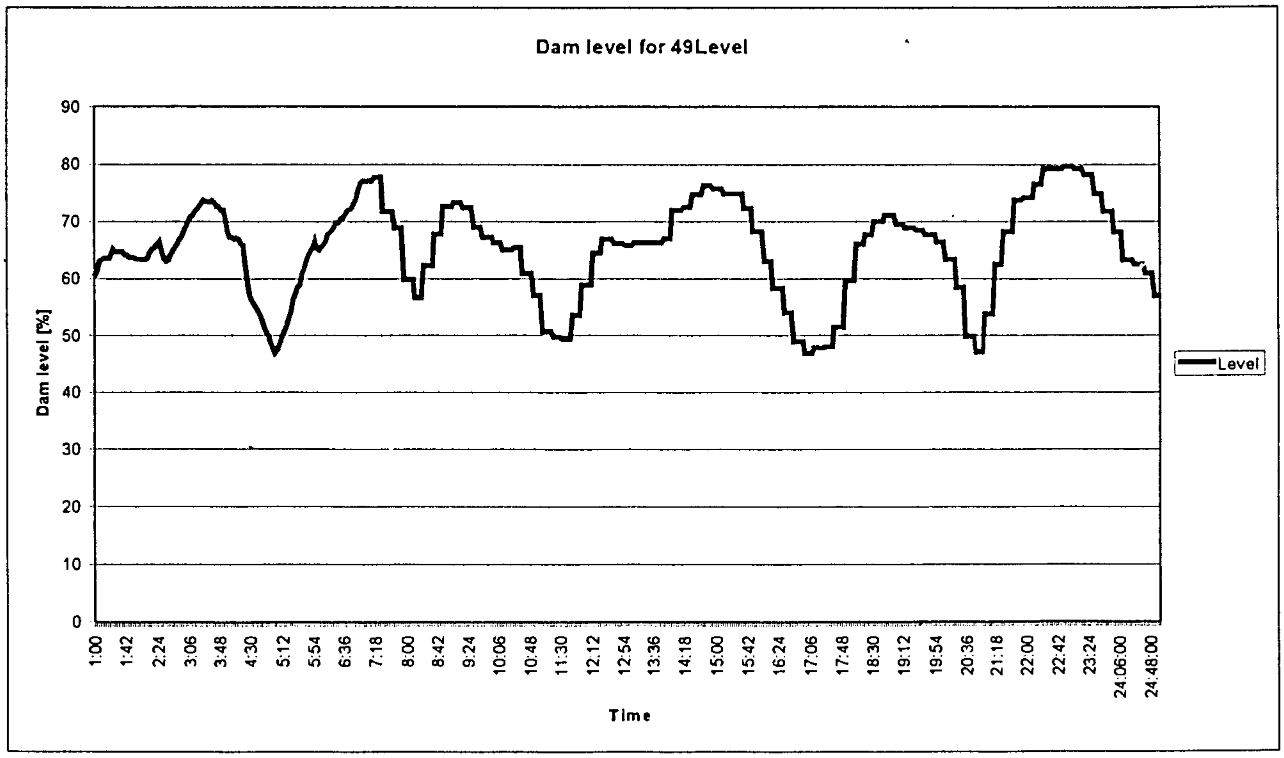

Figure B-27: 49Level dam levels

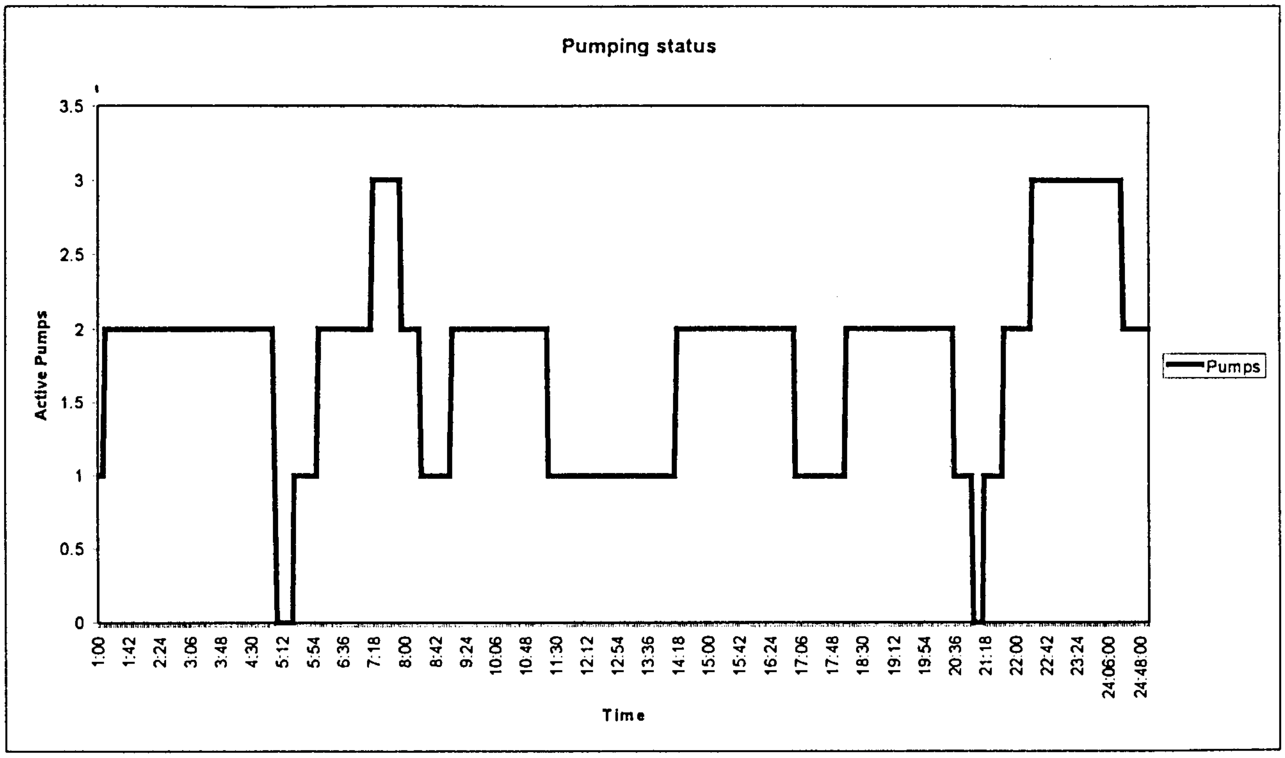

Figure B-28: Pumping status for 49Level pumps

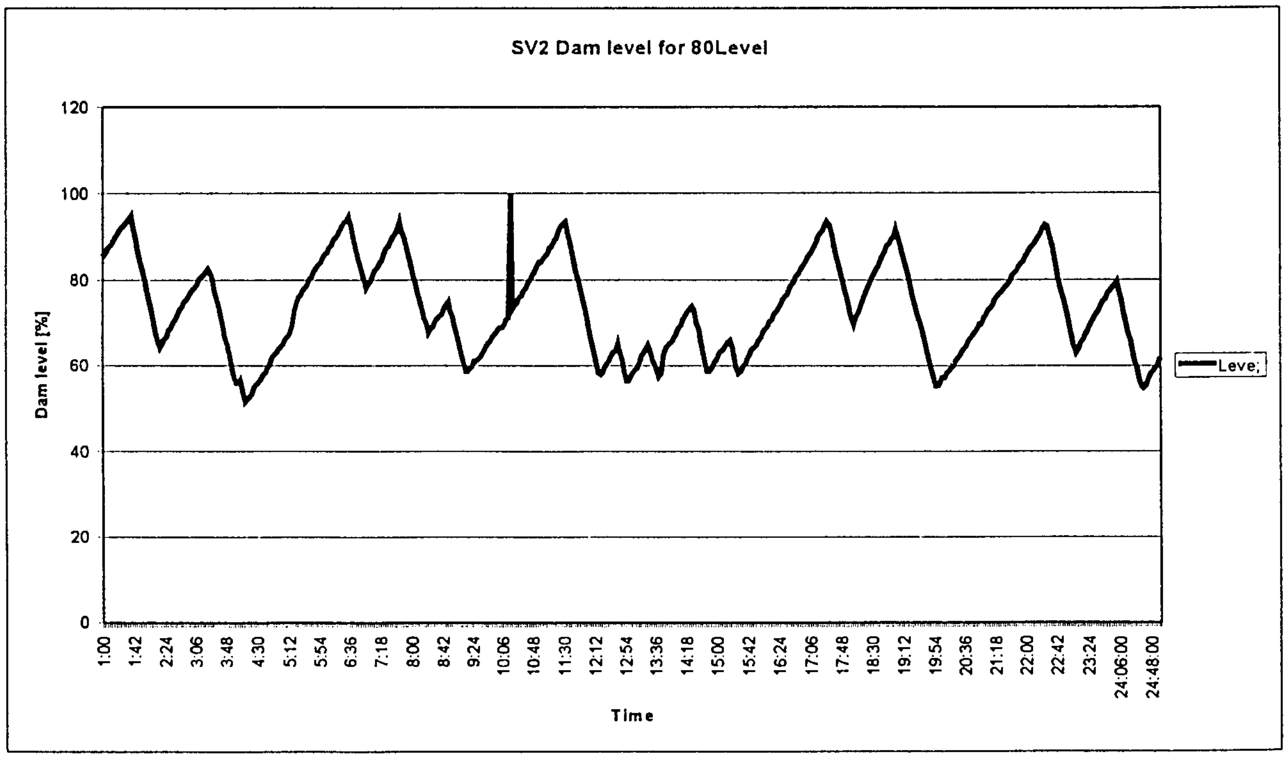

Figure B-29: 80Level SV2 dam level

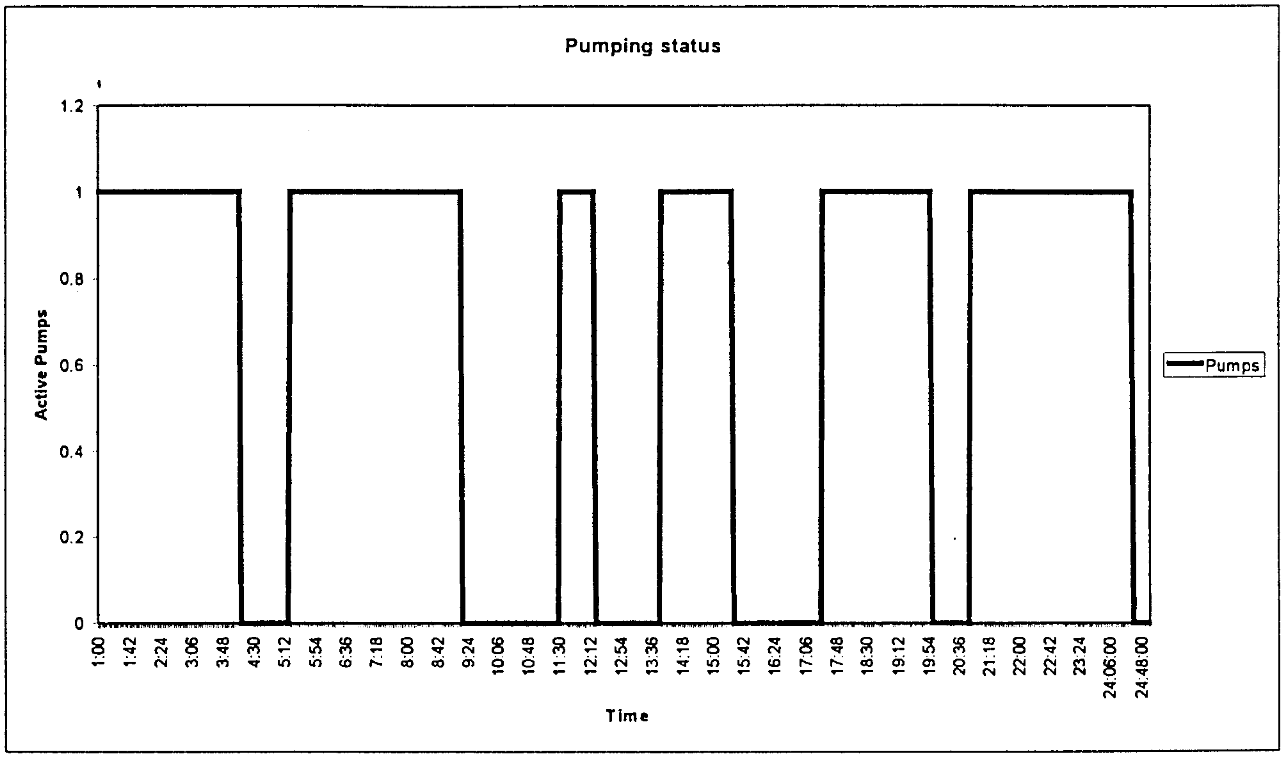

Figure B-30: Pumping status for 80Level SV2 pumps

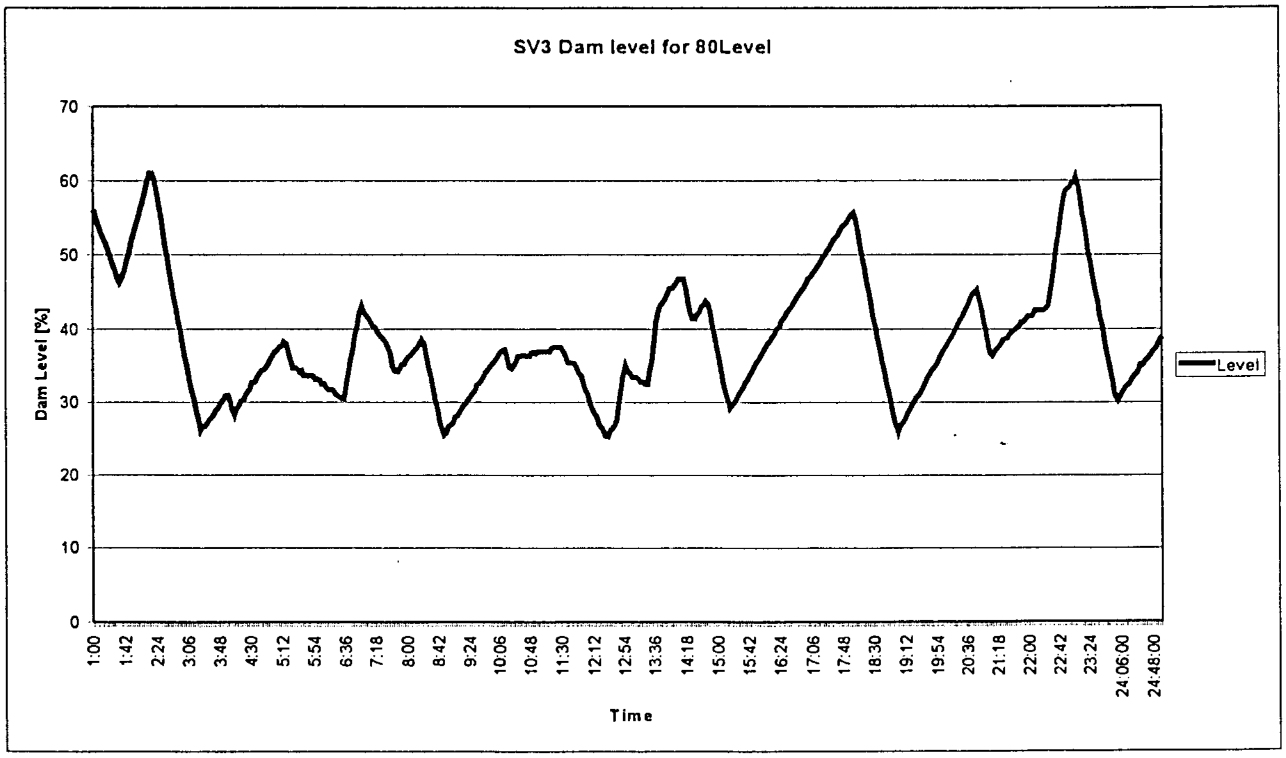

Figure B-31: 80Level SV3 Dam level

Appendix B – Measured data

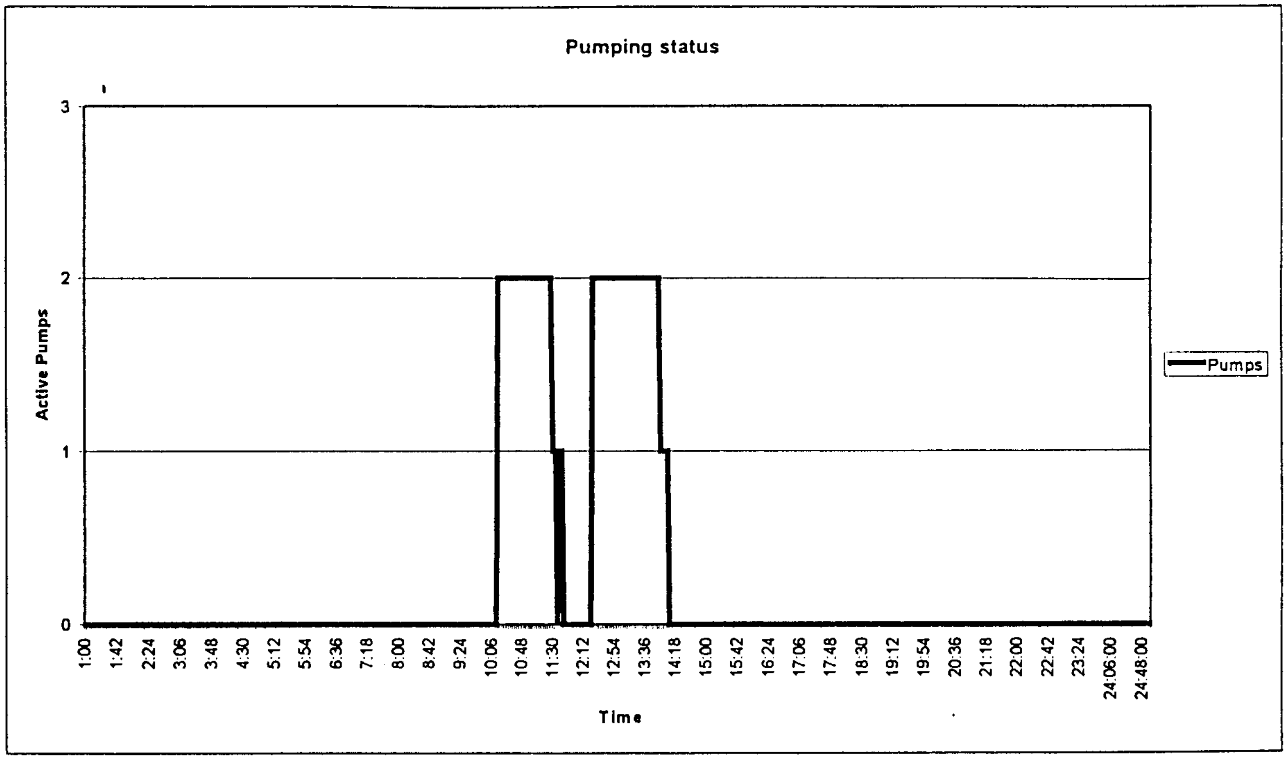

Figure B-32: Pumping status for 80Level SV3 pumps

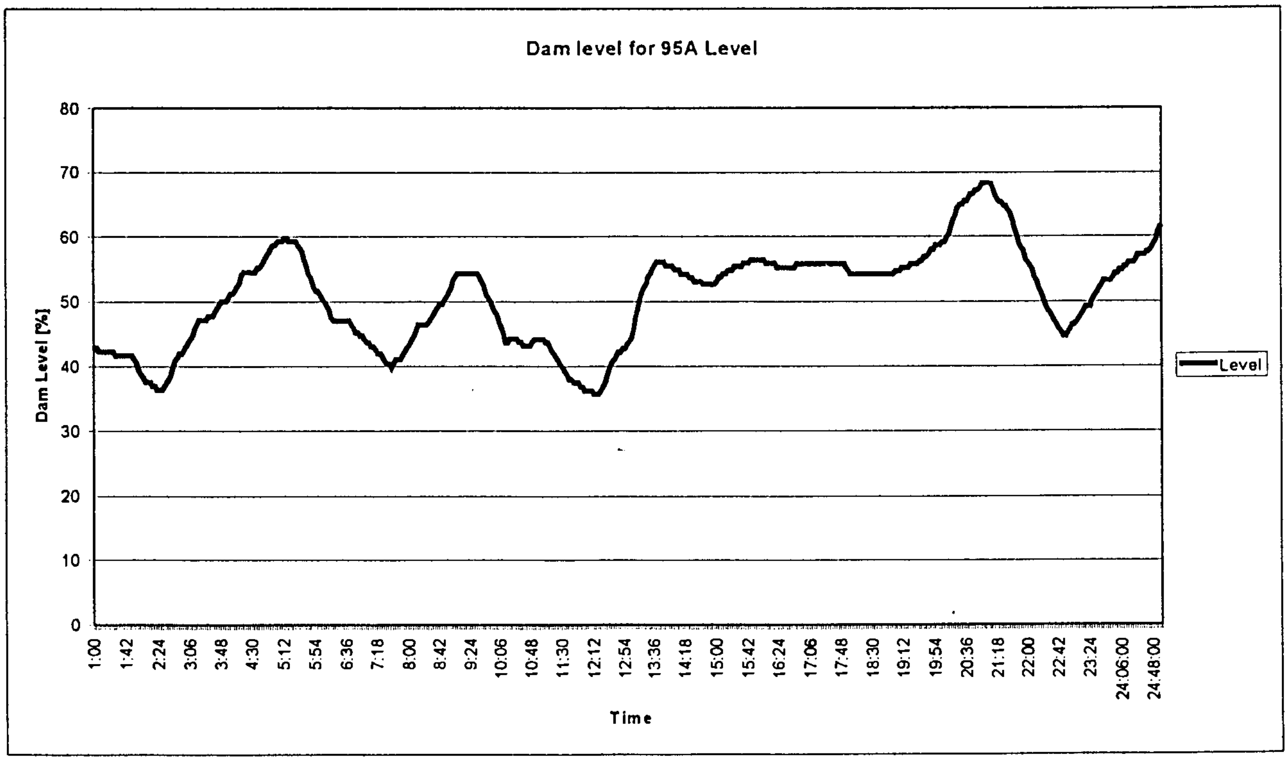

Figure B-33: 95A-Level Dam level

Appendix B – Measured data

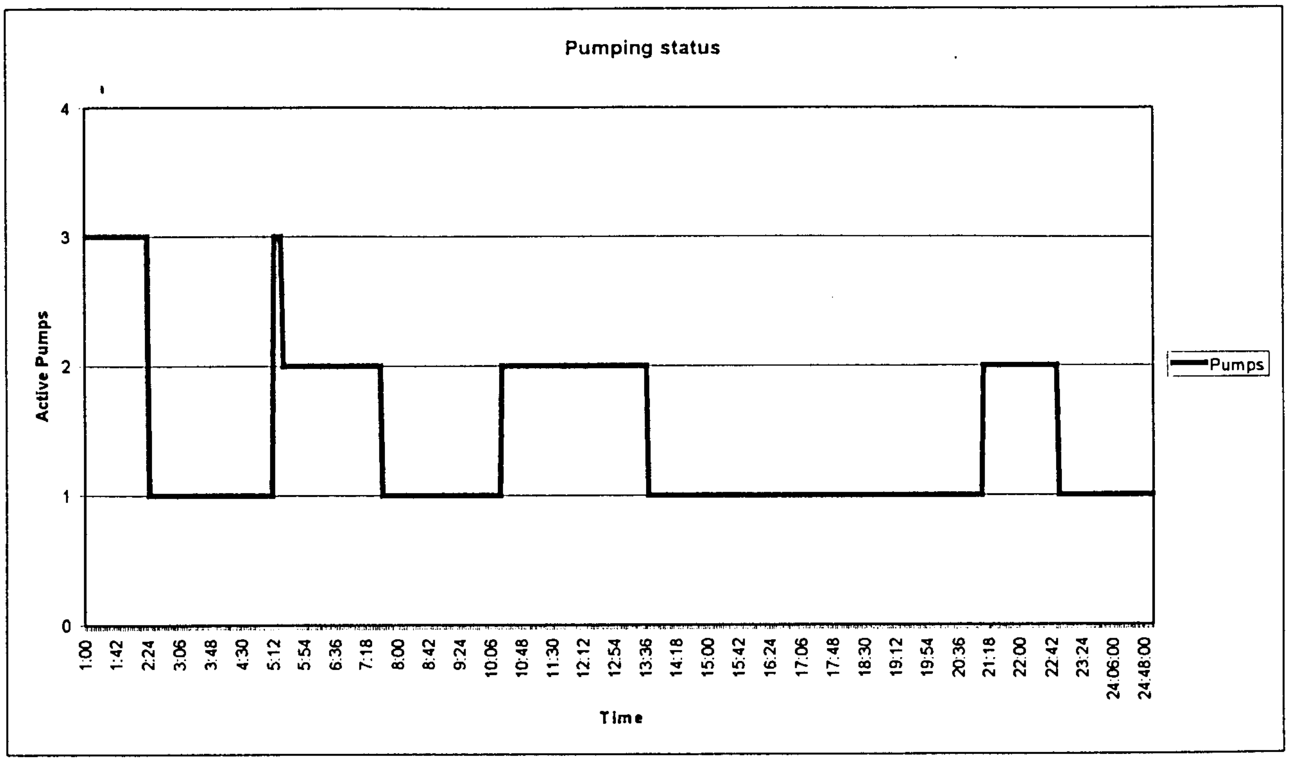

Figure B-34: Pumping status for 95A-Level pumps

This article discusses the DeepMine Programme, launched in July 1998 with four key objectives: a) to acquire knowledge of and develop appropriate technology for new ultra-deep level mines; b) to stimulate education and training; c) to establish a culture of training; and d) to encourage rapid technology transfer and implementation.(Durrheim,5/99, 4 - 11)

C.3 Mine Cooling and Ventilation

Air cooling and ventilation are needed in deep underground mines to minimize heat stress. As mines have become deeper, heat removal and ventilation problems have become more difficult to solve. This chapter deals with: worker heat stress; design considerations: sources of heat entering mine air; wall rock heat flow; air cooling and dehumidification; equipment and applications; mechanical refrigeration plants; underground heat exchangers; water sprays and evaporative cooling systems. This chapter includes graphs, diagrams, tables and formulae. Bibliography included.(95)

The task of ensuring an acceptable working environment to meet the requirements of ultra deep level mining in South Africa, in terms of ventilation and cooling, is being undertaken by CSIR: Mining Technology's programme of Environmental Safety and Health. The programme manager for Environmental Engineering, Wynand Marx, examines in this article existing and new ventilation and cooling technologies to meet the challenges presented by mining at greater depths. Includes a graph and a diagram.(Marx,9/97, 21 - 23)

This paper describes an economic case study for insulating the main air intakes for a proposed tertiary shaft system at Buffelsfontein Gold Mine. It was found that the cooling requirements were reduced by 40%, which would result in an annual cost saving of 1,8 million Rand. By constructing a framework around the periphery of the airway and applying the insulation to the framework it is easier to apply the insulation. However, the cavity created behind the insulation was shown to have limited effect on heat flow. The reduction in air pressure loss due to smoothing the tunnel walls is described and a break-even cost for insulation with varying virgin rock temperatures is given. Includes graphs, diagrams and tables.(Bottomley& Pretorius,90, 1407 - 1413)

C.1 The mining industry in South Africa

This article deals with mine-environment control in South African mines, new ways to advance safety and health standards underground, and specifically mentions ventilation and South Africa's role as world leader in the field. It also mentions the development of ventilation computer programmes with the creation of interactive tools which would allow the ventilation specialist to model in virtual reality any facet of mine ventilation. Includes photographs of ice-cooling plant at Western Deep Levels, and ventilation shaft, fan house and pre-cooling towers at Vaal Reefs. (Marais,9/94, 40 - 44)

C.2 The Deep Mine initiative

Ultra deep mining of narrow tabular ore deposits, such as the Witwatersrand type gold and Bushveld platinum deposits, will surely become inevitable in future in South Africa. The problems and challenges presented by the gradual increase in average working depths are especially significant in the area of mine environmental control. the single dominant challenge in this context is the heat problem, which is aggravated at depth mostly, but not exclusively, due to increased virgin rock temperatures. The ultimate future of mining at great depth will increasingly depend on the industry's ability to contend in an acceptable and cost-effective manner with the environmental control problems related to the provision of satisfactory ventilation and cooling. Includes graphs.(Marx,90)

In this paper the author identifies what they consider to be the critical areas in the problems associated with deep level mining, requiring technological solutions. This perspective will then be applied to work currently being carried out by both the Faculty of Engineering at the University of the Witwatersrand and the Mining Technology Division of the CSIR, and gaps for additional developments will be identified. Finally the Co-operative Research Centre methodology operating in Australia is described. Includes a graph and a table.(Pickering,9/96, 173 - 176)

APPENDIX C

RELEVANT PROJECT LITERATURE

An extensive literature survey was conducted into the mining industry and especially into the ventilation and cooling systems. This section shows the literature relevant to this project that wasn't used in the report itself.

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This paper describes the ventilation and refrigeration requirements planned for a new deep gold mine, specifically the South Deep Project of Johannesburg Consolidated Investment Company Ltd, which is to use the trackless mechanised mining method. One of the innovations is that refrigeration is to make use of plant on the so-called split ammonia system. Liquid ammonia, produced on surface, is sent underground via a special pipeline suspended in a dedicated borehole. In an isolated underground chamber, it expands into an evaporator, and is then returned to surface as a compressed gas. This system offers great reductions in capital expenditure and running costs, and eliminates the need to send underground and pump back to surface big quantities of service water required by conventional systems. Includes figures.(Patterson,90, 1323 - 1332)

This volume contains extensive information on mine ventilation. It covers the following: Conversion tables; software; statistics; airflow measurement; dynamic losses; Heat transfer; etc.Contains formulae, definitions, numerical data, graphs and diagrams.(99)

This volume contains extensive information on mine ventilation. it covers the following: Fan performance; combined fans; drifts and evasees; air crossings; duct design; fan types used in industrial ventilation; heat exchangers; refrigeration cycles; refrigerant properties; refrigeration machines; ventilation ducting; pipe insulation; etc. Contains formulae, definitions, numerical data, graphs and diagrams.(99)

In this paper the selection of a target temperature in the design of mine-cooling systems is discussed; for South African mines, a reject air web-bulb temperature of 28° C is considered to be an appropriate target. A review of the various sources of heat in gold mines is presented, which serves to identify the major heat loads that must be removed when deep mines are cooled. Consideration of these heat loads yields a graph for the estimation of the refrigeration requirements for the cooling of South African gold mines, given only the production rate, the depth of the mine, and the virgin-rock temperature. The trend over the past six years towards the use of chilled service water, and the importance of this method of cooling are discussed. Another important trend that is mentioned is the siting of refrigeration plants on the surface. Since the economics of refrigeration plant on the surface is dependent upon the efficient recovery of energy from the water being sent down the mine, there is also a growing trend towards the use of energy-recovery turbines.(Whillier,82, 697 -)

(WHILLER,J.. Developments in underground refrigeration techniques,*South African Mining and Engineering* Journal,88,4135.)
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This paper deals with a method of hand-calculating the air-cooling requirements of a conceptualized underground mining operation. Separate air heat load calculations were conducted for adiabatic compression, electromechanical equipment, wall rock, broken rock, groundwater, and blasting operations. The result of these hand calculations can be further modified by the use of mine ventilation computer software that refine the heat source calculations, predict underground ambient air temperatures, and establish the air cooling requirements of a mine.(Bossard,93, 429 - 434)

Papers in these proceedings include: mine environment and diesel emissions; mine ventilation system and network analysis; mine ventilation system and network analysis; mine ventilation fundamentals and instrumentation; mine ventilation monitoring and control; expert system and computer applications; case studies.(91)

This paper outlines the alternative refrigeration system for the proposed Tertiary shaft system on Buffelsfontein Gold Mine. The aim was to identify a refrigeration system where the best technologies could be utilized to achieve the most efficient and reliable refrigeration system. Four systems were evaluated, namely; an ammonia system, a vertical hydrohoist with 4°C water, a vertical hydrohoist with ice; and a pump and energy recovery system with 0,5°C water. The design parameters were the following: a heat load of 78 MW with a maximum rock temperature of 66°C; and a philosophy of total air conditioning. Various figures included.(Janse van Rensburg)

Considerable advances have been made in mine ventilation software since the days of the electrical analogue. While these software systems are generally based on extensive practical experience, sound physical principles, valid mathematical models and efficient numerical methods, they are in general difficult to modify. In this paper, firstly, a partial survey of ventilation-related software is presented. This is followed by an introduction to advanced user interface concepts that will assist in increasing the overall usability of mine ventilation software. The concepts are demonstrated with a case study involving a ventilation pressure survey program.(Sastry, Bhaskar *et al*)

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(BUTTERWORTH,M.D. and MARX,W.M., 1998, First phase evaluation of a proposed ventilation and cooling strategy for No 2 shaft, Amandelbult Section Rustenburg Platinum Mines Ltd)

(BUTTERWORTH,M.D. and MARX,W.M., 1998, Second phase evaluation of a proposed ventilation and cooling strategy for No2, Amandelbult section Rustenburg Platinum)

(MATESA,J., 1998, Mine refrigration and air cooling)

C.4 Energy

Energy system models are essential for estimating and verifying the savings potential from modifications to plant equipment. These models describe system performance using a number of variables under a variety of conditions. Measurement and verification of energy savings performance contracts has heightened the need to develop these models. This article includes tables and graphs.(Austin)

The benefits of using thermal cool storage developed by TU Electric, a full-service electric utility which is the principal subsidiary of Texas Utilities Company, are reported. Thermal cool storage system can be sized to shift all or part of the building's electrical demand for cooling from peak to off-peak hours. Storage sizing decisions are usually based on economic as opposed to technical factors. Thermal cool storage involves the use of conventional HVAC equipment and a storage tank to shift the period of chiller operation in commercial buildings from peak to off-peak periods. By shifting electricity use to off-peak hours, cool storage benefits both utilities and their customers. Utilities improve load factors and off-peak sales, and customers lower their electric bills.()

This paper examines the energy requirements for the different systems that are presently used for the cooling of deep-level mines. The energy balance for each system is discussed, along with the manner in which this affects the size of chillers needed and the total energy requirements. A comparison of the energy requirements for the different systems is made, leading to an assessment of the overall 'Coefficient of Performance', which can be expected from each of the systems at different depths. Includes graphs and diagrams.(Dawes, Lloyd *et al*)

In this article recent developments in the field of Pelton turbine technology both for new projects and uprating and refurbishment schemes are discussed. Case studies are included to give some examples of trends in this field. To reflect the theme of this special issue, examples of projects in Switzerland and Italy have been selected. High head hydro plants are typically equipped with Peltod turbine. Because of high density of energy, high head hydro plants are extremely economical. (Keck, Scharer *et al*)

Thermal energy storage (TES) systems are often considered for load shifting only from peak to off-peak periods. If the entire system is approached aggressively, the cooling plant's energy consumption may be significantly reduced as well. A few situations where energy savings have been realized as a result of a TES retrofit project, are discussed. The results apply to university campuses, hospitals, major office buildings, and industrial complexes, where cooling is or can be supplied from a central chiller plant.(Williams)

Environmental control in deep level gold mines accounts for up to 40 % of electricity costs. mine cooling techniques are evolving continually but, as depths increase, the cost of providing the service can impact directly on the viability of the operation. Cost effectiveness is clearly the issue and since electrical energy constitutes the major operating cost for refrigeration systems, much effort is directed towards improving energy efficiency. The paper describes some of the techniques for reducing power requirements. These include: the energy recovery turbines used on water flowing down vertical shafts; the use of ice for reducing the mass of cooling medium reticulated into the mine and the consequent reduction in pumping requirements; and the optimum use of pre-cooling towers on surface to reduce mechanical refrigeration requirements. Includes figures, graphs and diagrams.(Stroh)

(DELPORT,G.J.)

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Areas which have been identified where power consumption can be improved include the refrigeration reticulation systems with particular emphasis on shaft pumping. Here the three-chamber pipe feeder system as well as the use of ice slurries are considered. The circulation of large volumes of air incurs significant power consumption and this situation can also be improved by re-use and re-circulation systems. Heat recovery and energy management possibilities on surface are also examined. Includes graphs and diagrams.(Stroh)

C.5 Electronic control

This paper addresses the simulation and control of mine ventilation and cooling systems, as well as the important aspect of monitoring. the paper discusses simulation for general mine ventilation planning and simulation for active or predictive control. In addition, more general types of controls are discussed. If monitoring and active control of underground ventilation and cooling systems are considered from the point of view of energy alone, control of such systems at a sophisticated level can easily be justified.(Von Glehn,9/99, 91 - 96)

C.6 Safety

Recent developments in cooling tower design and water treatment have overcome many of the difficulties associated with the use of cooling towers. It is now even possible to design cooling towers that have little or no plume emission, reducing the impact the tower may have on the surrounding area. The important aspects of cooling tower selection are detailed in this article. Also, aspects of tower design that are deemed important include tower type, casing construction, pump, fans, access, drift eliminators, packing, and water treatment.(Crunden)

C.7 Components

Cold water generation

The cooling of service water plays an important role in the overall cooling strategy of mines, since the chilled service water is distributed to the working faces, where it is traditionally difficult to install and maintain air coolers.In this article the effectiveness of the heat transfer between the chilled water, rock and ventilation air is examined both from a theoretical basis and from water temperature measurements within stopes. It is shown that to make greater use of the cooling potential of the chilled service water it will be necessary to pass it through air coolers prior to'using it in slopes.(Ramsden,1/91, 19-22)

Ammonia chillers

The optimized mine cooling system comprises pre-cooling towers and ammonia water chillers on surfaces with hydro-hoisting systems (water transformers) to circulate cooling water through the mine. Cooling coils and spray chambers are used for heat exchangers in or close to workings. The ammonia water chillers use a Mycon twin screw compressor, three evaporative Evapco condensers, economizer, surge drum and flooded Alfa Laval plate heat exchange as evaporator, giving a total capacity of 5,45 MW (R) and a refrigeration COP of 5,85. Figures showing the layout of a mine cooling system, the block flow diagram of ammonia water chiller, flow diagram of water transformer system, flow vs time for water transformer vessels, and various tables are included.(Hegermann,11/97, 43-59)

Chillers

From detailed experimental measurements on commercial reciprocating chillers, the loss mechanisms that dominate chiller performance can be identified, quantified and incorporated into a general irreversible thermodynamic model for predicting chiller behaviour. The data can also be used to demonstrate the weaknesses and inaccuracies of a host of endoreversible chiller models that have been presented, where the primary sources of internal dissipation have been ignored. The corresponding of rated capacity operation to near maximum efficiency, is explained in terms of a general thermodynamic model. This article includes graphs, formulae and diagrams.

(Ng, Chua *et al*)

Fundamental aspects of chiller behaviour, characterized by the chiller coefficient of performance as a function of cooling rate and coolant temperatures, that pertain to all refrigeration devices, are discussed. A simple thermodynamic model that captures the universal aspects of chiller behaviour is reviewed, further developed and validated against extensive experimental measurements. The model provides a procedure for predicting chiller performance over a broad range of operating conditions from a small number of selected measurements, as well as a diagnostic tool. The accuracy of the model is illustrated for reciprocating, centrifugal and absorption chillers. Universal aspects of chiller behaviour are further illustrated with less conventional small-scale cooling devices such as thermoacoustic and (Gordon& Ng)thermoelectric chillers. This article includes graphs, formulae and diagrams.

A steady-state cooling plant model was developed for use in evaluating optimal control of ice thermal energy storage systems. The plant model calculates the power consumption of the chiller, cooling tower, pumps, and fans under an infinitely variable range of operating conditions. Given the external parameters (cooling load, ambient conditions, stat-of-charge, and return air temperature) and the controls (discharge rate and temperature setpoints), the model implicitly calculates total power consumption. When embedded in the plant optimization routine, the set points that meet the load at minimal instantaneous power consumption can be found. Further, when this optimization is embedded in the optimal control routine, the sequence of charge/discharge rates that yield minimal operating cost over the entire simulation period can be found. This article includes diagrams, formulae and tables.(King& Potter)

This paper investigates the robustness of a diagnostic model for the performance evaluation of reciprocating chillers. The model, which is described by three adjustable parameters of the chiller, is verified by experimental results with three purpose-built system configurations. It is found that the model is both flexible and accurate with respect to changes in the system layout and the predictions of chiller coefficients of performance (COP) are well within the experimental uncertainties. This paper includes diagrams, tables, formulae and graphs. (Ng& Ong)

Firstly, conventional chillers of different types have been modeled and simulated using a software (DOE2). The chillers are rated for a generic building and meteorological weather of San Diego . Performance parameters such as the part/full-load efficiencies, the number of occurrences during peak hours and load frequencies are then calculated. These results gave typical performance values which can be used to compare screw, centrifugal, and reciprocating chillers among each other within a predefined scope. In the following section the field data of 39 conventional chillers and the manufacturers specifications of some of them are collected and analysed. This article includes graphs and diagrams.(Beyene, Guven *et al*)

This article shows the importance of economic optimization of large capacity or industrial refrigeration systems. Software was developed specifically to determine the economic optimum values of the design parameters of refrigeration systems. Both liquid chillers and groups of cold storage rooms operating at various levels of low temperatures are covered. It was found that condenser type, ambient temperature, yearly operating hours, electricity price, real interest rate and refrigerant are the most important parameters in the economic optimum design of refrigeration systems. This article includes graphs, diagrams, formulae and tables.(Usta& Ileri)

The computer program CHILLER was developed by COMRO to predict the performance of water chilling installations. CHILLER takes into account both specifications of and interactions between all components in predicting the behaviour of a complete installation under any specified set of conditions. Its precise predictions can point the way to assist with troubleshooting and system analysis. Furthermore it is easy to predict performance under altered operating conditions which may be considered. Three examples, drawn from actual cases on mines, illustrate the use of CHILLER in this way. In a manual performance survey which yielded a heat imbalance of more than 20%, the instruments principally at fault were positively identified. In an installation where cooling cars could not adequately load chillers, the program was used to examine the implications of a suggested alteration to the chillers to improve loading. Finally, a case arose where four large pre-existing chillers were to be used in a new installation. CHILLER was used to examine the feasibility of two alternate ways of connecting them into the chilled water circuit. This article includes diagrams, tables and graphs.(Bailey-McEwan)

Chiller plant owners and designers face new challenges in a deregulated electric environment. Though predicted results from retail wheeling and real-time pricing (RTP) may be appealing on the surface, utilities spearheading the RTP rate structure have already issued on-peak electric prices as high as $3.50/kWh (kilowatt hour). Selecting proper chillers now requires more than simply determining lowest operating costs, simple payback, or even lowest life-cycle cost. This article outlines the benefits from combining electric and alternative-drive chillers (hybrid system) to effectively and efficiently combat high electric prices. This article includes graphs and tables. (McGavisk)

This article discusses a control system in order to optimize overall chiller performance. Advantages of this system include: exact control of leaving water temperature without losing any chiller capacity under all operating conditions; loss of normal capacity will be apparent immediately allowing correction of operating problems before they become severe; the chiller and auxiliary equipment operate fewer hours per season to obtain the same cooling production; most chillers will operate with less noise and vibration when operated at full load thereby causing less wear and tear on the equipment; using modulating valves and a recirculating line, a "bumpless" startup and shutdown of chillers, and unloading chillers before shutdown is possible. Includes photograph and diagrams.(Williams)

(MIDDLETON,J.N..,1995. Retrofitting options for underground chillers used for airconditioning in deep gold mines,*Journal of the South* African Institute of Refrigeration &
Airconditioning,11,1.)

The efficiency of chillers (refrigeration and heat pump devices) is limited by the dissipation from their principal components: compressor, throttler, and heat exchangers at the condenser and evaporator. The authors derived analytical formulae for how the fixed finite resources of cycle time and heat exchanger inventory should be allocated so as to optimize chiller performance, by developing a generalized finite-time thermodynamics model for reciprocating chillers. Predictions for optimal operating schemes are compared with detailed experimental data from two different commercial chillers. They also discuss the limitations of currently-available chiller components affect optimal chiller design, as well as how potential steps to improve chiller efficiency can be evaluated within a universal thermodynamic framework.(Gordon, Ng *et al*,97, 191-200)

The cooling of deep mines in the South African gold-mining industry is achieved at present through the medium of chilled water, which is produced in refrigeration installations either on surface or underground. A well-known problem associated with the design of such installation is that the refrigeration duty is not constant, since there can be seasonal, daily and seven hourly variations in both refrigeration load and condensing temperatures. The water chillers in an installation can be shielded from short-term variations through the use of suitably sized water storage dams, but the burden of accommodating seasonal changed in duty falls directly on the water chillers. Long periods of inefficient part-duty operation can therefore be imposed upon the chillers during the year. Furthermore, different chillers in an installation may experience different types of part-duty. The year-round performance of typical water chillers in use on South African gold mines is examined, with particular reference to compressor behaviour. The current practice is generally to use centrifugal water chillers that are essentially the same as those developed for commercial and industrial air-conditioning applications. In many cases the controls necessary on this type of chiller result in unexpectedly poor part-duty adaptability and efficiency. Some suggestions are made for improving performance; ideally, water chillers for mines should be designed for their individual duty. The procedure necessary for the selection of water chillers on this basis is described. The behaviour of chillers incorporating screw compressors is also examined under similar circumstances, and the two types of chillers are compared. It is concluded that screw compressors may offer advantages under certain conditions.(Bailey- McEwan& Shone,84, 265-276)

(MADAN,C..,1993. R-134a : the best alternative for chillers,*ASHRAE Journal*, 1993,35,5, p.58,60.)

Compressors

A new steady-state model of vapor-compression type centrifugal liquid chillers is presented. The model has a number of advanced features and is capable of simulating both hermetic and open-drive centrifugal compressors. The model accounts for the real process phenomena such as superheating and subcooling in the heat exchangers as well as a capacity control formulation of the inlet guide vanes. The model algorithm is developed with the aim of requiring only those inputs that are readily known to the design engineer, eg the general parameters of the chiller, the chilled water flow temperature out of the evaporator and the return water temperature to the condenser inlet. The outputs include the condenser capacity, the refrigeration capacity (at the evaporator), the coefficient of performance, and also the mass flow rates and thermodynamic states of the refrigerant throughout the cycle. This article includes formulae, graphs, diagrams and tables.(Browne& Bansal)

In this paper the refrigeration cycle of the split ammonia system is examined. Specifically some thermodynamic aspects are examined which are important to an understanding of the split system and to the establishment of the system design and costs. In conclusion it is found that uncooled centrifugal compressors could be considered, when virtually all the heat could be rejected on the surface. Includes tables, graphs and diagrams.(Shone)

(BAILEY-MCEWAN,M., Development of computer program to predict performance of mine water chilling installations. Part 1: Performance of packaged single-stage ...)

Heat and mass exchangers

A mathematical model was developed for the analysis of spray-cooled, finned-tube heat exchangers. An experimental study was conducted on a four--row, finned-tube heat exchanger in a vertical air/water mist flow to validate the model. The results compared well with the predicted performance. the heat exchanger was tested in three orientations relative to the air stream. Significant performance enhancement was found by spraying relatively small amounts of water on to the heat exchanger. The two-phase pressure drop across the heat exchanger was also measured. The spray water mass flow rate was found to have a significant effect on the pressure drop across the tube bundle. Spray-cooling could be used on process heat exchangers, large compressor cooling installations in mines of dry-cooled power generation plants, during peak demand periods in hot weather but not on a continuous basis. Includes appendices.(Erens& Dreyer)

(RAMSDEN,R., Water to water high pressure heat exchanger cost study by Mrt Chemdes)

The analysis and performance prediction of various types of evaporatively cooled closed-circuit coolers and condensers are described. The project resulted from enquiries from industry for design methods to predict the performance of normally dry heat exchangers when sprayed of deluged with water. The project produced a prediction capability to successfully model closed circuit evaporative coolers and condensers, of any geometry likely to be encountered in practice, in such a way that meaningful comparisons could be made with other types of coolers, for example dry finned-tube heat exchangers and direct contact cooling towers in conjunction with liquid-liquid heat exchangers.(Erens, Dreyer *et al*)

In this article the authors take critical look at heat exchangers which are currently in use in the mines. Before describing thr various designs of heat exchangers an outline is given of methods which are used in South African mines for performance analysis and categorization. These are generally different to those used elsewhere in the world. Three groups of heat exchangers are discussed in detail: cooling coil units, horizontal spray chambers, and units which make use of cooling tower type packings.The paper is based on work carried out as part of the research programme of the Chamber of Mines of SA Research Organization as well as from developments in various mines and mining groups within the mining industry.(Bluhm, Ramsden *et al*,10/84, 358-366)

Mine ventilation and cooling practices involve the use of direct-contact water-air spray heat exchangers for the rejections of heat from refrigeration plant and for the cooling of ventilation air. The thermal duties of these units are typically between 0,5 and 20 MW. This study is aimed at developing a relationship between the basic design parameters and the overall performance trends of horizontal crossflow systems. This enables a code for the optimal design of these units to be outlined. The relevant literature relating to conventional heat exchanger theory, heat mass transfer from a discrete drop and the various methods of thermal performance analysis of direct-contact units, is reviewed. The study shows that by drawing an analogy with conventional heat exchanger theory, it is possible to explain, and to improve, the popular factor of merit method of analysis. This modified method has been used to evaluate the experimental data. A computer model of a single drop ejected vertically into a horizontal air stream is used to study the effects of varying design parameters. The dynamic behaviour of the drop is subjected to aerodynamic and gravitational forces only. Experimental work was carried out at two test sites underground in a gold mine. The sites are described in detail. A reasonable correlation between the performance measurements and an overall design parameter is shown.(Bluhm,81)

Bulk air coolers

In this paper cooling requirements for an ultra deep mine (Western Deep Levels) are under review. Two major areas of concern are the heat loads at depth and the practical limitations and power requirements for reticulating cooling in the vertical shafts. A pilot study to assess the practicalities of using an ice slurry for cooling purposes is discussed. The water displacement system, also known as 3-Chamber pipe-feeder is discussed. Includes photographs, diagrams and graphs.(Stroh, Lloyd *et al*)

(MACNAMARA,J.P., Study of cooling systems for hydro-powered mines: Bulk air cooling using high pressure water-to-water heat exchangers in conjunction with ...)

This article describes the advantages of cooling towers and bulk-air towers, the different tipes of towers, the maintenance and the refurbishment of towers.(Erens,11/96, 28-29)

Cooling cars

(FEIO,L.C.E., Thermal performance of the H.e. Radiators Cooling Car)

(FEIO,L.C.E., Thermal performance test of the Elca Engineering Cooling Car)

Spray chambers

The proceedings contains 7 papers. Topics discussed include instrumentation software, engine monitoring, spray chamber monitoring systems, virtual instruments in sensor software development, software for mass flow measurement, learning classifier system for parameter

Appendix C – Relevant Project Literature

Cooling towers

Chapter 20 of this handbook deals with cooling towers. The following aspects are addressed: principle of operation; design conditions; types of cooling towers; materials of Construction; Selection considerations; Application; Performance Curves; Field Testing; Cooling Tower Theory; Tower Coefficients.()

This chapter deals with cooling towers and in particular: principle of operation; design conditions; types of cooling towers; materials of construction; selection considerations; application; performance curves; cooling tower thermal performance; cooling tower theory; tower coefficients. This chapter includes graphs, diagrams, tables and formulae. Includes bibliography.()

Chapter 37 of this ASHRAE Handbook deals with cooling towers. Headings are: Principle of operation; design conditions; types of cooling towers; materials of construction; selection consideration; application; performance curves; cooling tower thermal performance; cooling tower theory; tower coefficients. This chapter includes graphs, diagrams, tables and formulae. Includes bibliography.()

This book gives state-of-the-art evaporative cooling tower techniques. Design practices and applications of modern cooling tower technology are presented. A design basis can be established through the detailed calculation procedures outlined and with selected use of the nearly 400 references compiled at the end of the book. Headings in the Table of Contents include: Properties and Definitions for the Air-Water System; Heat and mass transfer principles; Cooling Tower classifications; Mechanical components of cooling towers; cooling tower water treatment. Further this book includes appendices, figures, tables and a list of cooling tower terminology.(Cheremisinoff& Cheremisinoff)

This article describes a theoretical investigation for the steady-state counter flow wet cooling tower with modified definitions for both the number of transfer units and the tower thermal effectiveness. The model considered the resistance to heat transfer in the water film, the nonunity of the Lewis number, and the curvature of the saturated air enthalpy curve. The model compares very satisfactorily with other methods such as Logarithmic Mean Enthalpy Difference (LMED) and conventional effectiveness - NTU. (El-Dessouky, Al-Haddad *et al*)

The oriented spray-assisted cooling tower (OSACT) is a new approach to natural draft cooling tower design which increases air flow through the cooling tower while reducing water loading in the heat exchanger fill material. With the improvement in cooling system performance the economic competitiveness of power plants with cooling towers is enhanced.(Bowman& Benton)

In this article is reported about an expert system based on logic programming that has been developed, using a systematic procedure for the thermal design of natural and mechanical draft wet cooling towers of the counterflow and crossflow types. The present system is based on a rule-based system. The 'VIDHI' , expert system shell written in LISP, has been used as a tool to develop the present system. The 'VIDHI' shell is based on backward chaining. The inference mechanism of the system is similar to that of PROLOG. The rule set of the expert system was developed by using a tree structure for the entire design process. Besides designing a cooling tower for a given situation, the expert system can also be used for teaching and learning about cooling-tower design.(Mohiuddin, Kant *et* al)

Recent developments in cooling tower design and water treatment have overcome many of the difficulties associated with the use of cooling towers. It is now even possible to design cooling towers that have little or no plume emission, reducing the impact the tower may have on the surrounding area. The important aspects of cooling tower selection are detailed in this article. Also, aspects of tower design that are deemed important include tower type, casing construction, pump, fans, access, drift eliminators, packing, and water treatment.(Crunden)

(BLUHM,S.J., Prediction of performance of cooling towers and spray chambers)

(MATHEE,F..,1996. Upgrading of Vaal Reefs No. 8 shaft underground condenser cooling towers,*Journal of the Mine Ventilation* Society of South Africa.)

Appendix C – Relevant Project Literature

This paper describes the final part of the detailed methodology for the thermal design of wet, counterflow and crossflow types of mechanical and natural draught cooling towers. This part includes the following design steps: the fill or packing, total packed hight and the number of decks, water and air loading, pressure drop across the packing, natural draught tower, fan design for a mechanical draught cooling tower, blowdown and make-up water rate, water distribution systems and drift eliminators. Different empirical relations and assumptions are used in this part of the design procedure.(Mohiuddin& Kant,1/96, 52-60)

This paper describes part of the detailed methodology for the thermal design of wet, counterflow and crossflow types of mechanical and natural draught cooling towers. Starting with a brief introduction, an attempt is made here to present different steps of cooling tower design. The steps include: selection of a cooling tower; determination of tower characteristics ratio; computation of moist air properties; determination of ratio of the water-to-air loading; integration procedure for the tower characteristic ratio. The design of the cooling tower needs the use of different logical decision, empirical relations and assumptions. The choice of a proper tower and its proper design would increase its efficiency and help conserve energy.(Mohiuddin& Kant,1/96, 43-51)

(BURGER,R..,1997. Tower has power,Engineered Systems, 1997,14,8, p.78, 80, 82.)

This paper describes part of the detailed methodology for the thermal design of wet, counterflow and crossflow types of mechanical and natural draught cooling towers. Starting with a brief introduction, an attempt is made here to present different steps of cooling tower design. The steps include: selection of a cooling tower; determination of tower characteristics ratio; computation of moist air properties; determination of ratio of the water-to-air loading; integration procedure for the tower characteristic ratio. The design of the cooling tower needs the use of different logical decision, empirical relations and assumptions. The choice of a proper tower and its proper design would increase its efficiency and help conserve energy.[1]
(PANNKOKE,T..,1996. Cooling tower basics,*Heating, piping & Air Conditioning*, 1996,68,2.)
This paper describes part of the detailed methodology for the thermal design of wet, counterflow and crossflow types of mechanical and natural draught cooling towers. Starting with a brief

introduction, an attempt is made here to present different steps of cooling tower design.

Water distribution

In this paper the suitability of the various devices used in distribution systems to minimize the temperature rise of the water delivered to the underground workings and which also reduce the pumping requirements for returning the water back to the surface, is examined. Further, with the aid of a specially developed computer program their optimum operating conditions are determined. In addition the optimum combination of surface and underground refrigeration plants is examined for a hypothetical mine at various depths and the importance of pump efficiency on total distribution costs is discussed. Includes graphs, tables and diagrams.(Ramsden& De Carvalho)

In this paper the selection of a target temperature in the design of mine-cooling systems is discussed; for South African mines, a reject air web-bulb temperature of 28° C is considered to be an appropriate target. A review of the various sources of heat in gold mines is presented, which serves to identify the major heat loads that must be removed when deep mines are cooled. Consideration of these heat loads yields a graph for the estimation of the refrigeration requirements for the cooling of South African gold mines, given only the production rate, the depth of the mine, and the virgin-rock temperature. The trend over the past six years towards the use of chilled service water, and the importance of this method of cooling are discussed. Another important trend that is mentioned is the siting of refrigeration plants on the surface. Since the economics of refrigeration plant on the surface is dependent upon the efficient recovery of energy from the water being sent down the mine, there is also a growing trend towards the use of energy-recovery turbines.(Whillier)

Areas which have been identified where power consumption can be improved include the refrigeration reticulation systems with particular emphasis on shaft pumping. Here the three-chamber pipe feeder system as well as the use of ice slurries are considered. The circulation of large volumes of air incurs significant power consumption and this situation can also be improved by re-use and re-circulation systems. Heat recovery and energy management possibilities on surface are also examined. Includes graphs and diagrams.(Stroh)

Reference is made to the approach to mine cooling in which the service water is used as one of the means of distributing refrigeration, and attention is drawn to various engineering disciplines or functions necessary for effective distribution and recirculation of cold water from refrigeration plant. The demand for service water is intermittent, the peak flow-rates being typically two to three times the average flow-rate. The refrigeration plant, on the other hand, must preferably be operated steadily throughout the day and night, with the result that a large storage dam for cold water must be incorporated into each system in order to even out the surge in demand for water. These dams should be operated as constant-temperature, variable-volume reservoirs. The conventional cascade system involving dams on each level is not the best for sending water down mines, and schemes are described that avoid the need for such dams. Reference is made to various tests that were carried out, and to several large systems that were installed. Management and organizational problems that could arise as a result of new technological developments in mine cooling and reffered to, and cost figures are quoted to indicate the large potential savings, in addition to the improved environmental conditions, that can be achieved through the use of integrated water systems.(Van Der Walt& Whillier,78)

(EPPELHEIMER,D.M..,1996. Variable flow - the quest for system energy efficiency,*ASHRAE Transactions*, 1996,102,2, p.673-678.)
Reference is made to the approach to mine cooling in which the service water is used as one of the means of distributing refrigeration, and attention is drawn to various engineering disciplines or functions necessary for effective distribution and recirculation of cold water from refrigeration plant. The demand for service water is intermittent, the peak flow-rates being typically two to three times the average flow-rate.

Pumps

This article outlines opportunities for energy and other savings which could be made in South African gold mines by the use of shaft-balanced hydraulic cooling and heat rejection systems. Possible additional savings that could be achieved in the field of rock hoisting by the simultaneous use of balanced hydraulic systems for mine cooling and rock hoisting are discussed. Finally, the practical application of a balanced hydraulic system used as an effective heat exchanger for the transport of an 11 MW(R) refrigeration load from surface to the -970 m level of a hot German coal mine is described. Includes figures, graphs and diagrams.(Adams, Dawes *et al*)

(ALDER,G..,1999. Pumps in parallel and in series,*Journal of the South African Institute of Refrigeration and Air* Conditioning,15,2.)

Ventilation

(MEYER,C.F., Determine the friction factors of galvanised ventilation ducting)

In this paper the known classical criteria formulated by Czeczott, Kogut and Barczyk elucidating direction of airflow in certain side branches of simple networks are discussed. Equations describing characteristic parameters of equivalent substitute sections of these networks are given. Variations in the form of characteristics curves caused by changes in fans resistances and pressures are shown. Shifting of these characteristics to the third quadrant of the system brings about changes in direction of airflow in the side branches considered. A method is postulated for interpretation of thes conditions, enabling more precise assessment of stability of direction of air currents flow.(Frycz& Kolarczyk,10/85, 339-)

Layout and problems

In this second printing of Wang's technical paper (first one in September 1990) some editorial errors are corrected: This paper examines the ventilation network problem from a viewpoint of solving a system of B equations in B unknowns, where B is the number of branches in the network. Based on Kirchhoff's current and voltage laws, the solution to the general ventilation problem must satisfy B network equations. In this paper, the air quantities and control-device pressures are chosen as variables and are grouped into B dependent variables (unknowns) and B independent variables, resulting in a system of B equations in B unknowns. Based on whether their variables are dependent or independent, the network branches are classified into four types: fixed, non-fixed, p-fixed, and q-fixed. The ventilation network problem may include all four types of branches. There are some conditions under which the problem, as defined in this manner, does not have a unique solution. To have a unique solution, the Jocabian matrix of the equations must be non-singular. It then follows that: a) the number of branches with independent air quantities must be less than or equal to the number of chords with respect to a spanning tree; b) the subnetwork of branches with independent air quantities must not contain any cutset; and c) the subnetwork of branches with dependent control device pressures must not contain any cutset. In addition to the problem formulation, a solution procedure applying the Newton (or Newton-Raphson) method is outlined and illustrated with an example problem. Includes formulae and figures.(Wang)

(PATTERSON,A.M..,1991. Practical problems in the distribution & application of refrigeration,*Journal of the Mine Ventilation Society* of South Africa,44,4.)

(TUCK,M.A. and DIXON,D.W..,1992. Automatic control of mine ventilation : future possibilities,*Journal of the Mine Ventilation Society of South* Africa.)

Fans

When plotted as head vs volume, fan curves start high and decrease with increasing volume, while mine head curves start low and rise with increasing volume. Their intersection is the system operating point. However, the fact that head loss is a negative number (debit) and fan head is an energy addition (credit) is often a stumbling block to student or audience comprehension since the curves seem to reflect the opposite. It is possible to use the intuitively correct curves and sill obtain the correct operating point. Adding the two curves produces a third curve that intersects the x-axis at the operating point, the point at which the fan energy input exactly matches air circulation energy loss. Using this technique also makes it easier to account for outside influences on the system, such as natural ventilating pressure. With the standard approach, it is quite easy to add or substract such influences to the wrong curve. This approach can be extended to the graphical solution of any series/parallel ventilation network. The results are the same, and the approach is logically consistent and less confusing.(English& Wang,3/98, 65-68) '

(SEN,P.K..,1997. Reducing power consumption for axial flow mine ventilation fans,*Journal of Mines, Metals &* Fuels, 1997,45,9-10, p.301-303.)
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(VIJAYA,G.,SASTRY,V.R. *et* al, 1995)
When plotted as head vs volume, fan curves start high and decrease with increasing volume, while mine head curves start low and rise with increasing volume. Their intersection is the system operating point. However, the fact that head loss is a negative number (debit) and fan head is an energy addition (credit) is often a stumbling block to student or audience comprehension since the curves seem to reflect the opposite.

Pelton wheels

This paper deals with the evaluation of options to arrive at the long-term refrigeration strategy for the Western Deep Levels South Mine and refers to the use of water-based systems, ice, and in particular microscopic ice and the use of energy recovery systems such as turbine-generator sets (Pelton Wheel turbine) and three chamber pipe feeder systems. Includes figures.(Lloyd& Cronje)

In this paper the suitability of the various devices used in distribution systems to minimize the temperature rise of the water delivered to the underground workings and which also reduce the pumping requirements for returning the water back to the surface, is examined. Further, with the aid of a specially developed computer program their optimum operating conditions are determined. In addition the optimum combination of surface and underground refrigeration plants is examined for a hypothetical mine at various depths and the importance of pump efficiency on total distribution costs is discussed. Includes graphs, tables and diagrams.(Ramsden& De Carvalho)

This report describes the execution and results of an efficiency test performed on a directly coupled 1107kW Pelton water turbine and pump set installed underground at Unisel Gold Mines, Ltd. (The set was installed for purposes of energy recovery from the service water going down the mine shaft.) The thermodynamic method of testing was employed. This involves measurement of the water temperature rises between inlet and outlet of both pump and turbine together with associated pressure changes. Includes formulae, tables and graphs.(Bailey-McEwan, Whillier *et al*)

In this article recent developments in the field of Pelton turbine technology both for new projects and uprating and refurbishment schemes are discussed. Case studies are included to give some examples of trends in this field. To reflect the theme of this special issue, examples of projects in Switzerland and Italy have been selected. High head hydro plants are typically equipped with Peltod turbine. Because of high density of energy, high head hydro plants are extremely economical. (Keck, Scharer *et al*)

(BROWN,C.J., The specification of Pelton Wheel Turbines in Hydro-power applications)

Environmental control in deep level gold mines accounts for up to 40 % of electricity costs. mine cooling techniques are evolving continually but, as depths increase, the cost of providing the service can impact directly on the viability of the operation. Cost effectiveness is clearly the issue and since electrical energy constitutes the major operating cost for refrigeration systems, much effort is directed towards improving energy efficiency. The paper describes some of the techniques for reducing power requirements. These include: the energy recovery turbines used on water flowing down vertical shafts; the use of ice for reducing the mass of cooling medium reticulated into the mine and the consequent reduction in pumping requirements; and the optimum use of pre-cooling towers on surface to reduce mechanical refrigeration requirements. Includes figures, graphs and diagrams.(Stroh)

Ice generation and distribution

A broad experimental investigation is described into the pneumatic conveying of ice particles through multi-section pipelines extending down mine shafts. The test results obtained from a pilot conveying installation prove that it is fully feasible to convey ice particles underground in this way at high flow rates for deep mine cooling purposes. Guidelines are formulated for use in the design of future ice conveying pipeline systems. These include equations for the prediction of the pressure gradients along the respective main pipeline sections. Includes Appendices.(Sheer)

In this paper the use of ice directly to reduce the temperature of the underground service water in a mine, is discussed. The Merriespruit section of the Harmony Gold Mine introduced this method in November 1985. The ice plant, the ice transport system, safety precautions, water quality and capital costs are some of the topics that the authors deal with in depth. Includes figures.(Middleton& Muller)

This paper deals with the evaluation of options to arrive at the long-term refrigeration strategy for the Western Deep Levels South Mine and refers to the use of water-based systems, ice, and in particular microscopic ice and the use of energy recovery systems such as turbine-generator sets (Pelton Wheel turbine) and three chamber pipe feeder systems. Includes figures.(Lloyd& Cronje)

This paper explains the comparison between tube and plate icemakers according to specific criteria. In conclusion the plate ice makers proved to be the better choice for the 5th ice plant at E.R.P.M Far East Shaft. Figures included.(Leonard,4/97, 428-437)

The paper describes how the ice produced by a 1000 ton per day surface ice plant is used for underground cooling at Harmony. A brief description is given of the heat problems experienced in that area of the mine, and of the cooling facilities available prior to the installation of the ice plant. The reasons for choosing an ice plant in preference to other cooling systems are described.

Details are given of the complete cooling system, as well as a brief description of the tests carried out to obtain information regarding the performance of ice melting dams. A diagrammatic sketch of the ice cooling system is also included.(Eschenburg, Hemp *et al*,86, 203-210)

This article describes the design and installation of the largest ice plant in the world at East Rand Propriety Mines Ltd. The ice will be used for cooling the deep levels of the new Far East Vertical shaft where at a depth of 3 000 meters the ambient temperature and humidity are so high that it would be impossible to carry out mining operations without extensive cooling. It is the first time that that an ice plant has been designed and purpose built for a Gold Mine. The article also discusses the advantages of an ice making system.(Klostermann,6/88, 307-313)

Ice storage

(King& Potter)A steady-state cooling plant model was developed for use in evaluating optimal control of ice thermal energy storage systems. The plant model treats the ice storage array as a heat exchanger wherein the charge/discharge and the log mean temperature difference between the brine and the storage freezing temperature. This article includes tables, formulae and diagrams.

This article discusses an ice storage chiller plant utilized by the State of Florida Regional Service Center, which has saved the owner in electricity, water, sewer and maintenance costs over the three foregoing years. The design team's use of thermal storage, a 20°F (-6°C) CHW Delta T, VFD's on the central station air handler, air-cooled chillers and a ventilation rate of 20 CFM/person make this an innovative, energy and demand-efficient, first-cost sensitive facility for use in the future. Includes photographs, graphs and tables.(O'Neal)

The advanced control strategy to take full advantage of the economies offered by ice storage and to ensure the safety of heat exchangers and other equipment, is discussed. Ice storage may be used in a number of different ways, and the selection of different options will depend on the requirements and limitations of each building. The main advantages of ice storage are due to the price difference between peak and off-peak electricity, coupled with more efficient use of the chillers.'(Duffin)

Dams

Reference is made to the approach to mine cooling in which the service water is used as one of the means of distributing refrigeration, and attention is drawn to various engineering disciplines or functions necessary for effective distribution and recirculation of cold water from refrigeration plant. The demand for service water is intermittent, the peak flow-rates being typically two to three times the average flow-rate. The refrigeration plant, on the other hand, must preferably be operated steadily throughout the day and night, with the result that a large storage dam for cold water must be incorporated into each system in order to even out the surge in demand for water. These dams should be operated as constant-temperature, variable-volume reservoirs. The conventional cascade system involving dams on each level is not the best for sending water down mines, and schemes are described that avoid the need for such dams. Reference is made to various tests that were carried out, and to several large systems that were installed. Management and organizational problems that could arise as a result of new technological developments in mine cooling and reffered to, and cost figures are quoted to indicate the large potential savings, in addition to the improved environmental conditions, that can be achieved through the use of integrated water systems.(Van Der Walt& Whillier,78)

Simulation

In this paper an analogous approach to the mathematical analysis of electrical networks, where the electrical devices are often modelled using idealized network elements such as current sources, voltage sources and resistors, is outlined for the modelling of mine ventilation networks, which can be considered nonlinear resistive networks. The proposed modelling technique uses the following five basic elements: H, Q, D, R and N. These elements are characterized by their pressure gain or loss, their air quantity and their pressure-vs-quantity relationships, each of which may be known or unknown. In addition to the definition of the basic elements, the necessary conditions for which there exists a unique solution are discussed. This is performed using theoretical developments derived from electrical circuit theory and illustrated in example networks. The proposed procedures are useful in the solution and characterization of mine-ventilation networks. Includes figures, graphs, tables and formulae.(Wang& Mutmansky)

(SPIRKO,K.)

The proceedings contains 7 papers. Topics discussed include instrumentation software, engine monitoring, spray chamber monitoring systems, virtual instruments in sensor software development, software for mass flow measurement, learning classifier system for parameter identification, computer simulation of photonic devices.[1]

(MIKOLAJCZYK,W..,1990. Changes of air temperature and specific humidity in a mine working during its cooling,35,2.)

(MARX,W.,DENT,C. *et al*, Mine ventilation and cooling simulation, CSIR: Mining Technology)

(WOLSKI,J.K.)

This paper addresses the simulation and control of mine ventilation and cooling systems, as well as the important aspect of monitoring. the paper discusses simulation for general mine ventilation planning and simulation for active or predictive control. In addition, more general types of controls are discussed. If monitoring and active control of underground ventilation and cooling systems are considered from the point of view of energy alone, control of such systems at a sophisticated level can easily be justified.(Von Glehn,7/99, 91-96)

(OBERHOLZER,J.W. and MEYER,C.F., 1995)

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(RAMANI,R.V..,1993. Current issues in US mine ventilation,*Mining Engineering*, 1993,45,10, p.1262 - 1267.)

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(YANG,Z.Y.,LOWNDES,I.S. *et* al.,1998. Application of Genetic algorithms to the optimization of large mine ventilation networks, 1998,107, p.A109 - A116.)

Air cooling and ventilation are needed in deep underground mines to minimize heat stress. As mines have become deeper, heat removal and ventilation problems have become more difficult to solve. This chapter deals with: worker heat stress; design considerations: sources of heat entering mine air; wall rock heat flow; air cooling and dehumidification; equipment and applications; mechanical refrigeration plants; underground heat exchangers; water sprays and evaporative cooling systems. This chapter includes graphs, diagrams, tables and formulae. Bibliography included.[1]
(MARX,W.M., 1998, ENVIROMINE : First phase development)

Appendix C – Relevant Project Literature

Software

The computer program CHILLER was developed by COMRO to predict the performance of water chilling installations. CHILLER takes into account both specifications of and interactions between all components in predicting the behaviour of a complete installation under any specified set of conditions. Its precise predictions can point the way to assist with troubleshooting and system analysis. Furthermore it is easy to predict performance under altered operating conditions which may be considered. Three examples, drawn from actual cases on mines, illustrate the use of CHILLER in this way. In a manual performance survey which yielded a heat imbalance of more than 20%, the instruments principally at fault were positively identified. In an installation where cooling cars could not adequately load chillers, the program was used to examine the implications of a suggested alteration to the chillers to improve loading. Finally, a case arose where four large pre-existing chillers were to be used in a new installation. CHILLER was used to examine the feasibility of two alternate ways of connecting them into the chilled water circuit. This article includes diagrams, tables and graphs.(Bailey-McEwan)

In this article the planning of the ventilation and refrigeration requirements for a proposed third shaft at Beatrix Mine, using Environ, is discussed. Detailed simulation of the mining network resulted in a reduction in the capital required, in terms of the original cost estimate, of approximately 50 million Rand. (Woodburn)

The VUMA project, aimed at devising a simulation software program was initiated in 1997. The objectives set for this year were to complete all programming structures and algorithms, sort the data handling protocols and interfaces and test the program so that a final product would be available for marketing. The report consists of a project summary and a sample of the VUMA 00 program screen sequences.(Biffi).

The increasing required cooling capacities for South African gold mines has focussed attention on exploring heat flow reduction methods to reduce operating costs. This report investigates mine wide effects on required cooling capacities and operating costs of a number of known heat flow reduction methods such as the use of backfill, high face advance rates, insulation of airways and recirculation, and various combinations thereof. A simplified mine model was investigated for a depth range of 2000 m to 5000 m and compared against a defined 'conventional' case. The COMRO Computer program ENVIRON was used to perform the calculations. The results indicated that substantial reductions in cooling requirements and costs are possible, which rapidly increase with increased depth of mining. The results further permit the estimation of a monetary value for differences in cooling and ventilation costs when differences in mining methods, which impact on any of the investigated scenarios, are considered. Includes graphs, diagrams and tables.(Haase)

This article describes the development of a Windows-based interactive mine ventilation simulation software program at the Waste Isolation Pilot Plant (WIPP). To enhance the operation of the underground ventilation system, Westinghouse Electric Corp developed a program called WIPPVENT. While WIPPVENT includes most of the functions of the commercially available simulation program VNETPC from Mine Ventilation Services Inc. and uses the same sub-routine to calculate airflow distributions, the user interface was completely rewritten as a Windows application with screen graphics.(McDaniel& Wallace)

A computer-program CLIMA was developed to predict the time-dependent climatic change in an underground airway. The dry and wet surface temperatures of the airway used in the program were calculated following a finite difference scheme. (Roy& Singh)

(HARDCASTLE,S.G.)
In view of the high cost of the insulation materials and recent regulations which prohibit the use of certain insulation materials, a careful examination of the actual benefits of insulating chilled water pipes was undertaken. The objective of the investigation was to produce general guidelines regarding the use of insulation, but the results of numerous studies have shown that the use of insulation is extremely site specific and thus no general guidelines can be given.

(MARX,W.M., Software Development)

(VON GLEHN,F.H., User's Manual for the computer program Minivnet for ventilation network analysis)

MFIRE is a mine ventilation and fire interaction computer simulation program. It allows transient state ventilation simulation and features mass based flow rates, natural ventilation, air recirculation, fan curve fitting, air-flow reversal and product of combustion tracking. MFIRE was designed to accommodate the needs of the mining industry for routine ventilation calculations and mine emergency planning. This paper describes recent work by the US Bureau of Mines and Michigan Technological University to improve MFIRE by incorporating humidity in the mass flow and heat exchange calculation, a data file preparation program, and variable reference density in the network calculations. Recent bug fixes are also discussed. (Laage, Yang *et al*,2/94, 145 - 148)

This paper describes an approach to mine ventilation systems analysis which is based an a symbolic upgrading of the numerical Sim Vent system. The result is VENTEX, a coupled expert system incorporating both procedural and declarative knowledge, that offers the possibility for a more profound exploitation of the available software at an expert level. The paper presents the global strategy of mine ventilation system analysis used in the VENTEX system and its formalisation using a modification of the object-oriented analysis model as well as the basic architecture of the system. The use of the VENTEX system is illustrated through a case study: the evaluation of the general ventilation state of the "Soko" brown coal mine in Serbia.(Lilic, Obradovic *et al*,11/97, 295-302)

Considerable advances have been made in mine ventilation software since the days of the electrical analogue. While these software systems are generally based on extensive practical experience, sound physical principles, valid mathematical models and efficient numerical methods, they are in general difficult to modify. In this paper, firstly, a partial survey of ventilation-related software is presented. This is followed by an introduction to advanced user interface concepts that will assist in increasing the overall usability of mine ventilation software. The concepts are demonstrated with a case study involving a ventilation pressure survey program.(Sastry, Bhaskar *et al*,5/93, 78-84)

(MARX,W.M., 1997, Software development : Final step project summary report)

This paper discusses current developments and some of the simulation programs and expert systems available to mine environmental engineers. The paper also discusses the essential elements which will make expert systems accepted and used by environmental engineers on mines. A proposal is made for the establishment of a central register of software which will make software more accessible to environmental engineering practitioners on mines and will encourage the development of more user friendly software.(Von Glehn,6/96)

Case studies

This article discusses an ice storage chiller plant utilized by the State of Florida Regional Service Center, which has saved the owner in electricity, water, sewer and maintenance costs over the three foregoing years. The design team's use of thermal storage, a 20°F (-6°C) CHW Delta T, VFD's on the central station air handler, air-cooled chillers and a ventilation rate of 20 CFM/person make this an innovative, energy and demand-efficient, first-cost sensitive facility for use in the future. Includes photographs, graphs and tables.(O'Neal)

This paper deals with the evaluation of options to arrive at the long-term refrigeration strategy for the Western Deep Levels South Mine and refers to the use of water-based systems, ice, and in particular microscopic ice and the use of energy recovery systems such as turbine-generator sets (Pelton Wheel turbine) and three chamber pipe feeder systems. Includes figures.(Lloyd& Cronje)

This paper outlines the considerations in selecting the cooling system adopted for the sub-shaft area of Loraine gold mine, near Welkom. Headings in this paper include: Calculation of heat load and prediction of refrigeration requirements; Detailed design of refrigeration plant and distribution system; performance of refrigeration system. Includes figures.(Pretorius, Ferguson *et al*)

This article discusses the second phase of the ventilation and cooling system at the

Rustenburg Section's Turffontein Shaft. The system is described by the project manager at Engineering (Corporate & Operational Office) as the biggest plumbing job Amplats has ever undertaken.()

This article describes a ventilation and refrigeration system design case study. The mine is to be situated in the bushveld Igneous Complex and a production target of 250kton/month is to be achieved using a single vertical shaft of 9,5m diameter. The environmental conditions are to be such that a cooling power of at least 300 W/m^2 is maintained. The thermal issues dominate the design process and ventilation flow rates based on these criteria satisfy the pollutant requirements.(Rose& Bluhm)

In this article the planning of the ventilation and refrigeration requirements for a proposed third shaft at Beatrix Mine, using Environ, is discussed. Detailed simulation of the mining network resulted in a reduction in the capital required, in terms of the original cost estimate, of approximately 50 million Rand. (Woodburn)

This project report submitted to the Faculty of Engineering of the University of the Witwatersrand for the degree of MSc reports on the study undertaken to minimize the technical environmental risks in extending the current Buffelsfontein infrastructure, an additional 1 000 metres in depth. A systematic approach was adopted in determining the environmental requirements, methods of ventilation and implications of physical limitations. Computer models were extensively used to predict and calculate sources of the mine heat and describe ventilation network changes with the deletion and addition of mining districts. Energy balances were undertaken to ensure suitable psychrometric conditions prevailed and that thermal environments complied with a minimum specific cooling power of 300 W/m^2. Despite the conservative methods of cooling and ventilation that were adopted in preference to more cost effective principles, such as the use of ice, hydrolift techniques and controlled reuse of air, there are no reservations that the exploitation of the tertiary orebody can be adequately cooled and ventilated. Includes: lists of figures, tables, appendices and symbols.(Dumka)

This report describes the execution and results of an efficiency test performed on a directly coupled 1107kW Pelton water turbine and pump set installed underground at Unisel Gold Mines, Ltd. (The set was installed for purposes of energy recovery from the service water going down the mine shaft.) The thermodynamic method of testing was employed. This involves measurement of the water temperature rises between inlet and outlet of both pump and turbine together with associated pressure changes. Includes formulae, tables and graphs.(Bailey-McEwan, Whillier *et al*)

(ROUGH,D. and VAN DER Walt,T..,1997. Nevada Gold Mine uses SA mine cooling technology,*Refrigeration & Airconditioning*,13,1.)

Cost savings

This paper describes an economic case study for insulating the main air intakes for a proposed tertiary shaft system at Buffelsfontein Gold Mine. It was found that the cooling requirements were reduced by 40%, which would result in an annual cost saving of 1,8 million Rand. By constructing a framework around the periphery of the airway and applying the insulation to the framework it is easier to apply the insulation. However, the cavity created behind the insulation was shown to have limited effect on heat flow. The reduction in air pressure loss due to smoothing the tunnel walls is described and a break-even cost for insulation with varying virgin rock temperatures is given. Includes graphs, diagrams and tables.(Bottomley& Pretorius)

The increasing required cooling capacities for South African gold mines has focussed attention on exploring heat flow reduction methods to reduce operating costs. This report investigates mine wide effects on required cooling capacities and operating costs of a number of known heat flow reduction methods such as the use of backfill, high face advance rates, insulation of airways and recirculation, and various combinations thereof. A simplified mine model was investigated for a depth range of 2000 m to 5000 m and compared against a defined 'conventional' case. The COMRO Computer program ENVIRON was used to perform the calculations. The results indicated that substantial reductions in cooling requirements and costs are possible, which rapidly increase with increased depth of mining. The results further permit the estimation of a monetary value for differences in cooling and ventilation costs when differences in mining methods, which impact on any of the investigated scenarios, are considered. Includes graphs, diagrams and tables.(Haase)

Dynamic programming was used to obtain optimal service schedules and costs for cleaning the condensers and evaporators of air-conditioning equipment. Results were obtained for a range of service and energy costs, characteristic fouling times, and equipment sizes for a single building and location. (Rossi& Braun)

Environmental control in deep level gold mines accounts for up to 40 % of electricity costs. mine cooling techniques are evolving continually but, as depths increase, the cost of providing the service can impact directly on the viability of the operation. Cost effectiveness is clearly the issue and since electrical energy constitutes the major operating cost for refrigeration systems, much effort is directed towards improving energy efficiency. The paper describes some of the techniques for reducing power requirements. These include: the energy recovery turbines used on water flowing down vertical shafts; the use of ice for reducing the mass of cooling medium reticulated into the mine and the consequent reduction in pumping requirements; and the optimum use of pre-cooling towers on surface to reduce mechanical refrigeration requirements.(Stroh)

The costs of ventilating and cooling deep level mines constitute a substantial percentage of total operating costs. Therefore, the reduction in these costs can play an important role in improving the profitability of the industry. Considerable progress has been made in introducing new and improved technology, a process which is still continuing. However, the greatest impact on cost reductions that can presently be made is to reduce heat flows into mines. Well known methods to achieve this are high face advance rates, backfilling of stopes, underground recirculation of ventilation air and insulation of airways. A comparative assessment of the effect of these methods on costs as a function of depth of mining is only possible, by computer simulation. The results of this investigation show that substantial reductions in ventilation and cooling costs are possible amounting to 67 per cent at a depth of 3000 m if high face advance rates are combined with backfill. The appropriate combination of heat flow reduction methods can prevent an increase in ventilation and cooling costs for future deep mining ventures. This article includes various graphs, tables and two appendices .(Haase,3/94, 34-44)