ASSESSMENT OF THE NATIONAL DSM POTENTIAL IN MINE UNDERGROUND SERVICES

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ABSTRACT

Title: Assessment of the national DSM potential in mine underground services

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Search terms: Amandelbult, cooling, Demand side management (DSM), ESKOM, Gold mines, Kopanang, National energy regulator (NER), optimisation, Platinum mines, pumping, Real time pricing (RTP), simulation, South African mining industry, Target, ventilation, underground services

ESKOM is moving towards a price structure for electricity which reflects, as far as possible, the real cost of generation. It is called real time pricing (RTP). ESKOM developed this cost structure to coax customers to use more electricity in off-peak periods (low cost of generation) and less electricity in peak periods (high cost of generation). However, many industries do not effectively use these price offerings from ESKOM to the detriment of themselves and ESKOM.

In previous research improvements to this situation for the South African mining industry were investigated. ESKOM funded research to find the potential for load shifting on mines using RTP. The RTP investigation focused on the supply side management (SSM) in the mining context of underground services on gold and platinum mines. Elements investigated included the ventilation, cooling and pumping (VCP) systems. (Except for pumps, these plants are generally installed aboveground.)

Previous research showed a national RTP and SSM potential to shift 500 MW of electrical load for a period of 5 hours.

Through the previous research it became clear that the mines were previously able to react partially to the price signals. However, it was proved by the research that the full load shift potential can only be realised through the use of integrated dynamic simulation and optimisation.

An even higher potential exists for load shift and electricity efficiency through demand side management (DSM) on the underground services. Therefore, if underground DSM strategies are combined with SSM strategies, a further and much bigger potential can be exploited to the benefit of ESKOM and the mines. Due to these factors this study was undertaken.

Three case study mines were identified for this study. They are Kopanang and Target, both gold mines, and Amandelbult, a platinum mine. The DSM potential on each of these mines was calculated using simulation, calibration, verification and optimisation.

These results were presented to mine management to negotiate the implementation of the proposed strategies on one of the mines. Kopanang's management agreed to the implementation of these strategies for a trial period of 3 months after which the success would be evaluated.

The results of the implementation, together with the case study results, were used to calculate the national DSM potential in the mining sector through extrapolation. The DSM potential amounts to 650 MW of load per day as well as 5% on electricity consumption. This amounts to a potential saving of R72.1 million per year using current tariffs. This means that ESKOM can save about R5000 million on the building of a new power station to supply the equivalent load to the DSM potential.

Now that the national impact has been calculated and discussed, all these findings must be used to motivate the implementation of these strategies throughout the mining sector. A similar project can be undertaken to look at possible DSM strategies in the industrial sector.

This might prove to be more difficult as the electricity intensive systems are mostly all linked to the final production. In the mind of management this out-weighs the possible cost savings that can be achieved.

ESKOM and the NER will have to rethink their strategy. Through DSM and load shifting actions alone the pending electricity crisis will not be averted. The current tariff structures should be amended to not only reflect the true cost of electricity but also provide incentive for DSM and load shifting.

Another problem that must be addressed to achieve the DSM targets set for 2007 is the *time that it takes to complete the study* as well *as the implementation time.* Software can easily be created to help in the speeding up of the case study itself, as the process and steps followed, as well as models used, are very generic (at least in the gold and platinum mining sector).

SAMEVATTING

Titel: Assessment of the national DSM potential in mine underground services

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Graad: Philosophiae Doctor

Sleutel terme: Amandelbult, DSM, ESKOM, goud myne, Kopanang, NER, ondergrondse dienste, optimalisasie, platinum myne, pomp, RTP, simulasie, Suid Afrikaanse mynbou bedryf, Target, ventilasie, verkoeling

ESKOM beweeg sover as moontlik na `n prysstruktuur toe wat die ware koste van elektrisiteits-opwekking reflekteer. Die tarief staan bekend as RTP. ESKOM het die kostestruktuur ontwikkel om kliënte aan te moedig om meer elektrisiteit in lae piek periodes (lae opwekkingskoste) en minder elektrisiteit in hoë piek periodes (hoë opwekkingskoste) te gebruik

Hierdie prysstruktuur word nie effektief deur die meeste industrieë gebruik nie, tot die nadeel van ESKOM en hulself. Maniere om die situasie in die Suid Afrikaanse mynbou bedryf te verbeter is gedurende vorige navorsing ondersoek.

ESKOM het dus navorsing befonds om die potensiaal om las te skuif deur die gebruik van RTP op myne te bepaal. Die RTP ondersoek het gefokus op die voorsienings kant bestuur van die ondergrondse dienste van goud en platinum myne. Die ventilasie-, verkoeling- en pompstelsels het deel gevorm van die ondersoek (Behalwe die pompe is al die stelsels gewoonlik bo-gronds geïnstalleer).

Vorige navorsing het getoon dat die potensiaal bestaan om 500MW elektriese las vir 5 ure van die dag te skuif.

Dit het duidelik uit die vorige navorsing geblyk dat die myne net gedeeltelik kan reageer op die prysseine. Die navorsing het gewys dat die volle potensiaal net deur die gebruik van geïntegreerde dinamiese simulasie en optimisering behaal kan word.

Nog `n groter potensiaal bestaan om las te skuif en elektrisiteits effektiwiteit deur aanvraag kant bestuur (DSM) op die ondergrondse dienste toe te pas. Dus deur die toepassing van DSM in kombinasie met SSM strategieë kan `n verdere en nog groter potensiaal vir ESKOM en die myne moontlik word. As gevolg van dié feite is die studie onderneem.

Drie myne is gekies as gevalle studies, naamlik Kopanang en Target, beide goud myne, en Amandelbult, `n platinum myn. Die DSM potensiaal vir elk van die myne is bepaal deur die gebruik van simulasie, kalibrasie, verifikasie en optimsering.

Hierdie resultate is voorgelê aan die mynbestuur gedurende die onderhandeling van die implementering van die voorgestelde strategieë. Kopanang se bestuur het toestemming gegee vir die implementering van die strategieë vir `n toets tydperk van drie maande waarna die sukses van die strategieë geëvalueer sal word.

Die resultate saam met die resultate van die gevalle studies is gebruik om die nasionale DSM potensiaal in die myn sektor te bepaal met behulp van ekstrapolasie. Die totale DSM potensiaal werk uit op 650MW las wat geskuif kan word sowel as `n 5% elektristeits-besparing. Dit kom neer op `n besparing van R72.1 miljoen per jaar as die huidige tariewe gebruik word. Dit beteken dat ESKOM R5000 miljoen kan bespaar op die bou van `n nuwe kragsentrale om `n ekwivalente las aan die DSM potensiaal te verskaf.

Die bevindinge van die studie moet nou gebruik word om die implementering van hierdie strategieë regdeur die mynsektor te motiveer. `n Soortgelyke projek kan onderneem word om te kyk na moontlike DSM strategieë in die industriële sektor

Dit mag dalk moeiliker wees weens die feit dat al die elektrisiteits intensiewe stelsels baie nou aan die produksie proses gekoppel is. Soos bespreek in die verslag is produksie baie belangriker as moontlike elektrisiteits koste besparings uit `n bestuursoogpunt.

ESKOM en die NER sal hulle strategieë moet heroorweeg. Deur DSM en las skuif alleen kan die komende elektrisiteits-krisis nie afgeweer word nie. Die huidige tarief

struktuur moet so aangepas word dat dit nie net die ware koste van elektrisiteit reflekteer nie, maar ook voldoende aansporing vir DSM en las skuif gee.

Om die DSM teikens vir 2007 te bereik sal nog `n probleem eers aangespreek moet word naamlik die *tyd wat dit neem vir die studie* sowel as *die implementering.* Sagteware kan geskryf word om te help met die bespoediging van die proses omdat die stappe wat gevolg word sowel as die modelle wat gebruik word baie generies is veral in die platinum en goud myn sektore.

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- Transfer of Energy, Momentum and Mass International (Pty.) Ltd. for the use of their simulation software.
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Finally, all thanks to my Creator, without whom none of this would have been possible. Thank you Lord, for your endless blessings.

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NOMENCLATURE

Abbreviations

A: Area (m^2)

a: Correlation coefficient, Power coefficient, Air resistance

ANMD: Average national mining demand (GW)

b: Correlation coefficient

c: Specific heat capacity (J/kgK), Correlation coefficient

CPI: Consumer price index

CSGP: Case study gold potential (%)

CSPP: Case study platinum potential (%)

BAC: Bulk air cooler

CBL: Customer base line

COP: Coefficient of performance

D: Diameter (m)

DSM: Demand side management

ECO: Electricity conservation opportunities

EM: Energy management

HSM: Heat stress management

I: Enthalpy (KJ/kg)

ICEE: Industrial and commercial electricity efficiency

ICLM: Industrial and commercial load management

K: Dimensionless coefficient

L: Level

LS: Load shifted (GW)

m: Mass flow (kg/s)

N: Rotational speed (r.p.m)

P: Pressure (kPa)

Pwr: Compressor power (kW)

PF: Power factor

Q: Cooling capacity (kW), Electricity consumption (kW), Heat load (kW), Airflow (kg/s)

REE: Residential electricity efficiency

REMS: Remote energy management system

RH: Relative humidity (%)

RLM: Residential load mangement

RTP: Real time pricing

RPM: Rustenburg platinum mines

SCADA: Supervisory control and data acquisition

SSM: Supply side management

T: Temperature (°C)

TOU: Time of use

t: Time (s)

U: Heat transfer coefficient (W/m^2K)

VC: Ventilation and cooling

VCP: ventilation, cooling and pumping

Subscripts

air: Air

ambient: The surrounding air

ce: Condenser outlet

co: Condenser outlet

e: Evaporator

ee: Evaporator outlet

ei: Evaporator inlet

eo: Evaporator outlet

f: flow

fg: Mixed gas state

h: Pressure head

inlet air: The air at the inlet

l: Water, Latent

li: Inlet water

max: Maximum

min: Minimum

p: Constant pressure

rock: Rock

s: Sensible

shaft: Shaft

sp: Spray pond

wb: Wet bulb

Greek

η: Efficiency

CHAPTER 1.

INTRODUCTION

In this chapter a background to the study is given. Furthermore the objectives as well as the contribution of this study are given. Lastly a brief overview of the thesis is given.

1 INTRODUCTION

1.1 Background

ESKOM is moving towards a price structure for electricity which reflects, as far as possible, the real cost of generation. It is called real time pricing (RTP). ESKOM developed this cost structures to coax customers to use more electricity in off-peak periods (low cost of generation) and less electricity in peak periods (high cost of generation).

However, many industries do not effectively use these price offerings from ESKOM to the detriment of themselves and ESKOM. In previous research, improvements to this situation for the South African mining industry were investigated [1] [2] [3].

It is obviously beneficial to ESKOM and the mines if the mines can operate electricity "clever" by using RTP, i.e. more electricity during inexpensive off-peak periods and less electricity in expensive peak periods.

ESKOM therefore funded research to find the potential for load shifting on mines using RTP. The RTP investigation focused on the supply side management (SSM) in the mining context of underground services on gold and platinum mines. The supply side in the context of this study is seen as all services that supply a service on a constant basis to the rest of the mine like the cooling plant delivering chilled water to the mine. Elements investigated included the ventilation, cooling and pumping (VCP) systems. (Except for pumps, these plants are generally installed aboveground.)

The research report published in July 2001 showed a national RTP and SSM potential to shift 500 MW of electrical load for a period of 5 hours [3].

Through the previous research it became clear that the mines were previously able to react partially to the price signals. However, it was proved by the research that the full load shift potential can only be realised through the use of integrated dynamic simulation and optimisation.

Preliminary investigations show that an even higher potential exists for load shift and electricity efficiency through demand side management (DSM) on the underground services. Demand side services are services that only supply a needed service if there is a specific demand for it like the BAC's that only need to run if the underground temperature reaches a specific temperature. Therefore, if underground DSM strategies are combined with SSM strategies, a further and much bigger potential can be exploited to the benefit of ESKOM and the mines. Due to these factors this study was undertaken.

1.2 Problem statement and criteria

It is widely known that especially gold mines are under extensive financial pressure because of increasing cost and fluctuating gold prices as well as exchange rates as determined by global markets. Mining companies have responded with restructuring and the closure of uneconomical shafts. This caused extensive retrenchments and labour and social turmoil. A lot is being done to reduce input cost, but very little in the field of electricity savings.

The cooling, ventilation and pumping systems account for about 25 % of the electricity costs [4]. If the use of electricity can be optimised and large savings and/or surplus electricity obtained, it, along with future changes in the electricity market may cause the following benefits [5]:

- Better environmental conditions underground at a lower cost,
- The demand for electricity by the ventilation, cooling and pumping systems in mines can be harmonised with the country's total electricity supply by integrating this with national Demand Side Management programmes by means of suitable price signals from ESKOM;
- Long term savings in costs and the delay in capital investment in the better utilisation of existing power stations, transmission and distribution systems for ESKOM;
- Tradable electricity that can be sold for additional profit;
- Reduced pollution and a resultant decrease of non-quantifiable external costs of electricity generation.

This can only be achieved through the use of integrated dynamic simulation as well as optimisation of the systems delivering the underground services to study the potential of both supply side and demand side management strategies. Such studies have been done especially on supply side management strategies [1]. The national potential for SSM in South Africa has also been determined previously [5]. All these studies were theoretical studies lacking the physical implementation of the proposed strategies to determine the actual achievable savings as well as the amount of load shifted. This study combines the use of simulation and optimisation on both the SSM and DSM of the mine underground services. This together with the implementation of the proposed strategies on one of the case studies is unique to this case study. No other reference to such a study was found during the literature survey spanning several databases (ScienceDirect and Compendex) as well as the internet.

There exists a demand for the quantification of the practically achievable DSM potential in South Africa in mine underground services.

This thesis presents a quantification of the potential, as well as a methodology for the implementation of DSM strategies on mines.

1.3 Objectives

The primary objective of this study is to calculate the national achievable DSM potential in mine underground services. To achieve this, the following secondary objectives must be met:

- The selection of three typical gold and platinum mines for this study
- The simulation, verification and optimisation of the electricity intensive systems on each of the case studies
- Identification of DSM and load shifting strategies to be studied
- Calculation of the DSM and load shifting potential on each of the case studies
- Implement the proposed strategies on at least one of the mines
- Measure the achievable DSM and load shifting potential
- Setup an implementation plan for future implementations
- Extrapolate the potential from the case studies to calculate the national potential

1.4 Contribution of this study

The author plans to contribute the following to the engineering community and the country's future:

- Calculate the achievable DSM potential in mine underground services utilising integrated simulation and optimisation techniques.

- Implement the proposed strategies to illustrate the feasibility and sustainability of these strategies. This physical implementation of the strategies is unique.
- Create a basic implementation plan for DSM strategies

1.5 Brief overview of the thesis

In Chapter 1 the background, objectives and contributions of the thesis is discussed. Chapter 2 looks at the selection of the three case study mines, some more background on the specific mines, current available tariffs, health and safety regulations and their impact on the study and lastly preliminary DSM potential is calculated.

Kopanang, the first of the three case study mines, is discussed in Chapter 3. The discussions include simulation models, their calibration and verification, optimisation models as well as the calculation of the DSM potential. The other two case studies Amandelbult and Target are discussed similarly in Chapters 4 and 5 respectively.

The implementation of the proposed strategies is discussed in Chapter 6. This includes the discussions with mine management to get approval for the implementation, the implementation process, the service delivered during the trial period as well as the measured results for this period. The uniqueness of the thesis, namely the physical implementation of the proposed strategies, is summarised in this chapter

After the implementation an implementation strategy was developed to help during future implementations. This strategy is discussed in Chapter 7.

Chapter 8 highlights the calculation of the national impact of DSM strategies on the mines, ESKOM and the environment. This chapter discusses one of the main objective of this thesis. Lastly al the findings of the thesis are summarised in Chapter 9 and recommendations for future work are made.

CHAPTER 2.

SELECTION OF PILOT MINES AND BACKGROUND INFORMATION

In this chapter the identification of the three case study mines as well as general background information regarding the case studies are discussed. This includes information on the mines, a summary of the available electricity tariffs, health and safety regulations and expected electricity cost savings.

2 SELECTION OF PILOT MINES AND BACKGROUND INFORMATION

2.1 Identification of suitable mines

2.1.1 Meetings with the mining groups

2.1.1.1 AngloGold

Various meetings were held to do DSM studies on the other AngloGold mines. The general reception of these proposals was good. They felt that the value of our studies was not apparent yet and that we should approach them once we have measured results on one mine for a year.

2.1.1.2 AVGold

AVGold is very technology conscious and aims to produce gold at less than $150 an ounce. They are very keen on any cost savings. After several meetings discussing the proposed study and its implications. AVGold agreed to the study being done on one of their Free State operations i.e. Target.

2.1.1.3 AngloPlatinum

AngloPlatinum is the biggest producer of platinum in the world. They are very interested in any savings that can be achieved. Performing a DSM and load shifting study on one of their mines was proposed. After follow-up meetings, discussing the implications of the study, permission to do this study on one of their mines was obtained i.e. Amandelbult.

2.1.1.4 Goldfields

Goldfields is very interested in DSM and load shifting strategies to reduce electricity costs. They have a few marginal mines on which they would like such studies performed, once the value of the study can be proven with measured results on a mine for a year.

2.1.1.5 Harmony Gold

Harmony is known for their cost effective operation of previously marginal mines. One area of their operational costs that is not used optimally, is their electricity. They are very interested in the proposed study. They requested that the first study be performed on one of their reduction plants and not on a mine.

2.1.2 Identify the suitable mines

2.1.2.1 Identification process

Three mines needed to be identified, to perform detailed DSM and load shifting studies on. The selected mines had to be representative of the platinum and gold mining industries in South Africa. The selected mines had to meet the following requirements:

- The systems and sub systems under investigation should be representative of systems found on the majority of mines. This is imperative to ensure that the results can be extrapolated to give a true reflection of the potential impact for the mining sector in South Africa
- The mine must have the potential for DSM and load shifting on underground services. These include underground pumping ventilation and cooling. These systems must have spare capacity to enable the implementation of DSM and load shifting strategies.
- The mine must be willing to implement the proposed strategies for a trial period if the predicted savings and proposed strategies warrant it.
- Be keen on the performance of the studies themselves. This prerequisite will ensure that the study is done in the shortest possible time as input from the mine is vital during the case study.

The selection of the three mines is discussed next.

2.1.2.2 Kopanang, AngloGold

The sinking of the shaft started in 1978 and reached a depth of 2240 m. The first gold from the shaft was produced in 1984. The shaft currently hoists 226 000 tons of material, including waste, per month. The mine currently employs 6 700 people, including contractors.

The mine is now focussing on the establishment of four major mining levels. The application of technology to cope with the planned concentrated mining activities at these levels currently receives considerable attention. These technologies include automation of the underground pumping stations and aboveground refrigeration systems.

A study was done in 2001 on the effective use of RTP on the mine supply side services. The mine management received the previous study very favourably. Due to this and the fact that most of the other mine groups are reluctant to allow such a study without a year's measured results of such a previous study, it was decided to extend the current study to include DSM and load shifting on the underground services.

2.1.2.3 Target, AVGold

In April 1995 AVGold initiated an underground exploration project that involved developing a decline system from Loraine mine into Target, to serve as a drilling platform. The Target ore-body displayed characteristics suitable for massive mining techniques, and feasibility studies for a 45 000 tonnes a month mine began. In July 1996 the decision was taken to increase the scope of the project to a 90 000 tonnes per month mine, which required the development of additional declines and infrastructure.

Currently production at Target equates to 130 tonnes milled per man per month. Target aims to improve on their productivity figures by making more extensive use of technology based on economic principles.

Target was selected as the second mine due to their eagerness to reduce their electricity costs and their open-mindedness regarding the control of the underground cooling and ventilation.

2.1.2.4 Amandelbult, AngloPlatinum

Rustenburg Platinum Mines (RPM) holds mineral rights throughout the Bushveld Complex under various titles. These are currently being exploited on a fully operational basis at the Rustenburg, Amandelbult and Union sections, covering a total of 2590 hectares.

Compared to 2000, total tons milled rose by 10.5%, head grade was up 2.2% and platinum refine increased by 19% at Amandelbult. Productivity increased year on year from 57.6 to 68.7 refined platinum ounces per employee. No.1 shaft refrigeration plant was commissioned in October 2001 and is now fully operational.

Amandelbult was selected to represent the platinum mines in this study. This is due to its large electricity consumption and spare plant capacity. This is ideal for DSM and load shifting.

2.2 Review and analysis of existing electricity tariffs

2.2.1 Pricing Structures for mines

2.2.1.1 Background

Due to varying demand the generation of electricity is not constant over time. The cost is dependent 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 [6]. For this reason ESKOM had devised various tariff structures with time of use (TOU) characteristics to accommodate and assist 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 for large customers [7]

- 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. The connection fee is differentiated on the capacity and number of phases of the supply.
- Capital cost: Applicable to a new connection, in order for ESKOM to recover by the tariff, a monthly charge and/or up front payment may be applied in addition to the standard tariffs. The monthly charge for all existing and new customers will be subject to a rebate at R2.00 per kW of chargeable demand.
- Rebate: This is a reduction of the monthly charge based on the demand or kWh consumption of the supply. The rebate caters for capital related costs included in the tariff.
- Service Charge: A fixed charge payable every month, whether electricity is consumed or not, based on the utilised capacity per account.

- Administration Charge: A fixed charge payable per point of delivery (POD) every month, whether electricity is consumed or not, and determined on the utilised capacity of that POD.
- 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 Electricity Charge: A charge for each kilowatt-hour (kWh) of active electricity consumed.
- Reactive Electricity Charge: This charge applies only to MEGAFLEX. It is levied on every excess kilovarhour (kvarh) registered (30% more than kWh registered). If the customer's installation is operating at a power factor of 0,96 or better, there will be no reactive electricity charge.
- Voltage surcharge: 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 lower the voltage surcharge charged. This is calculated as a percentage of demand (where applicable) and active electricity charges.
- Transmission Surcharge: The demand charge (where applicable), active electricity charges and reactive electricity charge (where applicable) are subject to a transmission surcharge after the voltage surcharge have been levied, depending on the distance from Johannesburg.

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

2.2.1.2 NIGHTSAVE

NIGHTSAVE is for 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 fee for mines is usually the greater of R9 824.56 (VAT excl.) or 5% of actual project cost (VAT excl.) payable per point of delivery. The connection fee for other capacities is also indicated in *Table 2.1*.

Capacity	Connection fee
25 kVA	R 2,894.74
50 kVA	R 3,333.33
100 kVA	R 3,947.37
200 kVA	R 5,526.32
315 kVA	R 5,964.91
500 kVA	R 9,824.56
> 500 kVA	The greater of R9 824.56 or 5% of actual project cost

Table 2.1: Connection fees (VAT excl.)

- Service charge: Charged per account and is based on the sum of the utilised capacity of all the POD's linked to the account. The service charge (VAT excl.) is given in *Table 2.2*.

Utilised capacity	Service charge
<= 100 kVA	R 30.09
> 100 kVA and <= 500 kVA	R 419.63
> 500 kVA and <= 1 MVA	R 1,267.62
> 1 MVA	R 1,270.27
Key customers	R 6,645.36

Table 2.2: Service charge per month (VAT excl.)

- Administration charge: Determined and payable for the utilised capacity of each POD linked to the account. The administration charges for the different capacities are indicated in *Table 2.3*.

Utilised capacity	**Administration charge**
<= 100 kVA	R 66.83
> 100 kVA and <= 500 kVA	R 117.26
> 500 kVA and <= 1 MVA	R 918.86
> 1 MVA	R 923.02
Key customers	R 960.57

Table 2.3: Administration charges per month (VAT excl.)

- Demand charge: Maximum demand is charged on either kVA or kW. The integration periods applicable to the two are as follow:
  - On kVA 30 minute integrating periods are applicable.
  - On kW 60 minute integrating periods are available.

The demand charges are indicated in *Table 2.4*.

	High demand season (June-August)	**Low demand season (September-May)**
/kVA	R 26.15	R 10.66
/kW	R 30.77	R 12.54

Table 2.4: Peak demand charges per month (VAT excl.)

No demand charge is applicable during off-peak periods (indicated in *Figure 2.1*). 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.

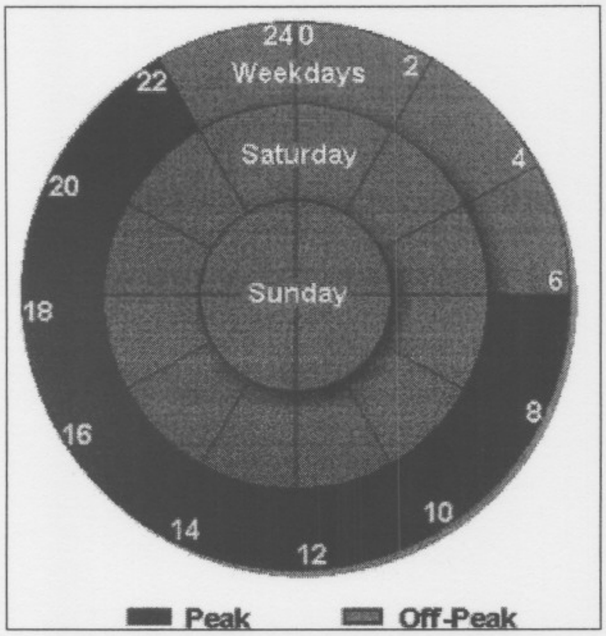


Figure 2.1: NIGHTSAVE peak and off peak hours

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

- Active electricity charge: Charge per kWh of the total electricity consumption of the month. The charge for the different seasons is indicated in *Table 2.5.*

High demand season (June-August)	**Low demand season (September-May)**
12.42c/kWh	9.16c/kWh

Table 2.5: Active electricity charges (VAT excl.)

- Voltage surcharge: This is calculated as a percentage of demand and active electricity charges. The various surcharges are indicated in *Table 2.6.*

Supply voltage	Surcharge
> 132 kV	0.00%
>= 66 kV and <= 132 kV	7.63%
>= 500 V and <= 66 kV	10.07%
< 500 V	17.30%

Table 2.6: Voltage surcharge.

- Transmission surcharge: The demand charge and active electricity charges are subject to a transmission surcharge, after the voltage surcharge has been levied, depending on the distance from Johannesburg. The surcharges for the different distances are indicated in *Table 2.7*.

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

Table 2.7: Transmission surcharge

2.2.1.3 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 a part of the day when electricity is charged at a maximum or peak cost. *Figure 2.2* indicates the different Time-of-Use (TOU) ratings.

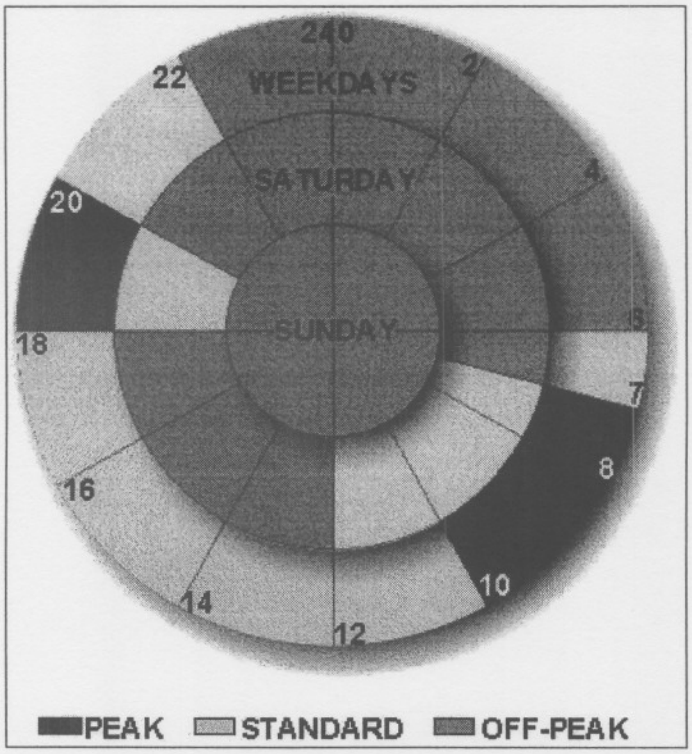


Figure 2.2: Time-of-Use ratings

The basic charges associated with this tariff system are:

- Connection fee: The fee for mines is usually the greater of R9 824.56 (VAT excl.) or 5% of actual project cost (VAT excl.) payable per point of delivery. The connection fee for other capacities is indicated in *Table 2.1*.
- Service charge: Charged per account and is based on the sum of the utilised capacity of all the POD's linked to the account. The service charge (VAT excl.) is given in *Table 2.2*.
- Administration charge: Determined and payable for the utilised capacity of each POD linked to the account. The administration charges for the different capacities are indicated in *Table 2.8*.

Utilised capacity	**Administration charge**
> 1 MVA	R 846.84
Key customers	R 888.21

Table 2.8: Administration charges per month (VAT excl.)

- Demand charge: Per kW of maximum demand supplied during peak or standard periods (indicated in *Figure 2.2*) per month. 30-minute integrating periods are applicable. The demand charges are indicated in *Table 2.9*.

	High demand season (June-August)	Low demand season (September-May)
/kW	R 8.17	R 8.17

Table 2.9: Peak demand charges per month (VAT excl.)

No demand charge is applicable during off-peak periods (indicated in *Figure 2.2*).

- Active electricity charge: Charge per kWh of the total electricity consumption of the month. The charge for the different seasons and time of use periods is indicated in *Table 2.10*.

	High demand season (June-August)	Low demand season (September-May)
Peak	45.49c/kWh	13.92c/kWh
Standard	13.11c/kWh	9.21c/kWh
Off-peak	7.76c/kWh	6.94c/kWh

Table 2.10: Active electricity charges (VAT excl.)

- Reactive electricity charge: Supplied in excess of 30% (0.96 Power factor (PF)) of kWh recorded during peak and standard periods. The excess reactive electricity is determined per 30-minute integrating period and accumulated for the month. Charged at 2.85c/kvarh (VAT excl.).

- Voltage surcharge: This is calculated as a percentage of demand and active electricity charges. The various surcharges are indicated in *Table 2.6*.

- Transmission surcharge: The demand charge and active electricity charges are subject to a transmission surcharge, after the voltage surcharge has been levied, depending on the distance from Johannesburg. The surcharges for the different distances are indicated in *Table 2.7*.

2.2.1.4 Real Time Pricing (RTP)

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 short term 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 large electricity transactions in future.

The objectives of the RTP product are [8]:

- The promotion of economic efficiency through appropriate marginal cost based price signals.
    - To stimulate optimal behaviour through dynamic price signalling. This includes:
    - Electricity conservation when the system is constrained, as signalled by high prices.
- Increased electricity 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 risk related cost of the response is greater than 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 [9].

Two part RTP consists of a Customer Base Line (CBL) load cost and a RTP cost. The CBL load is calculated from the previous years measured electricity demand. The electricity demand is used to calculate an average demand profile for certain day types for both summer and winter. The customer can define these specific day types, examples of these are:

- Weekday
- Saturday
- Sunday
- Public holiday
- Long public holiday

This load is then used to calculate the electricity cost for a 30 day and 31 day month as if the user was still on the NIGHTSAVE or MEGAFLEX tariff. This cost is then divided by the total electricity consumption to calculate the CBL unit cost (c/kWh) for a 30 day and 31 day month. The CBL cost is a fixed cost even if the user does not use the electricity.

The RTP part of the tariff has a debit and credit price for every hour of every day. This price is calculated by ESKOM every day for the next day. The RTP cost is calculated as follows: If more electricity than the CBL load is used this excess amount is billed with the RTP debit price. When less than the CBL load is used this amount of load is credited with the RTP credit price.

2.3 Investigate and analyse health and safety regulations and requirements

2.3.1 Current health and safety regulations

The health and safety aspects concerning this study mainly include the regulations that deal with the working environment in terms of temperature and air supply. The following is a summary of the required environmental conditions in South African mines [10]:

2.3.1.1 Regulation 10.6.2

The workings of every part of the mine where people are required to travel or work shall be properly ventilated to maintain safe and healthy environmental working conditions for the workmen, and ventilating air shall be such that it will dilute and render harmless any flammable or noxious gases and dust in the ambient air.

2.3.1.2 Regulation 10.7.1

The velocity of the air current along the working face of any stope shall average not less tan 0.25 m/s over the working height.

2.3.1.3 Regulation 10.7.2

The quantity of air supplied at the working face of any development end such as a tunnel, drive cross-cut, raise of winze which is being advanced and at the bottom of any shaft in the course of being sunk, shall not be less than 150 cubic decimetres per second for each square metre of the average cross-sectional area of the excavation.

2.3.1.4 Regulation 10.12

No person shall work or permit any other person to do any work in any part of the mine where the conditions are conducive to heat stroke, unless such work is carried out in accordance with a code of practice approved by the Principal Inspector of Mines.

On mines having workplaces with environmental conditions potentially conducive to heat stroke (where T_{wb} reaches a level of 27.5 °C), a formal heat stress management (HSM) program governed by an approved code of practise is required.

It is evident that the ultimate responsibility for ensuring a safe working environment within the requirements of the law rests with the mine manager. Most mines in South Africa use wet-bulb temperature as the primary indicator of adequacy of thermal conditions. The limit at which formal HSM procedures are required is 27.5°C wet-bulb, while 32.5°C wet bulb is taken as the boundary for routine work. A dry bulb temperature of 37°C is accepted as the upper limit for physical work to be performed.

2.3.2 The impact of the regulations and actual environmental conditions on potential DSM strategies

2.3.2.1 Amandelbult, AngloPlatinum

Amandelbult strives to keep the environment at the working areas at a temperature below 27.5°C wet bulb. Temperature readings are taken daily at 14:00 at the working areas to monitor the acceptability in the working environment.

Currently, the situation is such that a temperature below 27.5°C can be maintained in summer conditions when the cooling plant is operating at full capacity. Due to the operating conditions being very different from the design conditions the environmental conditions are at the limit of acceptability. Therefore, no excess capacity exists for a DSM action to be implemented during this time.

In winter conditions, however, surplus capacity exists on the cooling plant and DSM actions can be implemented. In these times the cooling plant is not required to operate at full capacity to ensure the minimum allowable temperature in the working areas.

2.3.2.2 Kopanang, AngloGold

Kopanang strives to keep the environment at the working areas at a temperature below 27.5°C wet bulb. Temperature readings are taken daily at 14:00 at the section leading up to the working areas. This temperature should be below 21.5°C wet bulb to ensure a temperature of no more than 27.5°C wet bulb in the working section.

Currently, Kopanang is struggling to maintain the temperature below 27.5°C wet bulb in the working areas in summer. This is due to the shift in production intensity to four major working areas.

The doubling of the production from the designed specifications also added to the cooling and ventilation problem. Kopanang is currently redesigning their ventilation and cooling layout. Therefore, no access capacity exists for a DSM action to be implemented during summer conditions.

After the implementation of the redesigned cooling and ventilation systems, DSM actions in summer may be considered.

In winter conditions, however, excess capacity exists on the cooling plant and DSM actions can be implemented. In these times the cooling plant is not required to operate at full capacity to ensure the minimum allowable temperature in the working areas.

2.3.2.3 Target, AVGold

Target strives to keep the environment in the working areas at a temperature of 25.5°C that is lower than the upper limit for acceptability, 27.5°C. Wet bulb temperature measurements are taken daily and currently a system that will provide real time temperature measurements in the working areas throughout the day is being installed.

Currently, Target is struggling to maintain a wet bulb temperature of 25.5°C at the exit of the working area. This is due to the construction of a new condenser spray pond. Target is also busy upgrading their cooling plant from a current cooling capacity of 15 MW to 24 MW.

The cooling plants are situated underground. Therefore the aboveground climate conditions have no impact on the underground conditions. DSM strategies will include the optimisation of the cooling power airflow relation to ensure the correct wet bulb temperature in the working areas.

2.4 Identify and analyse potential DSM actions and alternatives

2.4.1 Amandelbult

To ensure maximum safety in the working areas no actions will be investigated concerning the air flow equipment. Additionally any changes in the airflow system are very expensive, and therefore not very economically viable.

The study will focus on possible DSM strategies on the surface Bulk Air Cooler (BAC) as this is the main component in the cooling system. The water flow and temperature to the BAC will be controlled to ensure that the conditions at the working areas remain under 27.5°C wet bulb. This, together with load shifting on the underground pumps will reduce the load on the refrigeration plant.

2.4.2 Kopanang

To ensure maximum safety in the working areas no actions will be investigated concerning the air flow equipment. Additionally any changes in the airflow system are very expensive, and therefore not very economically viable.

The study will focus on possible DSM strategies on the surface Bulk Air Cooler (BAC) as this is the main component in the cooling system.

Kopanang is currently re-designing the cooling system of the mine, making it impossible to analyse other possibilities at this time. More possibilities can be assessed once the system design has been finalised.

In spring and autumn DSM potential does exist on the BAC. During these times the number of cells of the BAC will be controlled to ensure a wet bulb temperature of below 21.5°C at the underground monitoring point. This will reduce the refrigeration load and thus the electricity consumption.

2.4.3 Target

DSM strategies will include the optimisation of the clear water pumping plants to limit the use of energy during ESKOM's peak periods. An automatic pump system will regulate the underground clear water dam levels and will control the pumps so that the necessary water can be pumped at the minimum cost.

The underground power versus airflow relation will be optimised to ensure the minimum electrical energy needed to maintain acceptable underground climate conditions. Here the fan speeds and cooling characteristics will be controlled to ensure the optimum underground air speed and temperature. This will include the minimisation of cooling power during ESKOM's peak periods.

2.5 Conclusion

2.5.1 Summary

In this chapter the outcome of the meetings held with the main mining groups to identify three suitable gold or platinum mines for the project were discussed. After these meetings three suitable mines were identified using the following criteria.

- The systems and sub systems under investigation should be representative of systems found on the majority of mines. This is imperative to ensure that the results can be extrapolated to give a true reflection of the potential impact for the mining sector in South Africa
- The mine must have the potential for DSM and load shifting on underground services. These include underground pumping ventilation and cooling. These systems must have spare capacity to enable the implementation of DSM and load shifting strategies.
- The mine must be willing to implement the proposed strategies for a trial period if the predicted savings and proposed strategies warrant it.
- Be keen on the performance of the studies themselves. This pre requisite will ensure that the study is done in the shortest possible time as input from the mine is vital during the case study.

These are Kopanang, Target (both gold mines), and Amandelbult (a platinum mine). The available electricity tariffs to the mining sector were also discussed in detail. The application of these tariffs on the three mines was also discussed.

The relevant health and safety regulations were discussed, as well as the current conditions in the three pilot mines. The impact of these conditions on potential DSM actions was also analysed and the preliminary savings revised.

2.5.2 Recommendations

These potential savings are only based on the electricity accounts, preliminary system sizes and the potential DSM actions identified. This potential will be established in more detail taking the following into account:

- Operational constraints on the systems targeted for DSM actions
- The actual electricity user profiles of the past year.

The operational constraints include maintenance schedules, control set points and physical system limits like minimum and maximum fluid flows and dam levels.

The simulation, verification, optimisation and detail savings calculations are discussed for each of the three case studies in the next 3 chapters

CHAPTER 3.

KOPANANG: CASE STUDY 1

In this chapter all the steps in the detailed electricity cost savings calculation process in the case of Kopanang is discussed. This includes the simulation and optimisation models (development, setup as well as verification), proposed DSM and load shifting strategies as well as the calculation of the electricity cost savings potential.

3 KOPANANG: CASE STUDY 1

3.1 The configuration and verification of the simulation models

3.1.1 Background information

3.1.1.1 General

The sinking of Kopanang's shaft started in 1978 and reached a depth of 2240 m. The first gold from the shaft was produced in 1984. The shaft currently hoists 226 000 tons of material, including waste, per month. The mine currently employs 6 700 people, including contractors.

The mine is now focusing on the establishment of four major mining levels. The application of technology, both new and adapted, to cope with the planned concentrated mining activities at these levels currently receives considerable attention.

These technologies include automation of the underground pumping stations and above ground refrigeration systems.

3.1.1.2 System layout

3.1.1.2.1 Underground pumping

Chilled water is gravity fed from the surface cold water confluence dam through the turbine on level 38 to the chill water dam on level 38. The chill water flow of ±250 kg/s is enough to drive the turbine driven pump that is used in conjunction with the electrical pumps on level 38. The cold water is gravity fed to all the working areas where it is used for the cooling of the pneumatic rock drills and the rock face.

This water together with the spilled drinking water gravitates down along gullies to the settler dam at level 74. At the settler the silt is gravitated out of the water. The clear water is now fed to the hot water dam on level 75. This dam has a capacity of ±9000 m^3.

Four electrical pumps are available on level 75 to pump the water to level 38. These pumps deliver a flow of approximately 120 kg/s. All four pumps can be used in emergencies but normally one is always on standby.

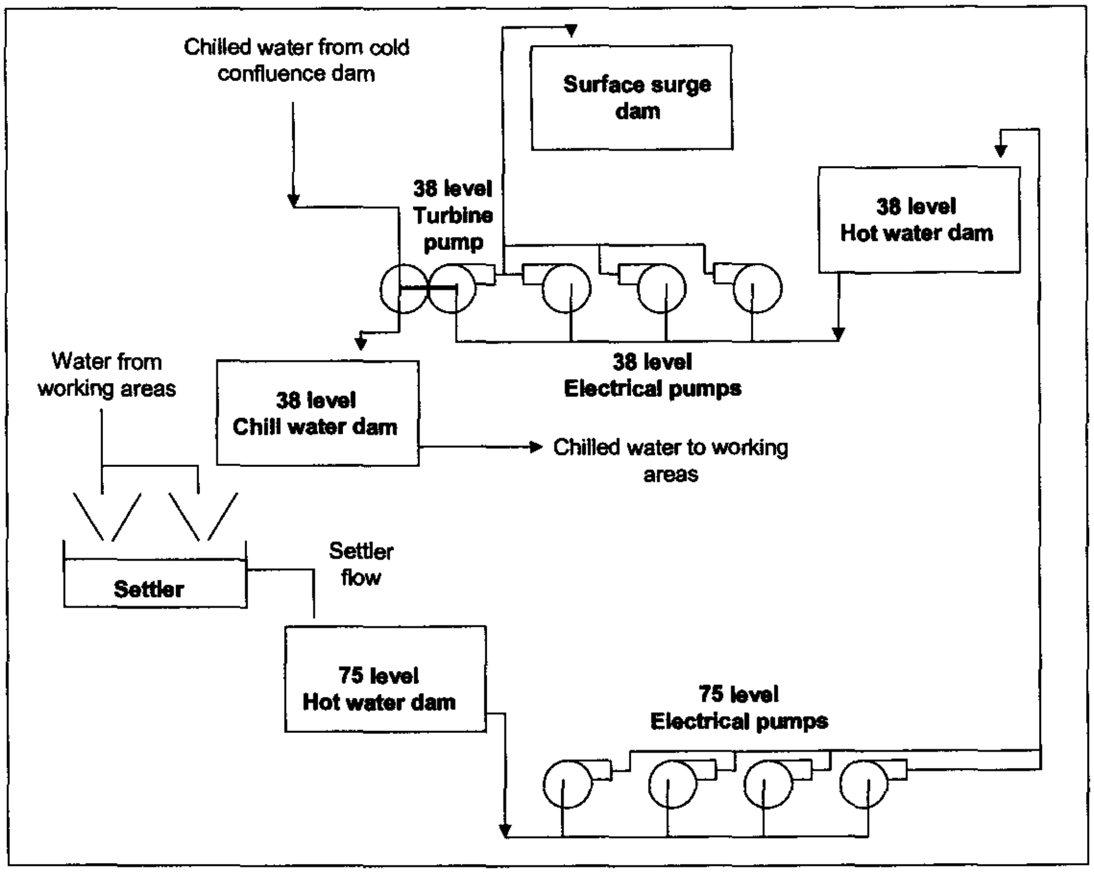


Figure 3.1: Schematic layout of the underground pumping system at Kopanang.

On level 38 the water from level 75 flows into the hot water dam with a capacity of approximately 5500 m^3. There are three electrical pumps on this level. Only two are normally used. The turbine pump is also used constantly during the week. These pumps deliver a flow of 115 kg/s on average. The turbine is only turned off for maintenance to the fridge plants during Sunday mornings.

The water from level 38 is pumped into the surge dam on surface. This is graphically illustrated in *Figure 3.1*.

3.1.1.2.2 Surface refrigeration

The water enters the surge dam at 27°C from the mine. This water is pumped through the two pre cooling towers at a leaving temperature of ±15°C. The transfer pumps pump this water to the hot confluence dam. Here the water returning from the bulk air cooler and the pre cooling towers mix.

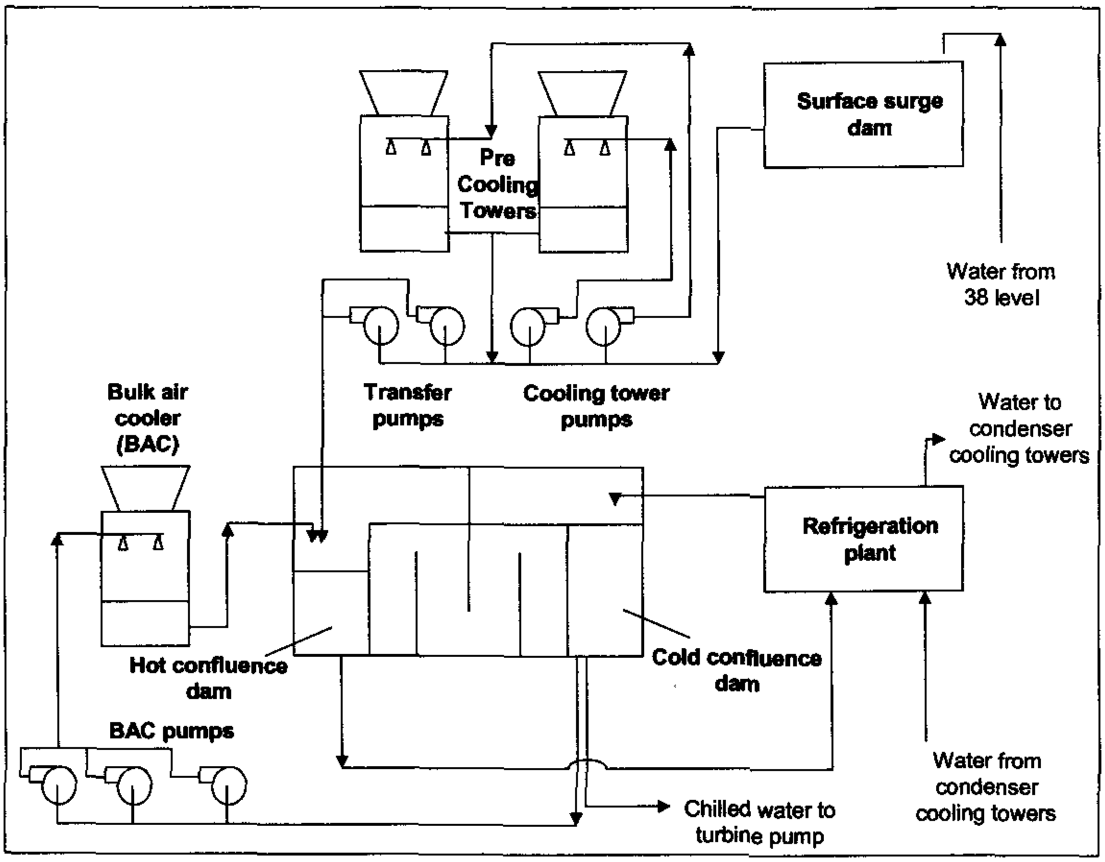


Figure 3.2: Schematic layout of the surface refrigeration system at Kopanang

This water now enters the refrigeration plant via the evaporator pumps. The plant consists of six identical chillers with a combined cooling capacity of 33 MW. The coefficient of performance (COP) of the chillers is 5.5. The evaporator pumps pump the hot water through the evaporator where it leaves the evaporator on its way to the cold confluence dam at 3.5°C. The condenser water is pumped to the condenser cooling towers to be cooled. Each chiller has its own condenser cooling tower.

The water at the cold confluence dam is sent to the underground turbine (250 kg/s) and to the bulk air cooler (250 kg/s per cell). The bulk air cooler (BAC) consists of three cells in parallel each with its own chilled water pump. The BAC is used to cool the entering ventilation air used for cooling of the mine. The water leaves the BAC at 8°C.

3.1.1.3 Electricity audit

There are four main electricity intensive systems namely refrigeration, underground pumping, winding and compressors. The contribution of each of these to the total electricity consumption of the mine can be seen in *Figure 3.3* and *Figure 3.4*.

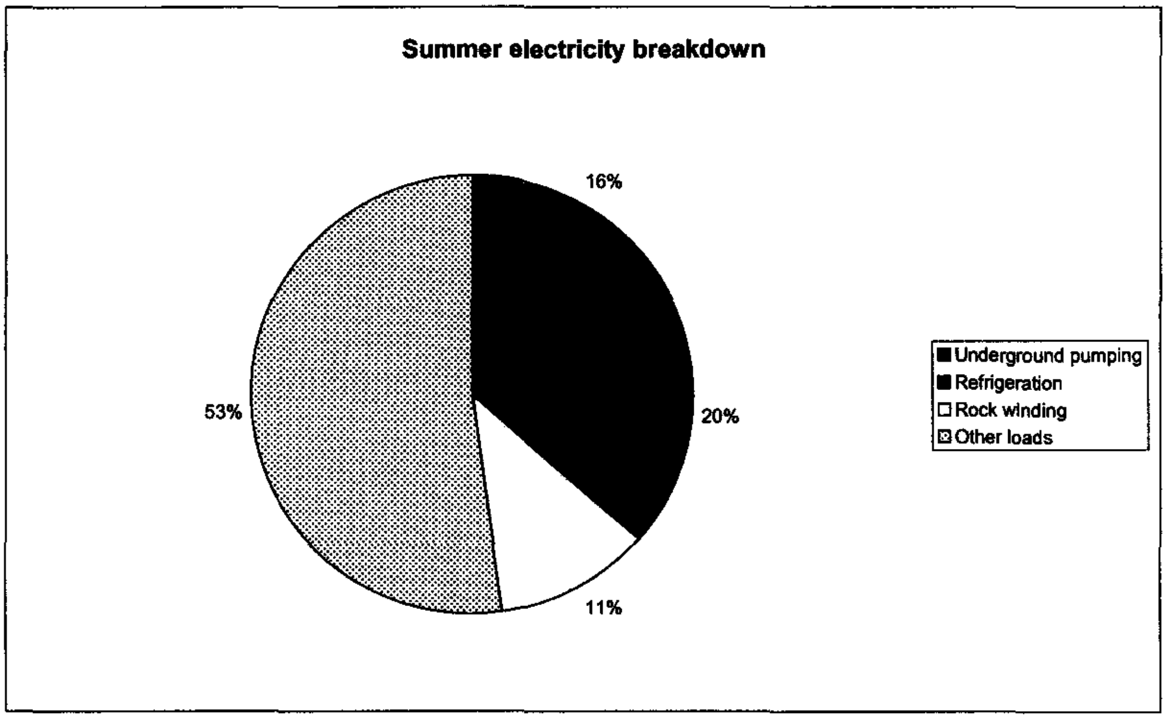


Figure 3.3: Summer electricity breakdown of Kopanang

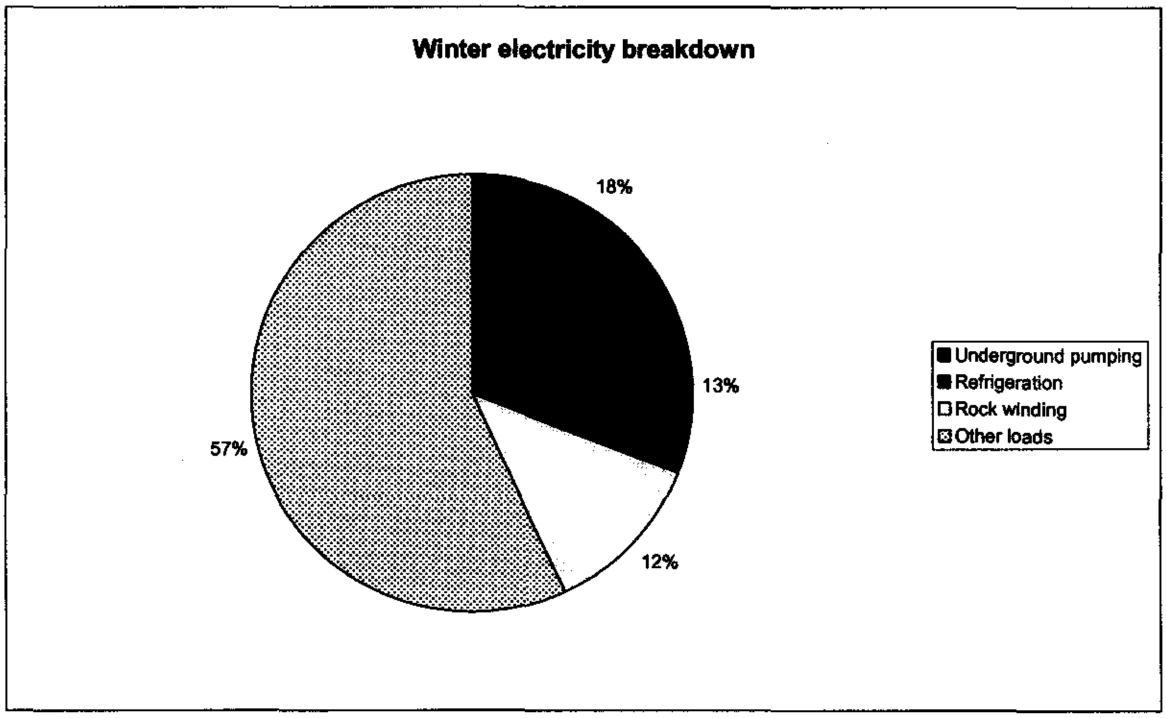


Figure 3.4: Winter electricity breakdown of Kopanang

The air compressors of this mine form part of a compressor ring shared by a series of mines. All the compressors that form part of this ring have their own billing point. For this reason the contribution of the air compressors is not shown in the figure. Only systems on the billing point of the mine will be considered. The base load includes the main ventilation fans, lights, workshops and air conditioning of office buildings. All these systems were not part of the study due to their constant or unpredictable nature.

Of the remaining three systems only rock winding was not made part of the study due to direct influence that the rock winders have on the mine production. Due to the link influence the mine was not prepared to schedule the winders according to electricity tariffs.

The electricity consumption of the underground pumping systems is not affected by the prevailing climate. The refrigeration system on the other hand is completely driven by the climate and thus the seasons. This is clearly visible in the decline in the contribution of refrigeration to the total electricity consumption in winter. The contribution dropped from 20 to 13%.

The effect of load shifting and DSM will be studied on these two systems.

3.1.1.4 Cost

The mine is currently on one of the Real Time Pricing (RTP) tariff structures namely two part RTP. This tariff consists of a Customer Base Line (CBL) load cost and a RTP cost. The CBL load is calculated from historic measured data. This load is then used to calculate the unit cost of electricity if the mine was still on the NIGHTSAVE tariff. The CBL cost is a fixed cost if no electricity is used.

The RTP part of the tariff has a debit and credit price for every hour of every day. This price is calculated by ESKOM every day for the following day. The RTP cost is calculated as follows. If the institution uses more electricity than the CBL they are billed on the amount exceeding the CBL with the RTP debit price. When the institution uses less than the CBL load they are credited with the amount of load less than the CBL times the RTP credit price.

The dynamic nature of this tariff makes scheduling very difficult without the use of optimisation. Optimisation will be used to find the optimum operating schedule of the underground pumping system. On the refrigeration side use of the thermal storage part of the hot and cold confluence dam will allow for load shifting. The employment of DSM strategies on the BAC will also be studied.

The mine had an electricity bill of R30.78 million in 2001. Refrigeration contributed R5.46 million and pumping R3.64 million to the bill.

3.1.1.5 Data availability

The mine has a comprehensive Supervisory Control and Data Acquisition (SCADA) system. All underground dam levels and operating of pumps are logged. On the surface the leaving chilled water temperature, number of BAC pumps active and number of chillers active are logged.

The BAC leaving air temperature and relative humidity were measured during the study. To study the environmental impact of the BAC on the working levels in the mine both air temperature and relative humidity at these levels were measured.

3.1.1.6 Conclusion

The mine is well suited for this case study. The management is very keen on any savings and open to suggestions. The infrastructure is in place to easily automate the systems under investigation. Due to the SCADA system most of the operational condition data is easily available.

The refrigeration plant as well as the underground pumping system has large dams that can be used for storage. This is a prerequisite for load shifting.

3.1.2 Simulation models

3.1.2.1 Underground pumping system

3.1.2.1.1 Background

The accurate prediction of the power consumption of the pumps is essential for any load shifting calculations. To predict a realistic operating schedule for the pumps the following needs to be accurately predicted.

- Flow from the settler
- Both hot water dam capacities
- Water flow of each pump

The way each of these where handled in the simulation is shown in section 3.1.2.1.2.

3.1.2.1.2 Methodology

3.1.2.1.2.1 Dam capacities

The dam capacities were unknown due to the build up of mud in them. These capacities were calculated using each dam's inlet and outlet flows as well as the dam levels.

A few assumptions had to be made as not all the necessary data was available. These are:

- The settler had enough capacity to ensure a constant flow to the level 75 hot water dam. The chilled water demand for the day was then divided by 24 to get the flow per hour.
- All the pumps on one pump station deliver the same flow. This flow was taken as the average flow of the individual pumps.

Using these assumptions together with the measured data of the dam levels and the number of pumps active of each level of every hour the dam capacities were calibrated.

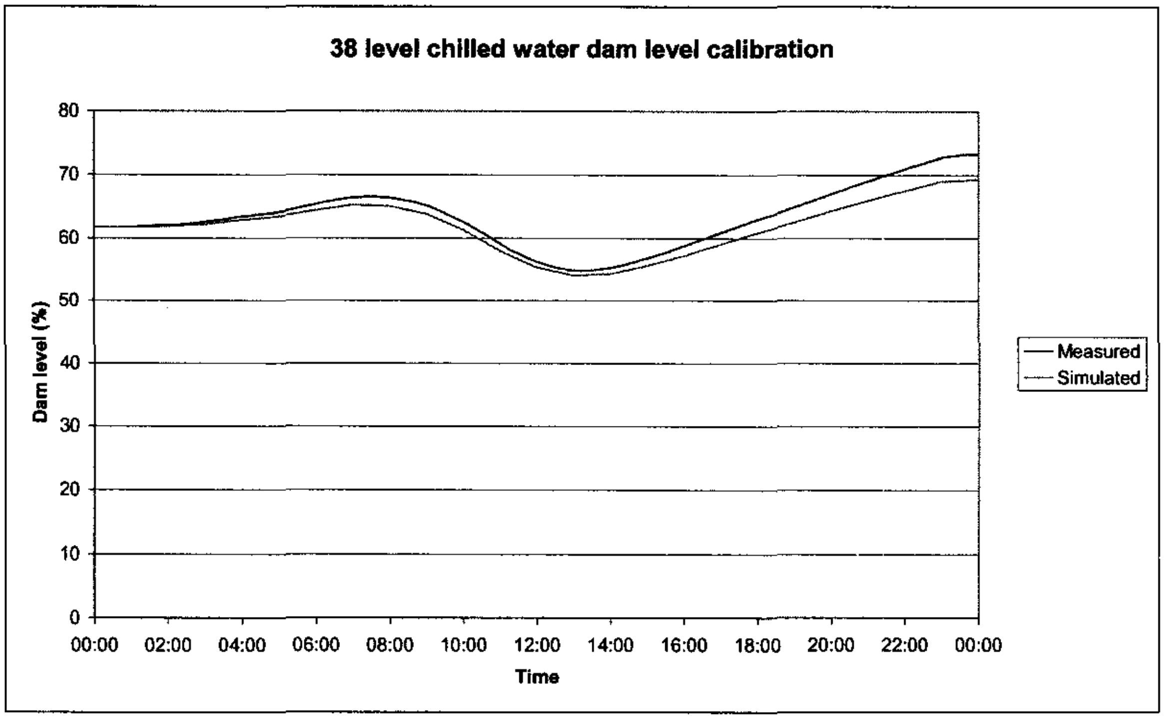


Figure 3.5: Kopanang level 38 chilled water dam calibration.

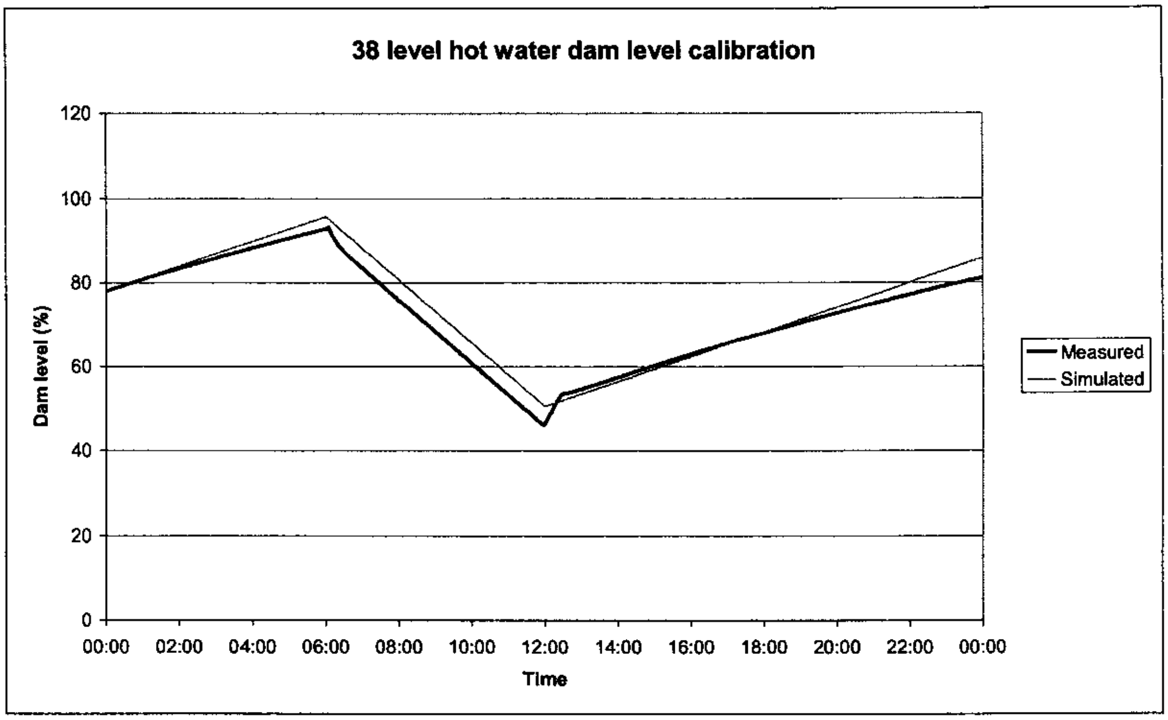


Figure 3.6: Kopanang level 38 hot water dam calibration.

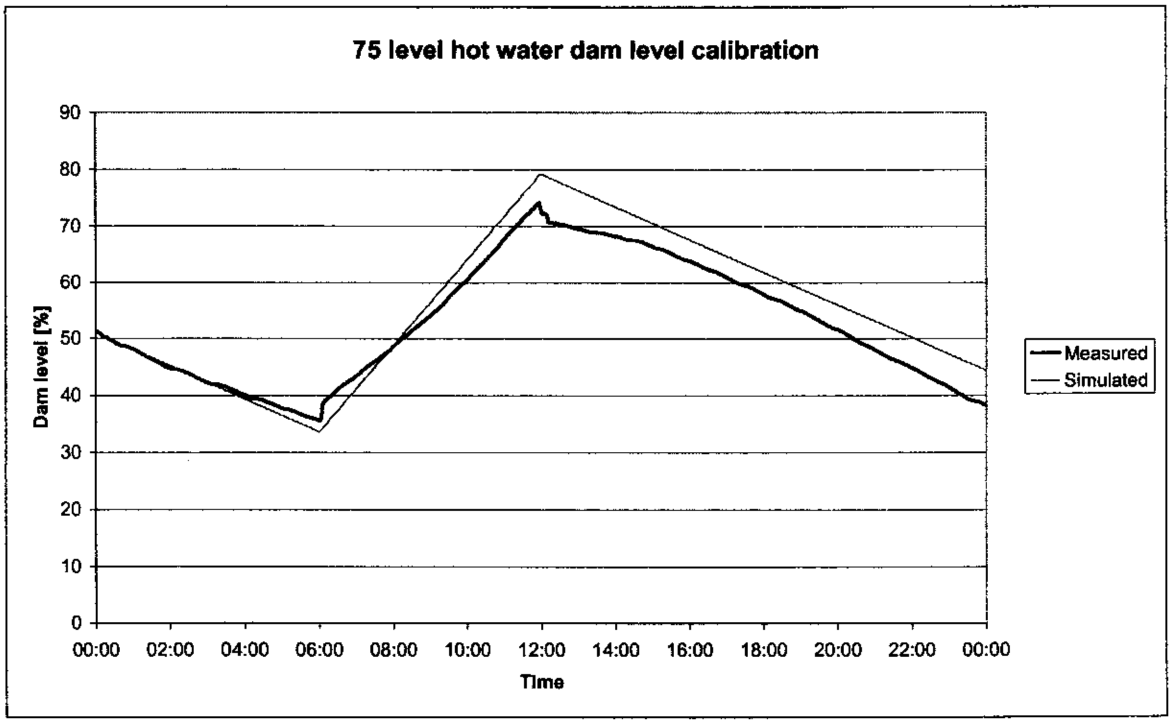


Figure 3.7: Kopanang level 75 hot water dam calibration.

The hot water dam on level 75 had a capacity of 9400 m^3. The capacity of the hot water dam on level 38 works out to be 5490 m^3 and the cold water dam on level 38 13000 m^3. The calibration results can be seen in *Figure 3.5*, *Figure 3.6* and *Figure 3.7*.

The apparent inaccuracies in the calibration are largely due to the fact that the scheduling of the pumps during the simulation can only be done on the hour for the hour. The maximum error of 16% occurred at the level 75 hot water dam. The average error of the calibration of this dam was 4.6%. This was also the worst average error of the three dams. Accuracies within 10% are taken as acceptable.

3.1.2.1.2.2 Electricity consumption

Just as the flow per pump was taken as constant the electricity consumption per pump at a pumping station was taken as the average power consumption of all the pumps at the pumping station. The electricity consumption was then calibrated using the same data as for the dam capacity calibration.

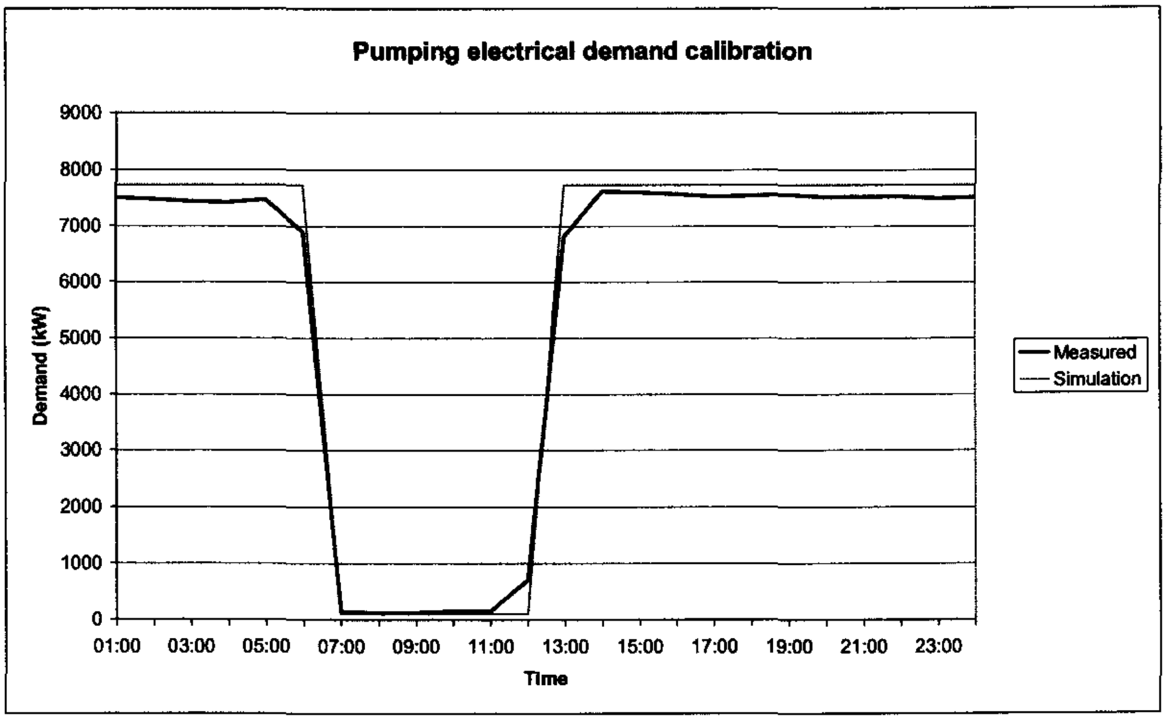


Figure 3.8: Kopanang underground pumping electricity calibration

The calibration results shown in *Figure 3.8* shows that the maximum error occurred during the times that the pumps were switched off. The prediction of the base load is not accurate enough. Due to the relative size of the base load this error is negligible. Disregarding this error the average error was 4% that is within the acceptable limit of 10%.

3.1.2.1.3 Verification

These calibrated values were used just as they were calculated during the calibration to predict the dam levels and electricity consumption for another day. These simulated values were then compared to the measured values of the same day.

3.1.2.1.3.1 Dam levels

The verification results are shown in *Figure 3.9*, *Figure 3.10* and *Figure 3.11*. The verification results were much the same as the calibration results. The level of the chilled water dam on level 38's was on average within 2.3% of the measured level. The accuracies of the two hot water dam levels were 2.3% for level 75 and 3% for level 38.

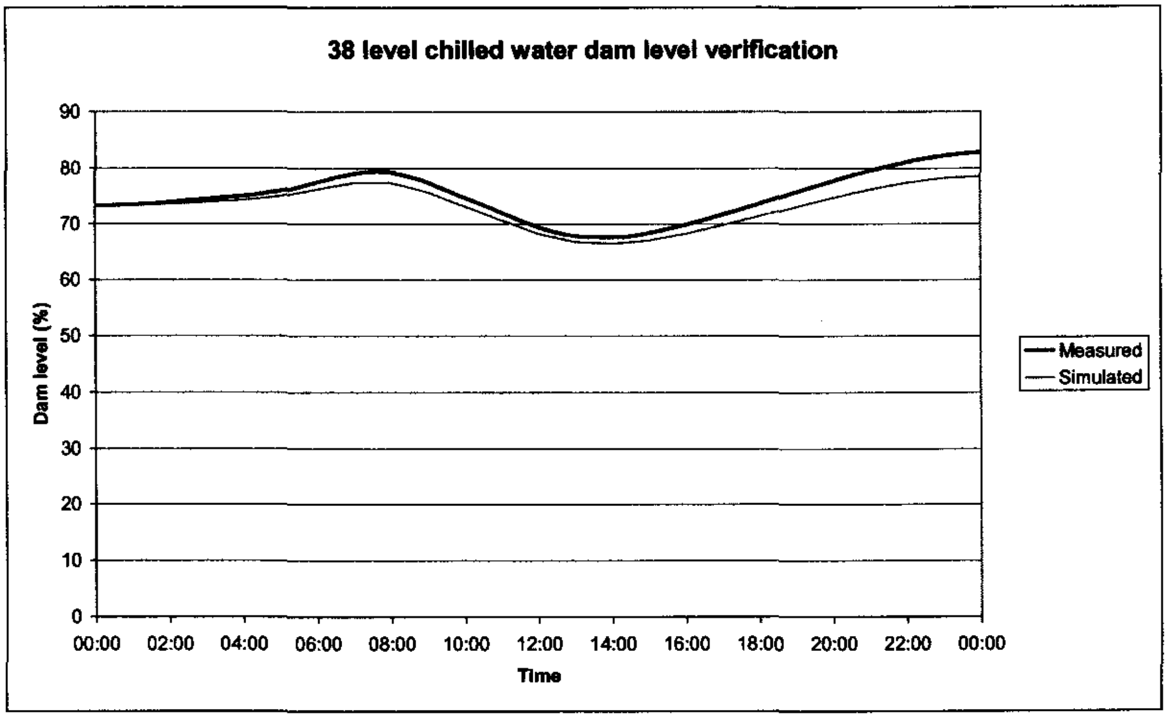


Figure 3.9: Kopanang level 38 chilled water dam capacity verification

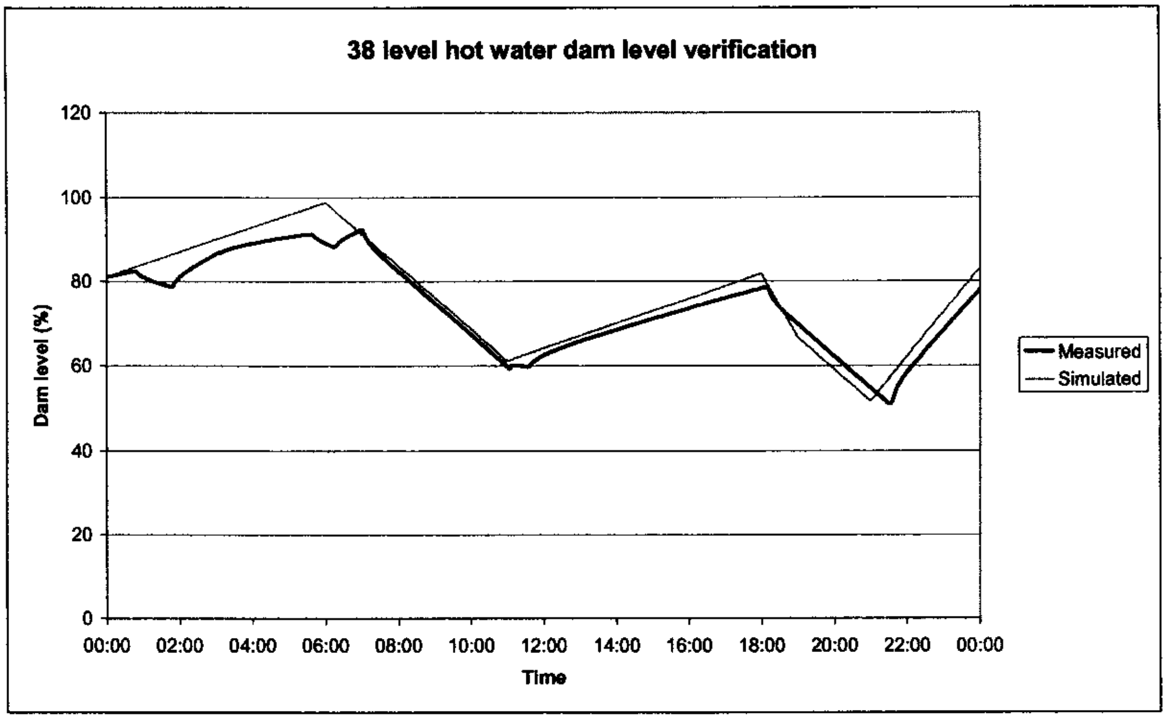


Figure 3.10: Kopanang level 38 hot water dam capacity verification

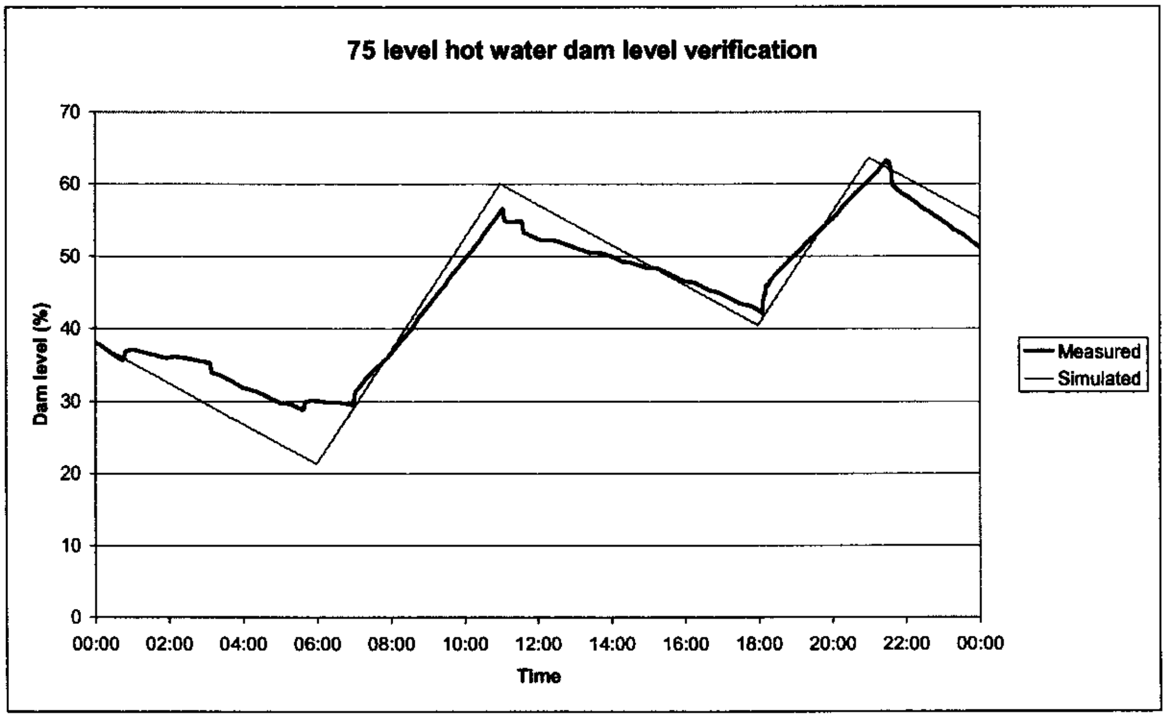


Figure 3.11: Kopanang level 75 hot water dam capacity verification

The dam capacities and pump flows are accurate enough for optimisation purposes.

3.1.2.1.3.2 Pumping electricity

The electricity consumption used by the number of pumps used during the dam level verifications was compared to the measured electricity consumption of the underground pumping feeder.

Just as during the calibration the maximum error occurred during the times that the pumps where switched off. This can be seen in *Figure 3.12*. Disregarding these errors as discussed in section 3.1.2.1.2.2 the average error was 2%. The underground pumping electricity model is accurate enough for the optimisation purposes and will be used as they are.

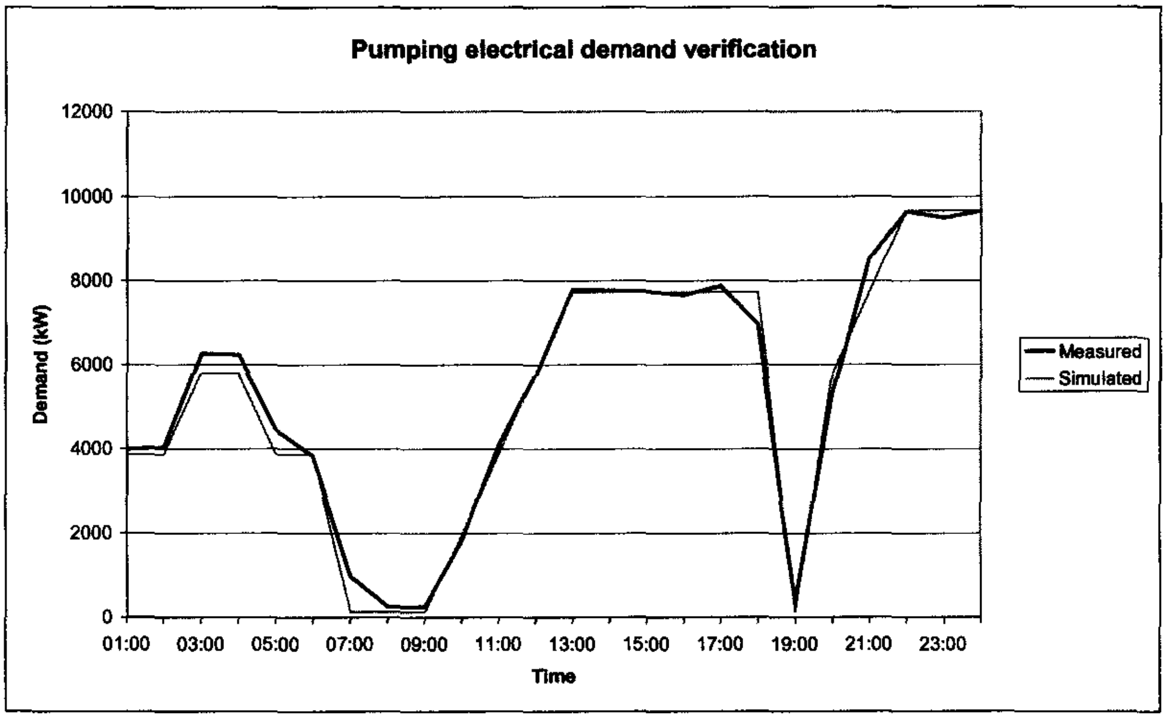


Figure 3.12: Kopanang underground pumping electricity verification.

3.1.2.2 Surface refrigeration system

3.1.2.2.1 Background

The accurate prediction of the compressor power consumption of chillers is essential for any load shifting calculations. To predict a realistic operation schedule for the chillers the following needs to be accurately predicted.

- Thermal performance of the pre cooling towers.
- Thermal performance of the BAC.

- Accurate prediction of the prevailing micro-climate.

The way each of these where handled in the simulation is shown in section 3.1.2.2.2.

3.1.2.2.2 Methodology

3.1.2.2.2.1 Climate

The climate model predicts the hourly temperature and relative humidity swing using the minimum and maximum temperatures for the day as predicted by the weather bureau. The fit employs the use of both second and third order polynomials to predict the temperature swing between the maximum and minimum temperatures. The calibration results can be seen in *Figure 3.13*. The temperature error is smaller than 2°C for 80% of the time, which is acceptable.

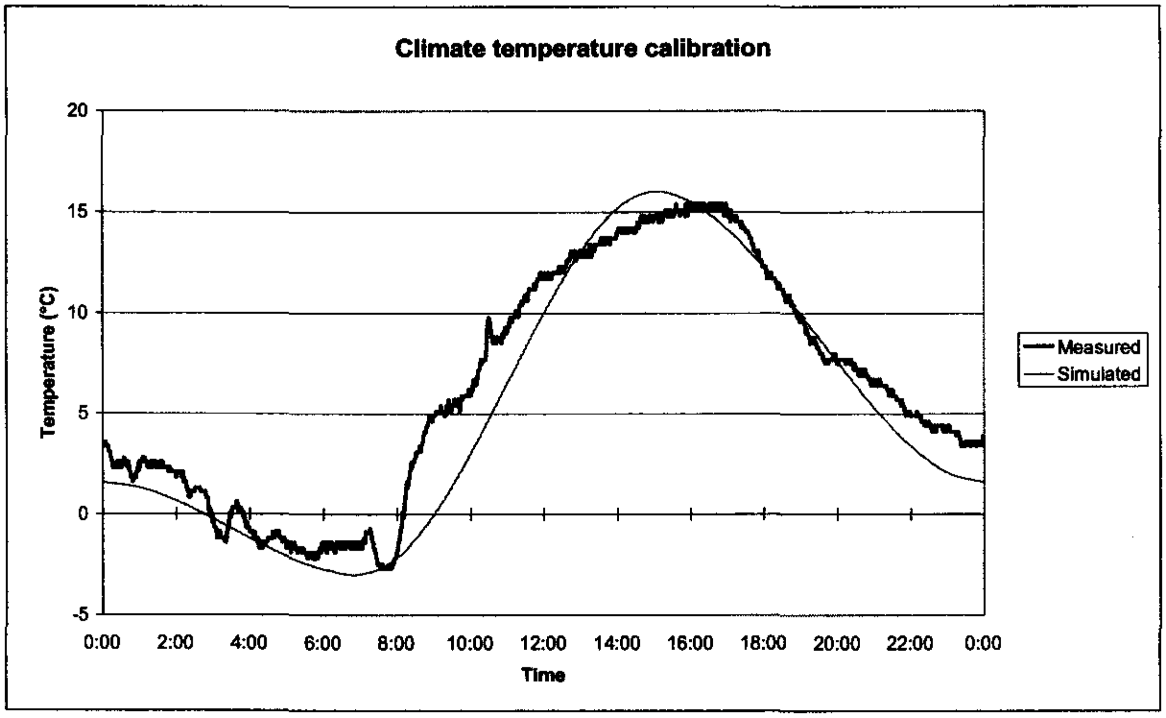


Figure 3.13: Kopanang climate temperature calibration

The relative humidity model is a linear fit through four variables. These are the maximum temperature (T_{max}), minimum temperature (T_{min}), current temperature (T) and the current hour (hour). These coefficients were calculated using the measured relative humidity for 2000 and 2001. The relative humidity (RH) is calculated using the following equation.

$$RH = a_0 + a_1 hour + a_2 T_{\max} + a_3 T_{\min} + a_4 T$$

Figure 3.14 shows the calibration results for a week extracted from of the data. The average error in the simulated values was 7.7%. This is acceptable, as any accuracy within 10% is taken as adequate. Furthermore the measurement of relative humidity can have a deviation of 10%.

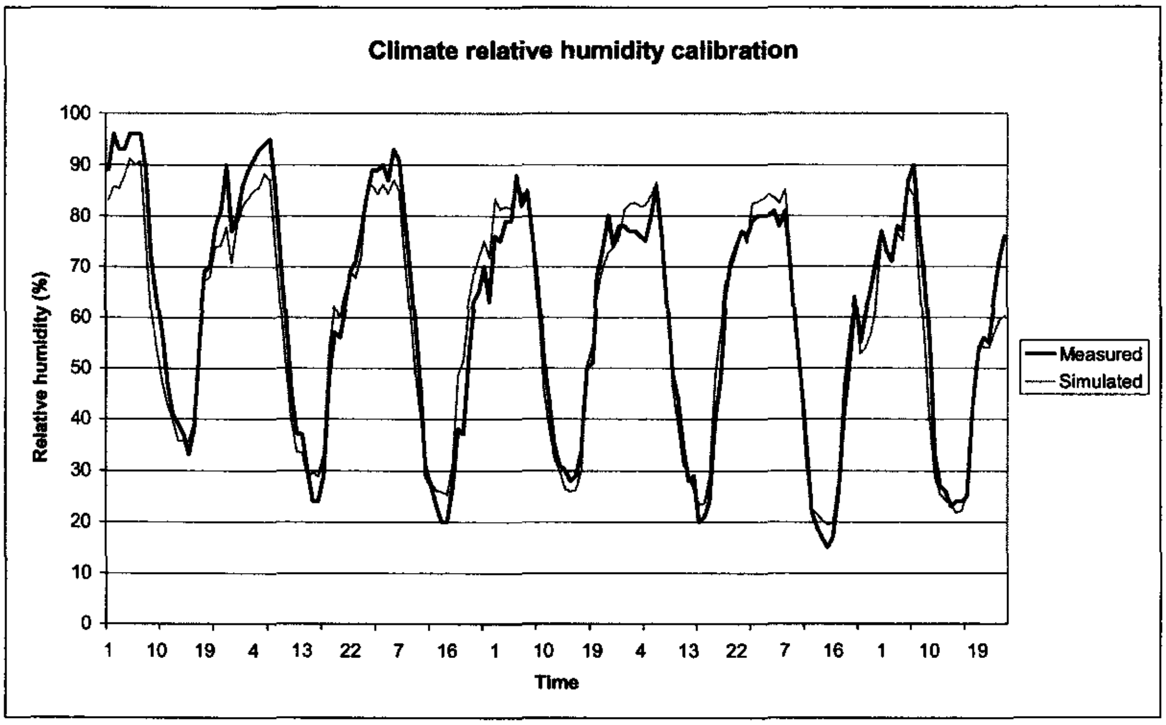


Figure 3.14: Kopanang climate relative humidity calibration for a typical week

3.1.2.2.2.2 Pre cooling towers

Both the bulk air cooler and pre cooling towers use the same power function fit to calculate the cooling capacity (Q). This fit is a function of water flow (m_l), entering water temperature (T_{li}) and entering air wet bulb temperature (T_{wb}). The only difference is the power coefficient (a). The cooling capacity is calculated as follows [11]:

$$Q = [(a_0 + a_1 T_{li})T_{wb} + a_2 T_{li} + a_3]m_l^a$$

The coefficients for the cooling tower were calculated using their design data. From this cooling capacity the outlet conditions are calculated. At the pre cooling tower model the outlet water temperature is the important one as it influences the cooling capacity of the chillers. The bulk air cooler (BAC) model was incorporated in the underground cooling model. No calibration was done only verification that will be discussed later.

3.1.2.2.2.3 Chiller compressor power

Due to the nearly constant return condenser temperatures it was found from measurements that the coefficient of performance (COP) of the chillers were very constant. This made it possible to further simplify the chiller model. This meant that if the cooling capacity were predicted correctly the compressor power would be accurate. The cooling capacity model [12] was also simplified neglecting the constant condenser conditions. The simplified equations were used as shown below.

$$Q = a_0 + a_1 T_{ei}$$

$$P_{wr} = \frac{Q}{COP}$$

With T_{ei}: Evaporator inlet temperature

$a_{0,1}$: Correlation coefficients

P_{wr}: Compressor power

The correlation coefficients as well as the COP were calibrated using measured data. The calibration of the compressor power can be seen in *Figure 3.15*.

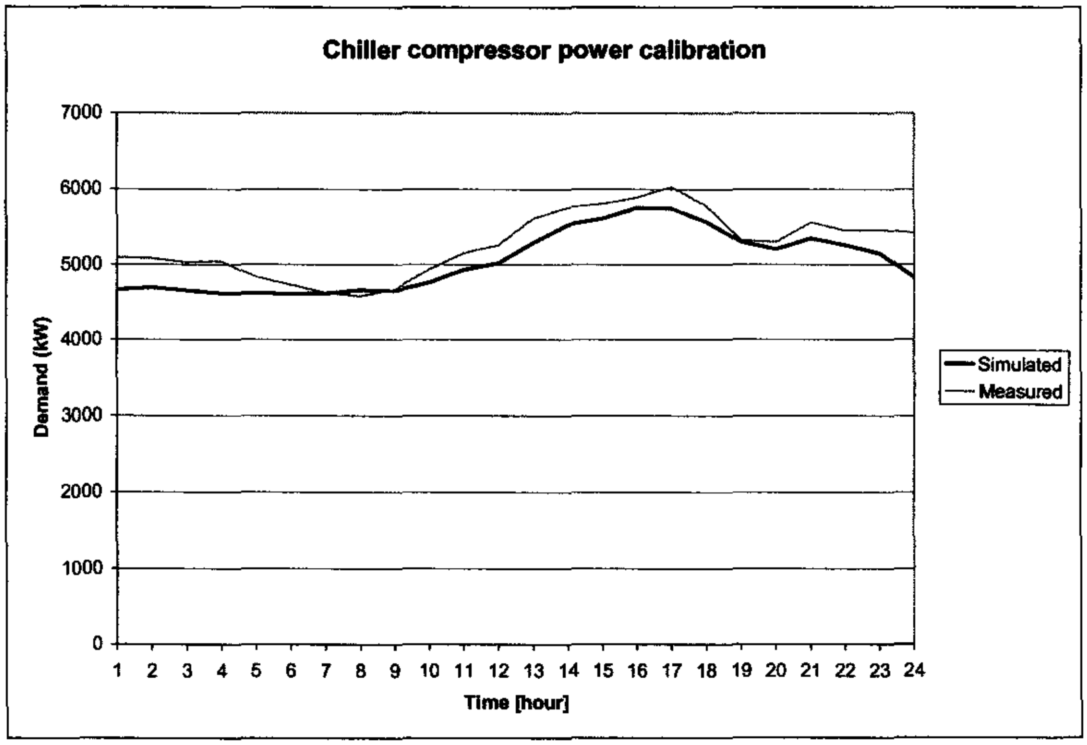


Figure 3.15: Kopanang chiller compressor calibration

The average error was 4.2%. The maximum error was 10.8%. The model is within 8% for 87.5% of the time. This is sufficiently accurate as an error of less than 10% for 80% of the time is taken as the norm.

3.1.2.2.3 Verification

3.1.2.2.3.1 Climate

Using the calibrated model a new day's climate was simulated using the predicted minimum and maximum temperatures of the day. The outputs of this model are then used as inputs to the BAC and pre cooling tower models.

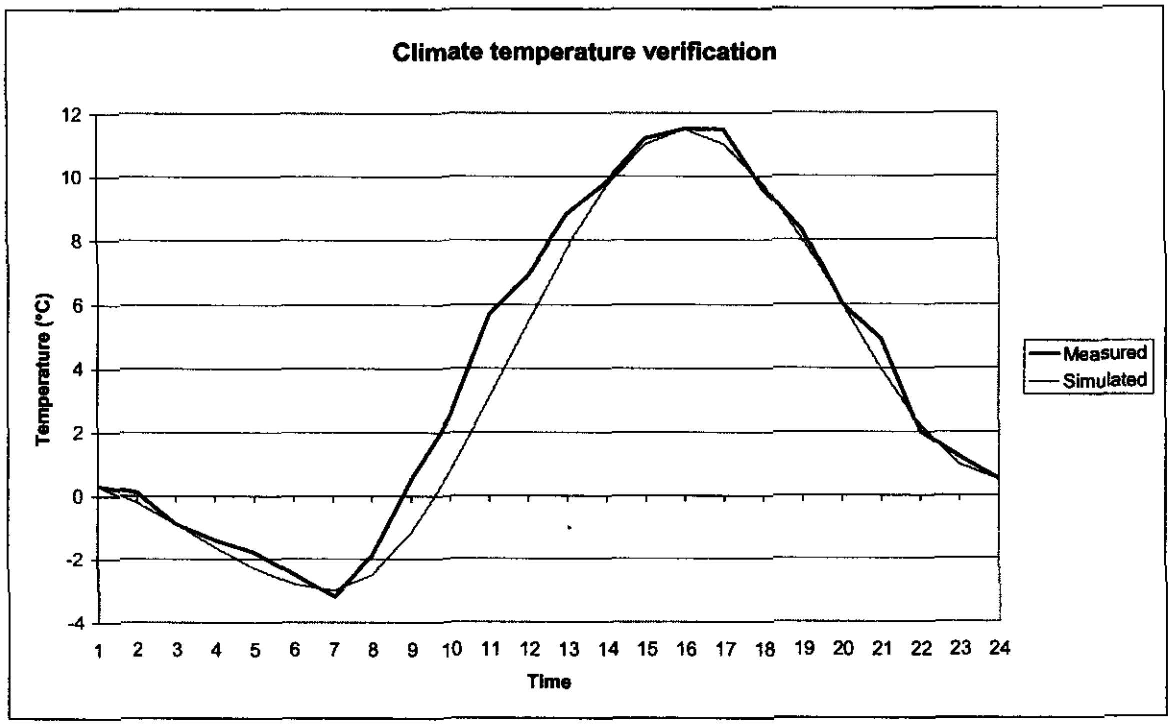


Figure 3.16: Kopanang climate temperature verification

The climate was simulated accurately as the error was smaller than 2°C for 95 % of the time (seen in *Figure 3.16*). This exceeds the norm of less than 2°C for 80 % of the time.

The simulated relative humidity shown in *Figure 3.17* has an average absolute error of 4.4%. This is also well within the norm of 10%.

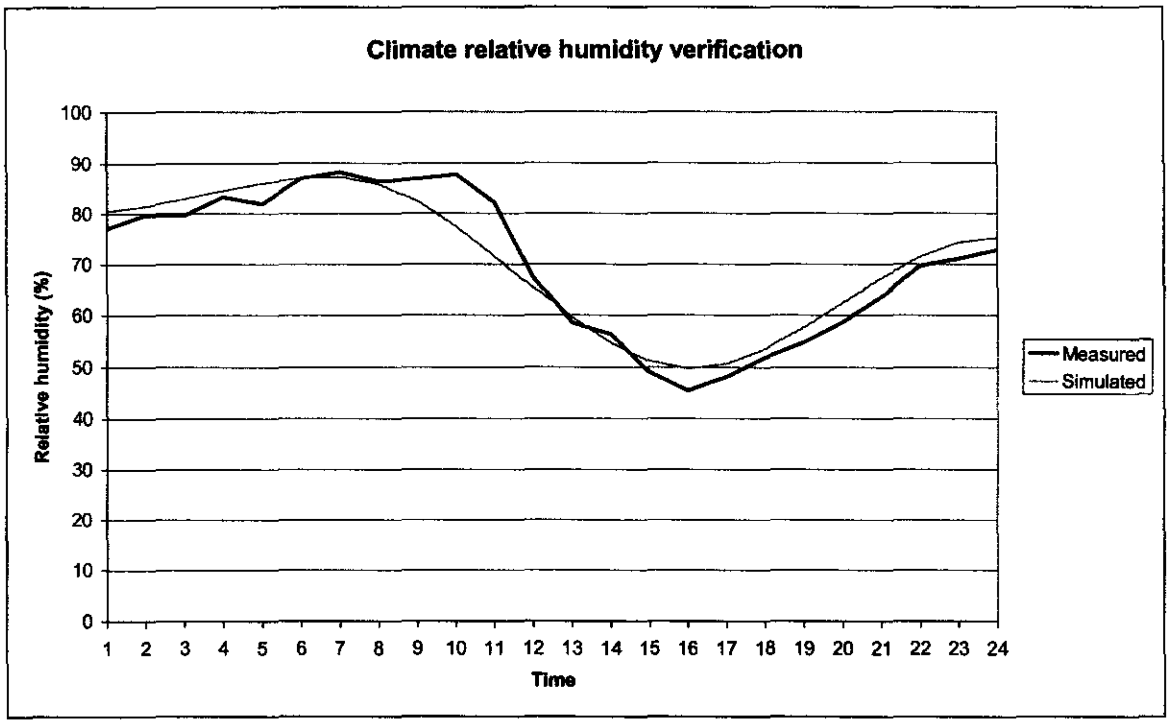


Figure 3.17: Kopanang climate relative humidity verification

3.1.2.2.3.2 Pre cooling towers

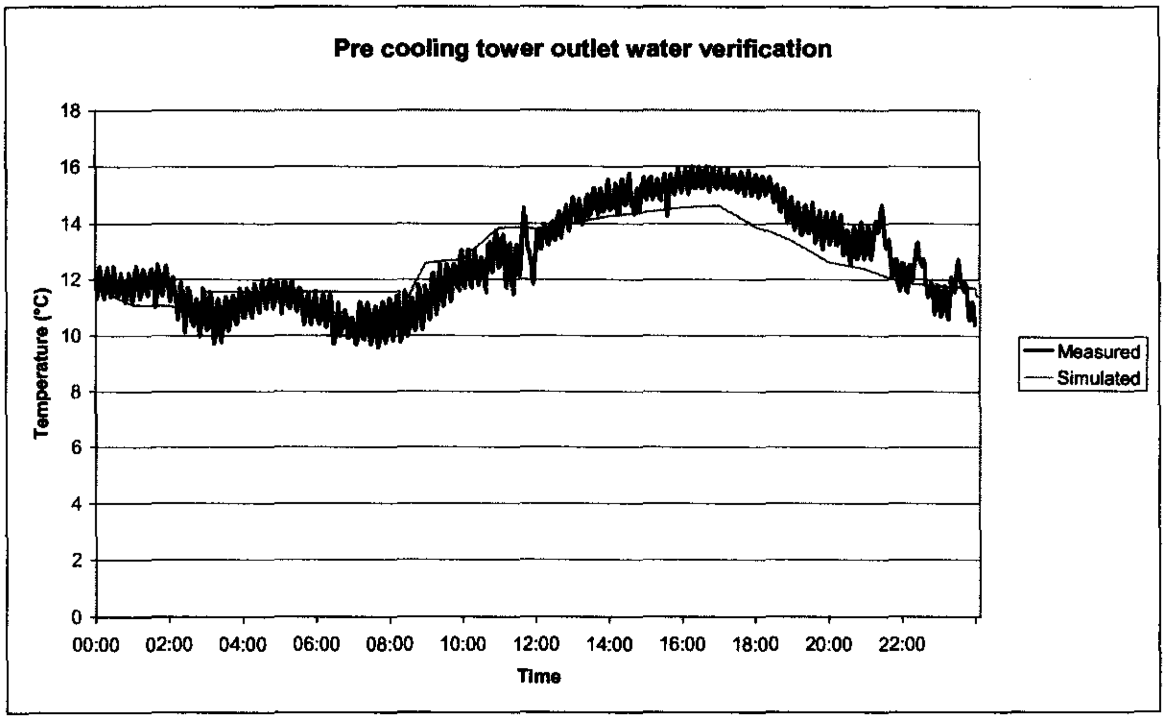


Figure 3.18: Kopanang pre cooling tower verification

Figure 3.18 shows the verification results of the pre cooling tower outlet water temperature. The simulated values are within 1.5°C of the measure values 96% of the time. This is well within the norm of within 2°C for 80% of the time.

3.1.2.2.3.3 Chiller compressor power

This calibrated chiller model was now verified using the operating conditions (climate) of another day. The verification showed the following results: The maximum error was almost the same at 10.9%. The average error was 5.1%. Finally the model's error was within 8% for 83.3% of the time. Looking at these results and *Figure 3.19* it can clearly be seen that the model is accurate enough for its use in optimisation.

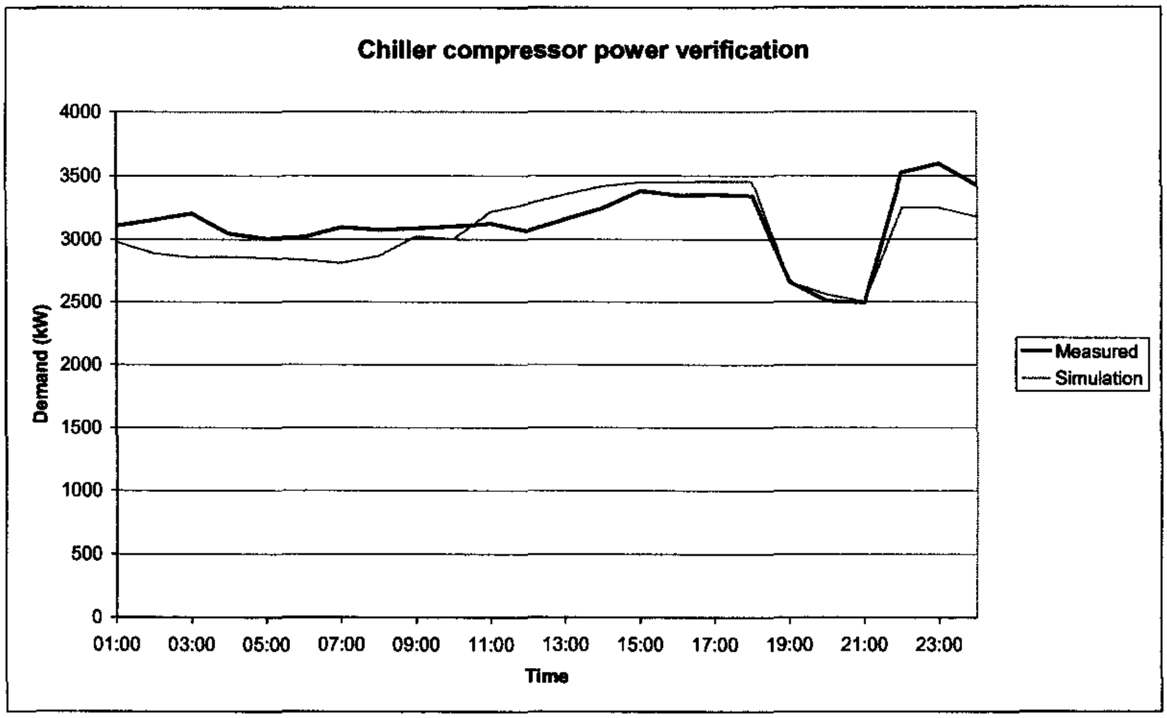


Figure 3.19: Kopanang chiller compressor power verification

3.1.2.3 Underground cooling model

3.1.2.3.1 Background

The accurate prediction of the wet bulb temperature on level 64 is essential to be able to schedule the BAC pumps. The scheduling of the number of pumps can have a large electricity savings potential. This model combines the BAC model as well as a shaft model.

3.1.2.3.2 Methodology

The thermal performance of the shaft will be simulated using electricity balance equations. The basic thermal model of the shaft is shown in *Figure 3.20.*

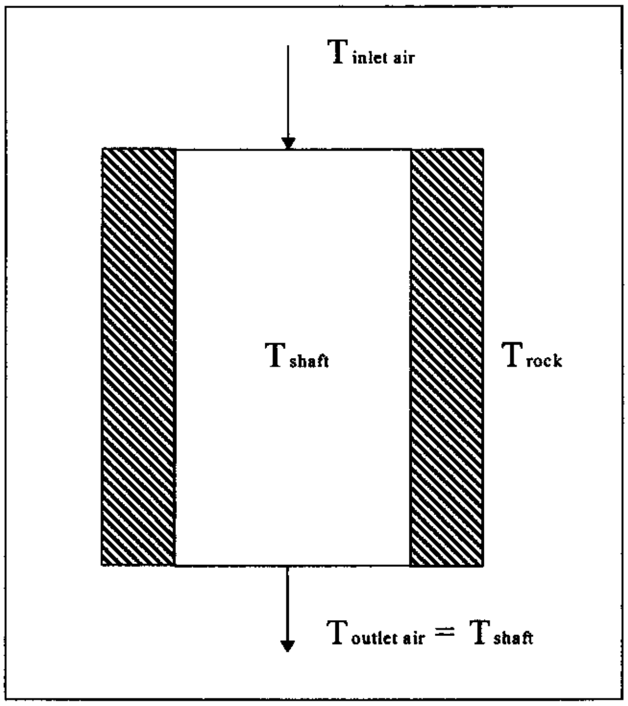


Figure 3.20: Schematic layout of the thermal model of the shaft as used at Kopanang.

The electricity balance of the system in *Figure 3.20* can be written as follows [13]:

$$C\frac{dT_{shaft}}{dt} = U_{shaft}A_{shaft}\left(T_{rock} - T_{shaft}\right) + m_{air}cp_{air}\left(T_{inletair} - T_{shaft}\right) \tag{3.1}$$

Separating the variables and using the initial values $T_{shaft} = T^0_{shaft}$ at $t = 0$ the shaft temperature can be solved using the following equation.

$$T_{shaft} = \frac{1}{a}\left[\left(aT^0_{shaft} - b\right)\exp\left(\frac{-a\delta t}{C}\right) + b\right]$$

Where $a = U_{shaft}A_{shaft} + m_{air}cp_{air}$

And $b = U_{shaft}A_{shaft}T_{rock} + m_{air}cp_{air}T_{inletair}$

The complete underground model consists of the BAC and the shaft model divided into 3 segments as shown in *Figure 3.21*. The models are interconnected through the air temperature that is passed from one model to the next. Starting with the outdoor climate right through to the leaving air temperature of the third segment. This temperature is the temperature on level 64.

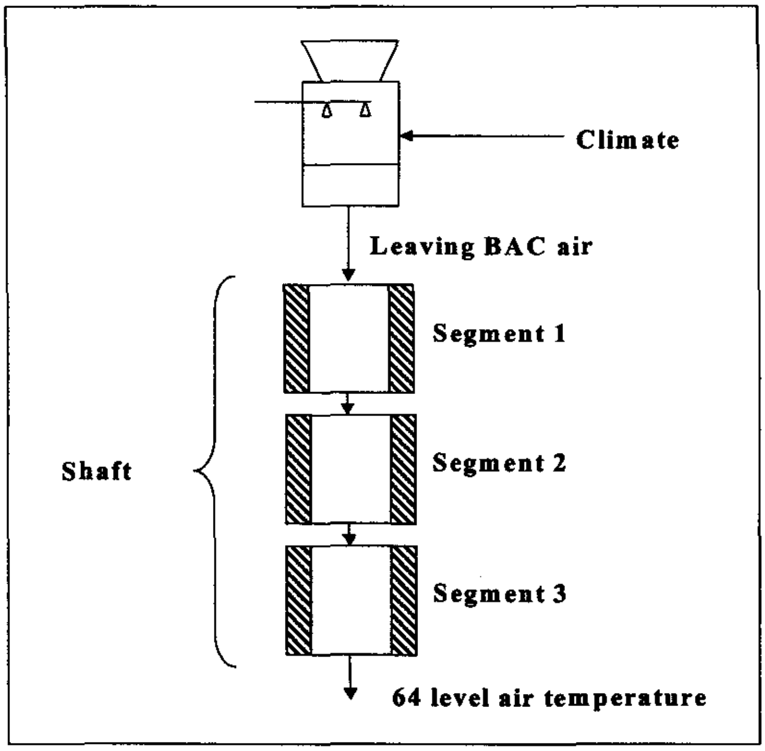


Figure 3.21: Complete schematic layout of the underground cooling model at Kopanang.

The values of the thermal capacity (C) and the heat transfer coefficient ($U_{shaft}A_{shaft}$) can be calibrated using the measured temperature profile of level 64. The calibration results are shown in *Figure 3.22*. The calibration is accurate as the measured and simulated temperatures never differ more than 2°C and are within 1°C of each other 84% of the time. The wet bulb temperature was then calculated using the psychometric relations. It is assumed that no mass transfer takes place.

The wet bulb calibration can be seen in *Figure 3.23*. The calibration is accurate as the measured and simulated temperatures differ with less than 2°C for 94% of the time. The accepted norm for our models is within 2°C for 80% of the time.

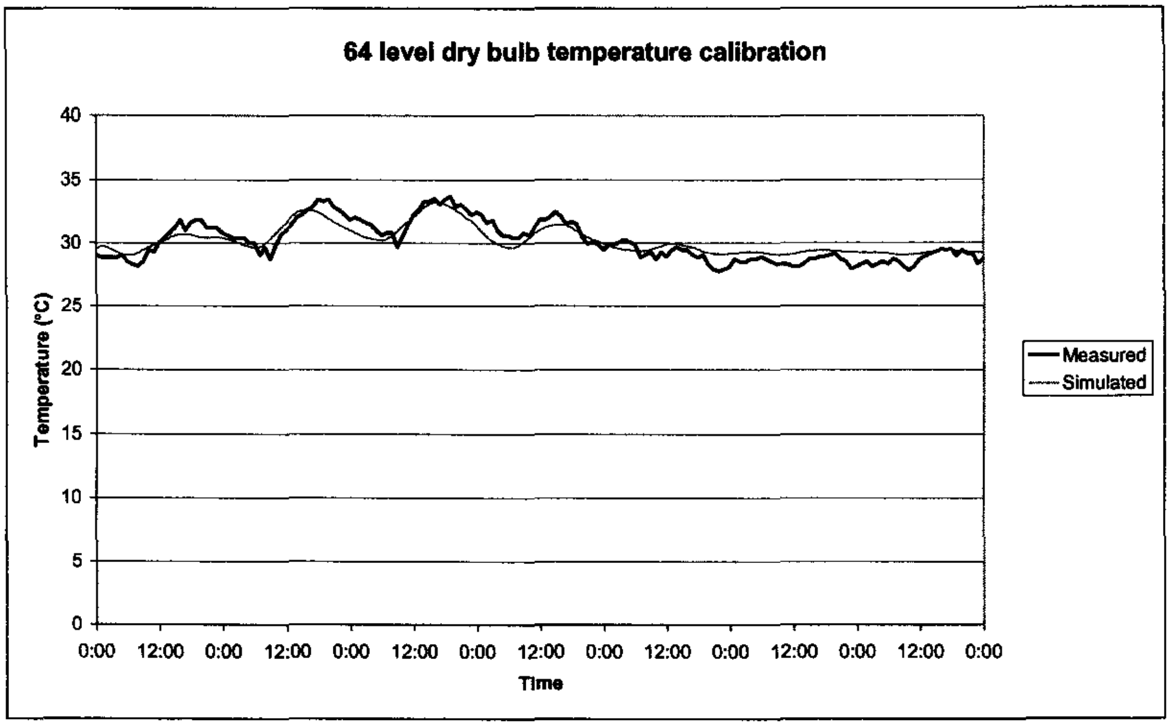


Figure 3.22: Kopanang 64 level dry bulb temperature calibration

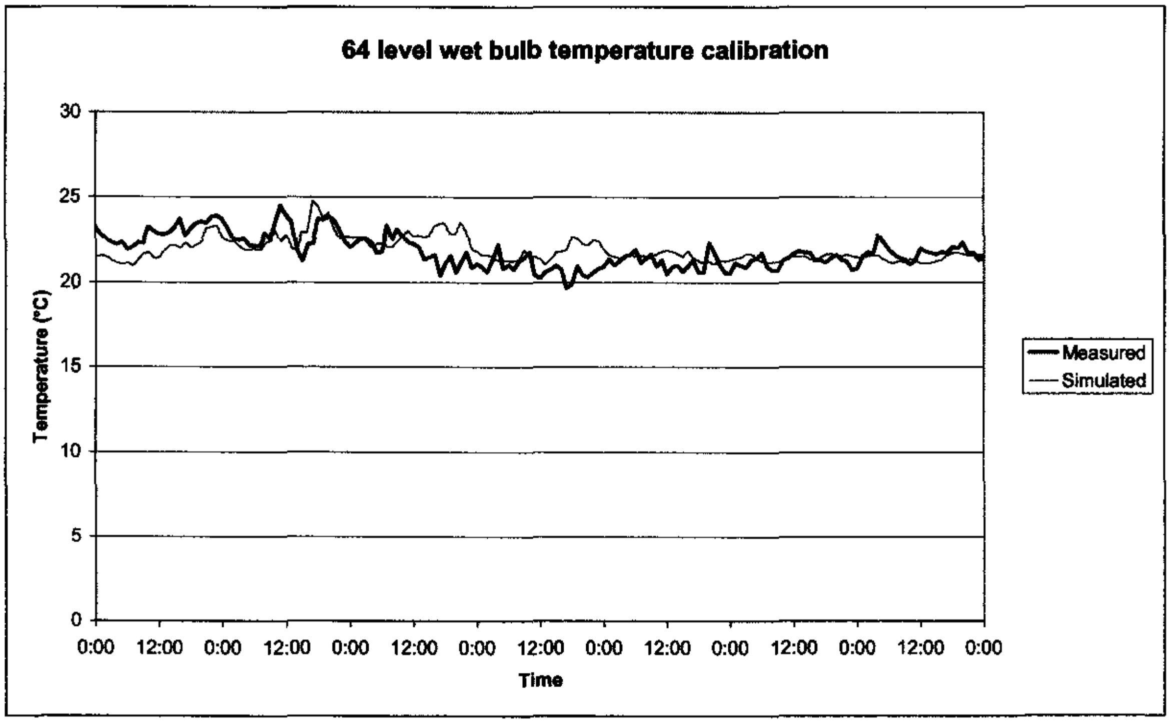


Figure 3.23: Kopanang 64 level wet bulb temperature calibration

3.1.2.3.3 Verification

Using the calibrated values of section 3.1.2.3.2 verification was done using the measured data of another two days. The dry bulb verification results are shown *Figure 3.24*. As with the calibration the errors were small and never exceeded 2°C.

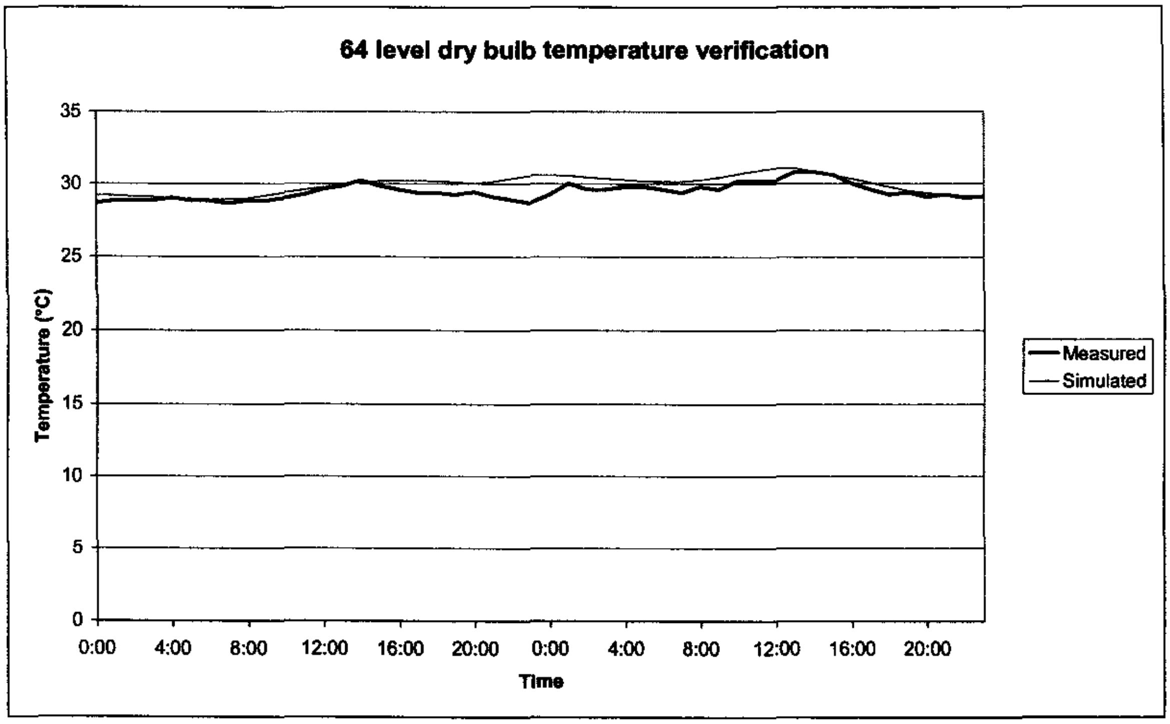


Figure 3.24: Kopanang 64 level dry bulb temperature verification

The wet bulb verification shown in Figure 3.25 showed that the measured and simulated data differed by less than 2°C for 91% of the time and within 1°C for 80% of the time. These results are acceptable as discussed during the calibration of the model.

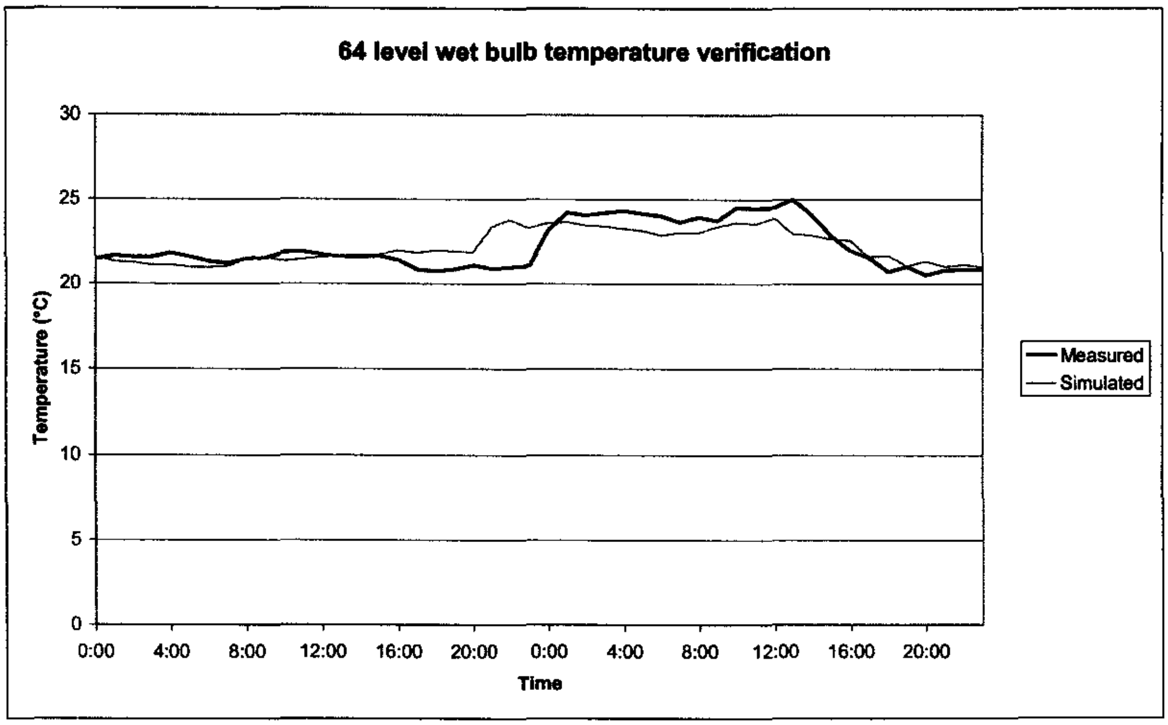


Figure 3.25: Kopanang 64 level wet bulb temperature verification

3.2 Analysis and optimisation of the electricity costs of each system and system type

3.2.1 Electricity cost analysis

3.2.1.1 Electricity cost of the different systems

The electricity bills for the twelve months before the commencement of the study were used to analyse the cost contribution of each of the systems on the mine. The breakdown is shown in *Table 3.1*.

Month	**Year**	**Total**	**Pumping**		**Refrigeration**	
		R	R	%	R	%
September	2000	2,371,427.60	228,445.56	9.63	376,867.39	15.89
October	2000	2,596,890.88	351,198.08	13.52	533,001.28	20.52
November	2000	2,522,647.82	449,112.34	17.80	533,131.14	21.13
December	2000	2,509,927.72	477,980.57	19.04	584,288.64	23.28
January	2001	2,399,843.97	249,013.13	10.38	428,970.88	17.87
February	2001	2,655,721.14	341,636.28	12.86	644,250.02	24.26
March	2001	2,612,240.85	334,108.64	12.79	557,313.35	21.33
April	2001	2,619,819.14	319,007.04	12.18	560,784.58	21.41
May	2001	2,541,424.81	223,532.14	8.80	511,690.01	20.13
June	2001	3,614,048.36	275,152.54	7.61	378,023.14	10.46
July	2001	3,506,114.47	200,313.11	5.71	256,465.35	7.31
August	2001	2,438,885.85	261,656.54	10.73	239,227.47	9.81
Total		**32,388,992.61**	**3,711,155.98**	**11.76**	**5,604,013.24**	**17.79**

Table 3.1: Kopanang electricity cost breakdown.

As seen the total electricity bill for the twelve months was ±R32.4 million. The underground pumping system contributed R3.7 million and the refrigeration system R5.6 million. It is also clear that electricity savings on the refrigeration system in summer can be very lucrative especially in the cooler summer months of April, May and September.

3.2.2 Objective function

The objective function is the value that is dependent on all the variables that must be optimised. In this case the total daily or weekly electricity cost is the value that must be minimised while still satisfying all of the constraints.

Only two-part-RTP will be used as the tariff for the optimisation. The objective function is the sum of all the hourly electricity costs. In this case this value will be the total daily electricity cost.

The hourly cost of Kopanang is calculated using the following steps:

- Firstly the total electricity usage for the hour is calculated by adding the following components electricity consumption together and adding that to the base load for that hour. The components are the underground pumps, chillers and BAC pumps.
- The CBL cost is now calculated using the hourly CBL load and the CBL tariff.
- Lastly the RTP debit and credit costs are calculated and added to the CBL cost. This cost is calculated by subtracting the CBL load from the Total load. If this value is positive it is multiplied by the RTP debit tariff if not with the RTP credit tariff.

3.2.3 Boundaries

The boundaries are those values that are not dependent on any of the outputs of the models, but do influence the models directly or indirectly. The boundaries are also normally one of the values that need to be calibrated from time to time.

The boundaries in this case are the settler flow, minimum and maximum temperatures, base load and price signal.

The settler flow was calculated from measurements taken on the mine. The hourly average for every hour of every day was taken to calculate the weekly boundaries.

The minimum and maximum temperatures are given by the weather forecast of every day. These temperatures drive the optimisation of the cooling systems together with the daily RTP price. The RTP price is downloaded daily from the ESKOM website for the following day.

3.2.4 Constraints

The constraints are the values that enforce the physical operational limits of the system onto the optimisation. The accurate implementation of these limits is essential to ensure that the outputs of the optimisation are practical and can be implemented.

3.2.4.1 Underground pumping system

There are two types of constraints applicable on this system. These are the available number of pumps and minimum and maximum dam levels on each level. On level 75 there are 3 electrical pumps each capable of delivering a maximum flow of 115l/s. The level 75 hot water dam must be kept between 40% and 80% at all times.

On level 38 there are 2 electrical pumps each capable of delivering a maximum flow of 115l/s. The turbine-pump is always in operation during the week but must be switched off on Sunday mornings for maintenance. The level 38 chilled water dam has a minimum operating level of 30% and a maximum operating level of 90%. The hot water dam level on level 38 must never drop below 35%, as this will cause the turbine pump to trip. The maximum level is 80%.

The last constraint is that the pumps on one pump station may not be switched on and off more than 10 times per day. This is the same amount of on and off switches used currently. The pumps can not operate constantly due to the dam capacities and varied demand.

3.2.4.2 Surface refrigeration system

On the surface refrigeration system the maximum number of chillers available is 6. The chilled water supply must always be colder than 3.5°C. The maximum cooling capacity deliverable by one chiller is 5500kW.

3.2.4.3 Underground cooling system

Here the maximum number of BAC pumps available is 3. The wet bulb temperature on 64 level must always be kept under 21.5°C.

3.2.5 Variables

The variables are the values that are changed to minimise or maximise the objective function while still satisfying the constraints.

On the underground pumping system the number of pumps active every hour on each level is a variable. The number of refrigeration plants active every hour is the variable of the surface refrigeration system. The last variable is the number of BAC pumps active every hour at the underground cooling system.

3.2.6 Optimisation model for each typical day

3.2.6.1 Background

A typical week can be split into three typical day types after looking at the maintenance schedules and typical operating strategies employed on the mine currently. These are a weekday, Saturday and Sunday. The way these were handled in the optimisation is now discussed. An optimisation model for every month for each of these days must be built.

3.2.6.2 Boundaries

The boundaries, of the base load, CBL load, RTP tariff and minimum and maximum temperatures, for the potential savings calculations are calculated from the previous years measured data. An hourly average is used to calculate the typical profile for the boundary for each typical day for each month.

The boundary of the settler flow is not dependent on the seasons and thus the previous 3 months measured data was used to obtain the boundaries.

3.2.6.3 Constraints

3.2.6.3.1 Weekday

The only constraint that is added during a weekday is that all the pumps must be switched off from 07:00 to 08:00 for routine maintenance inspection.

3.2.6.3.2 Saturday

On Saturday evenings the hot water dam levels of 75 level should be 50% and 38 level 70% at 24:00.

3.2.6.3.3 Sunday

On Sundays the chillers and BAC pumps are switched off from 06:00 to 14:00 for weekly maintenance. This also means that no water is passed to the underground during this time and that all the underground pumps are switched off for this period as well.

3.3 Economic implications of the different DSM alternatives

3.3.1 Comparison of optimised and previous years loads

3.3.1.1 Two part RTP

Kopanang was already on two-part RTP at the time of this study. This means that only the optimal use of this tariff will be studied. The actual measured load is compared to the optimised load for all of the typical days of every month.

A short discussion about each of the profiles is given including the amount of load shifted as well as the electricity savings on the refrigeration system in appendix A.

These findings are summarised in *Table 3.2*

	Week day		Saturday		Sunday	
Month	Shifted load MW	Electricity saving %	Shifted load MW	Electricity saving %	Shifted load MW	Electricity saving %
September-00	60	-5	46	9	37	8
October-00	42	-2.5	46	-13	33	30
November-00	48	-9	44	-6	19	45
December-00	33	6	39	-4	45	41
January-01	48	-21	47	-24	53	2
February-01	36	9	53	6	48	12
March-01	45	9	35	5	25	50
April-01	47	9	63	5	26	51
May-01	47	13	19	43	28	39
June-01	24	29	43	16	24	55
July-01	25	23	22	32	19	50
August-01	38	0	42	-7	24	49
Average	40.9	5.0	41.8	5.2	31.8	36.0

Table 3.2: Load comparison for Kopanang

3.3.1.2 Summary

Currently the refrigeration plant is controlled to deliver a constant amount of water at 3.5°C. Through changing the control strategy to control the refrigeration plants to just supply enough cooling to meet the demand both electricity savings as well as an enhancement to the underground comfort levels can be achieved.

In the summer months on average 4% on weekdays and 3% on Saturdays more electricity was used to meet the desired underground comfort levels. On Sundays the demand can be met using 32% less electricity. The biggest contribution of the new strategy in summer is the fact that the desired comfort levels are achieved at just a slight up in the electricity consumption during a typical weekday and Saturday. On average 43.7MW of load can be shifted on a typical weekday. On a Saturday this figure rises to 46.1MW and on a typical Sunday during the summer months only 35MW can be shifted.

In the winter months this new strategy can save on average 21.67% on weekdays, 30.33% on Saturdays and 38% on Sundays. On a typical weekday in the winter months 32MW of load can be shifted. This amount of load drops to 28MW on a typical Saturday and to 23.67MW on a typical Sunday.

3.3.2 Cost savings

3.3.2.1 Background

The mine is currently on two part RTP [14]. Two part RTP together with one part RTP are the best tariffs if load shifting is possible.

Through the use of simulation models and optimisation the potential sustainable electricity savings will be calculated.

3.3.2.2 Savings calculation

The calculated saving is based on the following profiles for the year 2000.

- RTP prices and CBL cost
- Minimum and maximum temperatures
- Settler flow
- Electricity base load and CBL load

To calculate the saving the hourly averages of the boundaries were taken for every day type for every month. These profiles were then used in the optimisation model to calculate the optimum cost for every day.

The optimum cost is now compared to the cost on the actual electricity profile measured for the twelve months prior to September 2001. These savings are then extrapolated to calculate the monthly savings. The monthly savings are then added together to get the potential yearly saving.

3.3.2.3 Results

The potential savings calculated for every month is summarised in *Table 3.3.*

Month	Actual cost Rand	Optimised cost Rand	Saving Rand
Jan	2385950	2264014	121937
Feb	2656600	2569116	87483
Mar	2588857	2519664	69193
Apr	2551484	2417635	133849
May	2487609	2415196	72413
Jun	2518501	2418230	100271
Jul	2369826	2223797	146029
Aug	2378291	2307275	71016
Sep	2420099	2170165	249934
Oct	2614710	2420948	193761
Nov	2656600	2569116	87483
Dec	2656600	2519664	136936
Total	**30285125**	**28814821**	**1470304**

Table 3.3: Potential savings results at Kopanang

The greatest potential for savings is possible during the spring and autumn months as the price signal is still fairly high and there is a limited need for refrigeration. This is apparent when one consider the potential savings that are possible during September and October. The times of high electricity prices fall during the early morning and evening. The temperatures at these times also reduce the need for refrigeration further.

3.3.3 Infrastructure implications of these alternatives

This analysis is necessary to establish the cost, capital and operating, required for the implementation of the proposed strategies. The main components required is a complete SCADA (supervisory control and data acquisition) system as well as an electricity management system.

A SCADA system is implemented currently. The underground pumps are controlled from a central control room using the SCADA system. No actual extra hardware is required to implement a similar process for controlling the refrigeration systems.

On Kopanang a separate piece of software will be implemented that uses the SCADA system to get the required conditional data for the control algorithms and in turn gives back a control signal to the SCADA system that in turn switches the components on and off.

This software will be made available as part of a service agreement in which a percentage of the savings will be paid to the service provider. The provider will be responsible for supply of a daily optimum schedule to the electricity management software. The service provider will also be responsible for the weekly calibration of the optimisation model to ensure accuracy.

This means that the implementation on Kopanang will only cost a percentage of the savings. This means that the mine will pay less for their electricity consumption even if the service fee is included in the electricity cost.

3.4 Conclusion

3.4.1 Summary

New simulation models were developed and existing models simplified for their use in optimisation. The simulation models calibration and verification showed that they were accurate enough to use in the optimisation.

The simulated energy consumptions were always within 10% of the measured values. Simulated temperatures were 80% of the time within 2°C of the measured temperatures.

An analysis of the electricity costs was undertaken. In this analysis the electricity bills for the twelve months preceding the studies were taken.

It was found that pumping operations contributed R3.7 million and the refrigeration systems R5.6 million to the total electricity bill of Kopanang. The complete setup of the optimisation models for each of the mines was discussed in detail. The main components of the optimisation models that were discussed are the boundaries, constraints, variables and the objective function.

After looking at the operating strategies, maintenance schedule and tariff structures the typical day types were selected. At the end there were three typical day types for each mine namely weekday, Saturday and Sunday. The optimisation model for each of these typical days was set up. In the cases where the two-part-RTP tariff is to be optimised an optimisation model for every typical day for every month of the year was built. In the cases where MEGAFLEX was optimised an optimisation model for every typical day for summer as well as winter was built.

Currently at Kopanang the refrigeration plant is controlled to deliver a constant amount of water at 3.5°C. Through changing the control strategy to control the refrigeration plants to just supply enough cooling to meet the demand both electricity savings as well as an enhancement to the underground comfort levels can be achieved.

In the summer months on average 4% on weekdays and 3% on Saturdays more electricity was used to meet the desired underground comfort levels. On Sundays the demand can be met using 32% less electricity. The biggest contribution of the new strategy in summer is the fact that the desired comfort levels are achieved at just a slight up in the electricity consumption during a typical weekday and Saturday. On average 43.7MW of load can be shifted on a typical weekday. On a Saturday this figure rises to 46.1MW and on a typical Sunday during the summer months only 35MW can be shifted.

In the winter months this new strategy can save on average 22% on weekdays, 30% on Saturdays and 38% on Sundays. On a typical weekday in the winter months 32MW of load can be shifted. This amount of load drops to 28MW on a typical Saturday and to 24MW on a typical Sunday. This leads to a cost saving of R1.47 Million for the year.

3.4.2 Recommendations

Implementing intelligent control on the hot and cold confluence dams to use their thermal storage capacity in times with high RTP prices can improve the savings. The placement of the BAC closer to the working areas can also vastly improve the underground environmental conditions on the mine as well as improve the overall efficiency of the refrigeration plant and save electricity.

The implementation of one of strategies at one of the mines needs to be negotiated with the mine management and then be implemented for a test period. In this period the actual cost savings must be calculated. This is discussed in chapter 6.

After this phase of the project an implementation strategy must be set up to help in future DSM projects on mines (chapter 7). Lastly a national impact study on the implementation of DSM strategies on mine underground services must be completed (chapter 8).

CHAPTER 4.

AMANDELBULT: CASE STUDY 2

In this chapter all the steps in the detailed electricity cost savings calculation process in the case of Amandelbult is discussed. This includes the simulation and optimisation models (development, setup as well as verification), proposed DSM and load shifting strategies as well as the calculation of the electricity cost savings potential.

4 AMANDELBULT: CASE STUDY 2

4.1 The configuration and verification of the simulation models

4.1.1 Background information

4.1.1.1 General

Rustenburg platinum mines (RPM) holds mineral rights throughout the Bushveld Complex under various titles. These are currently being exploited on a fully operational basis at the Rustenburg, Amandelbult and Union sections, covering a total of 2590 hectares.

Compared to 2000, total tons milled rose by 10.5%, head grade was up 2.2% and platinum refine increased by 19% at Amandelbult. Productivity increased year on year from 57.6 to 68.7 refined platinum ounces per employee. No.1 shaft refrigeration plant was commissioned in October 2001 and is now fully operational.

Amandelbult was selected to represent the platinum mines in this study. This is due to its large electricity consumption and spare plant capacity. This is ideal for DSM and load shifting.

4.1.1.2 System layout

4.1.1.2.1 Underground pumping

Drilling water is gravity fed from the surface dams at shaft no.1 and shaft no.2. The water is gravity fed to all the working areas where it is used cooling of the pneumatic rock drills and rock face.

This water together with the spilled drinking water gravitates down along gullies to the settler dams. At the settlers the silt is gravitated out of the water. The clear water is now fed to the clear water dams on level 17 at shaft no.1 and between levels 19 and 20 at shaft no.2. The dams at shaft no.1 have a capacity of ±3500 m^3. The dams at shaft no.2 have a capacity of ±3600 m^3.

Three electrical pumps are available on level 17 at shaft no.1 to pump the water to the surface. These pumps deliver a flow of approximately 138 kg/s. All three pumps can be used in emergencies but normally only one pump is used.

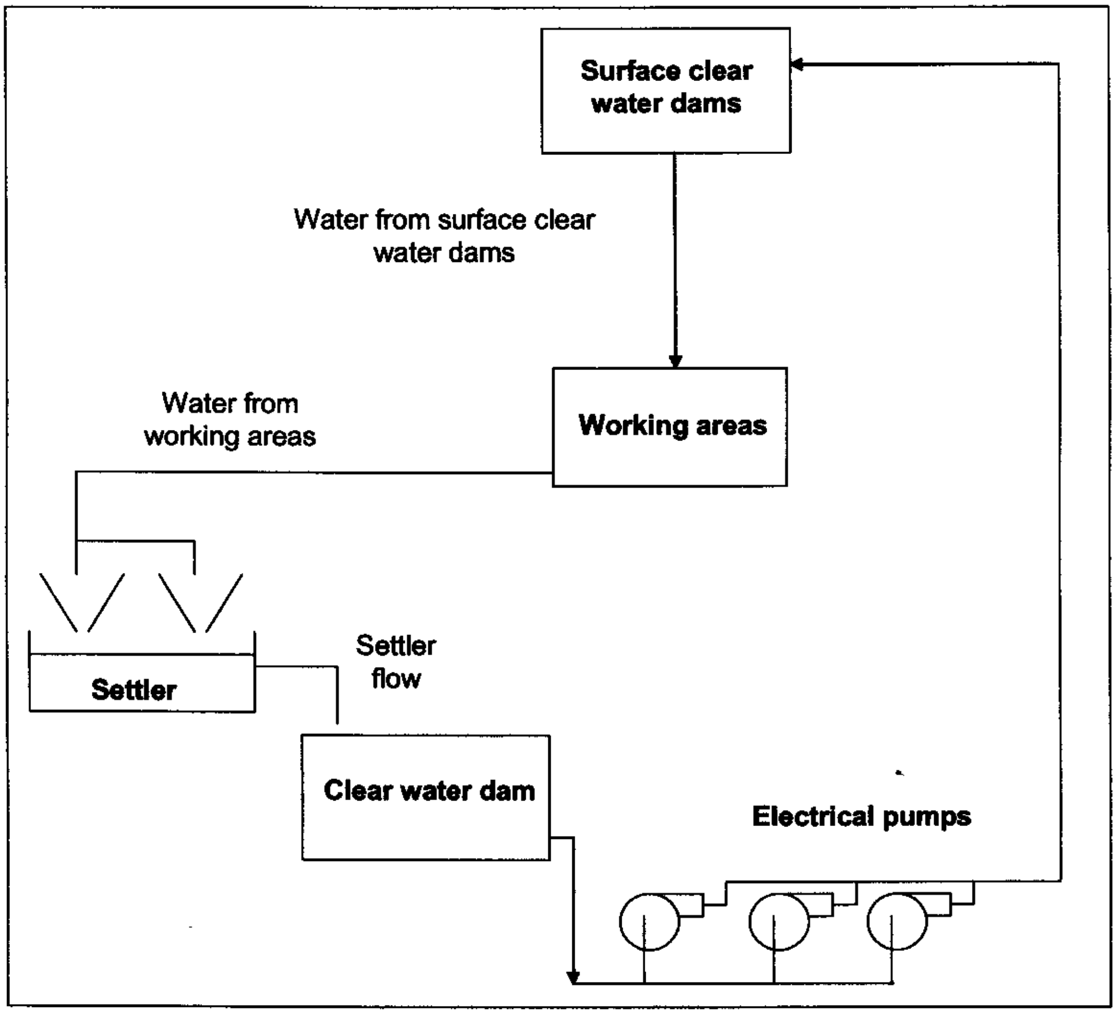


Figure 4.1: Schematic layout of the underground pumping system at Amandelbult.

There are three electrical pumps on level 20 at shaft no.2. Only one is normally used. These pumps deliver a flow of 120 kg/s on average. At both these shafts the water is pumped to surface clear water dams. This typical layout is graphically illustrated in *Figure 4.1.*

4.1.1.2.2 Surface refrigeration

The surface refrigeration plant consists of two chillers, a condenser, cooling tower and a bulk air cooler both with two cells. The evaporators are connected in series and the condensers are connected in parallel. The basic refrigeration plant layout is indicated in *Figure 4.2.*

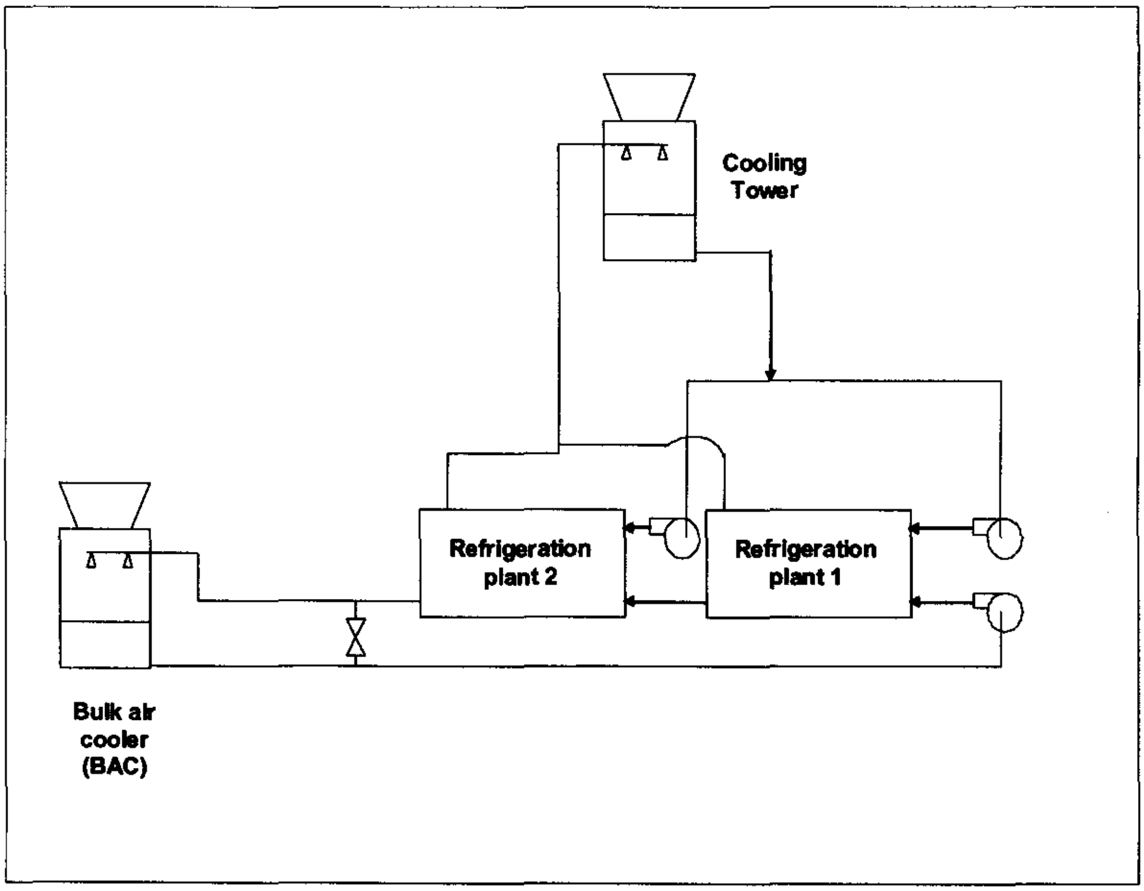


Figure 4.2: Schematic layout of the surface refrigeration system at Amandelbult

The chillers are controlled to deliver a minimum leaving evaporator temperature. This temperature is 5°C in summer and as low as 0.5°C in winter. The leaving evaporator water is pumped to the bulk air cooler where the water (400 kg/s) is used to cool the ventilation air entering the mine. The air is normally cooled to a wet bulb temperature of between 5°C and 7°C. This is much lower than the design specifications as indicated in *Figure 4.3*.

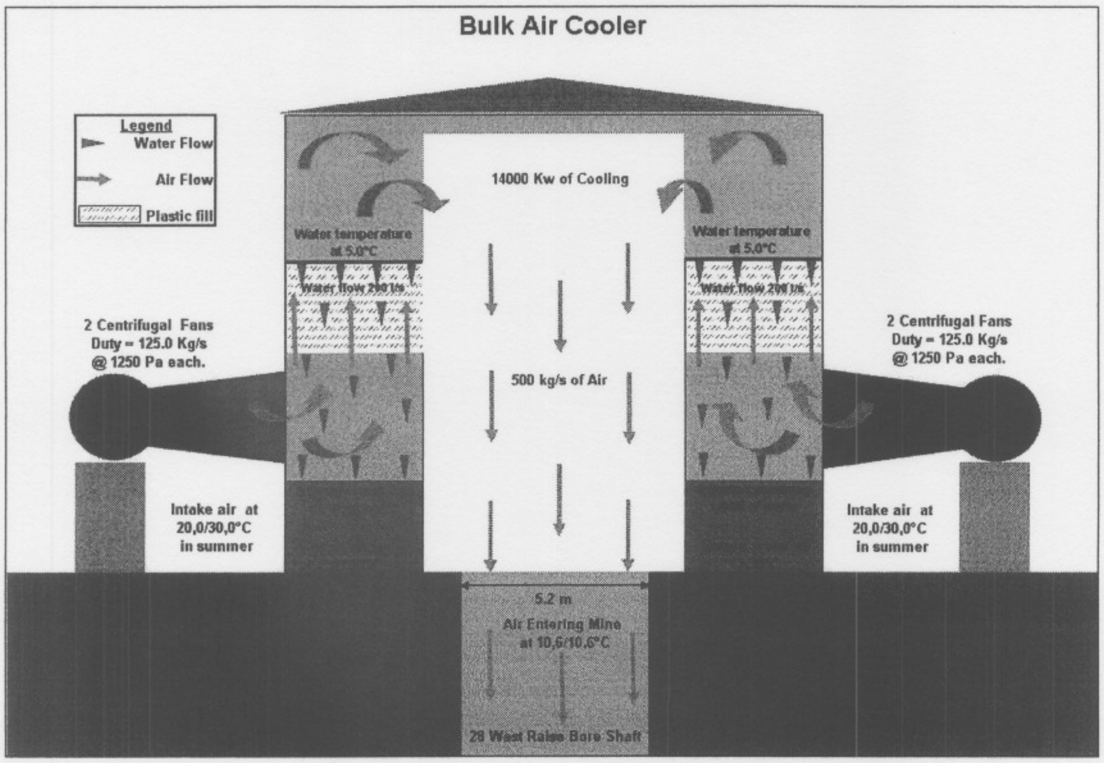


Figure 4.3: Bulk air cooler specifications at Amandelbult

The evaporator flow varies between 400 and 450 kg/s. The flow depends on the BAC bypass valve control. The valve is controlled to ensure a minimum entering evaporator temperature of 13°C at the chillers. The refrigeration plant design specifications are indicated in *Figure 4.4*.

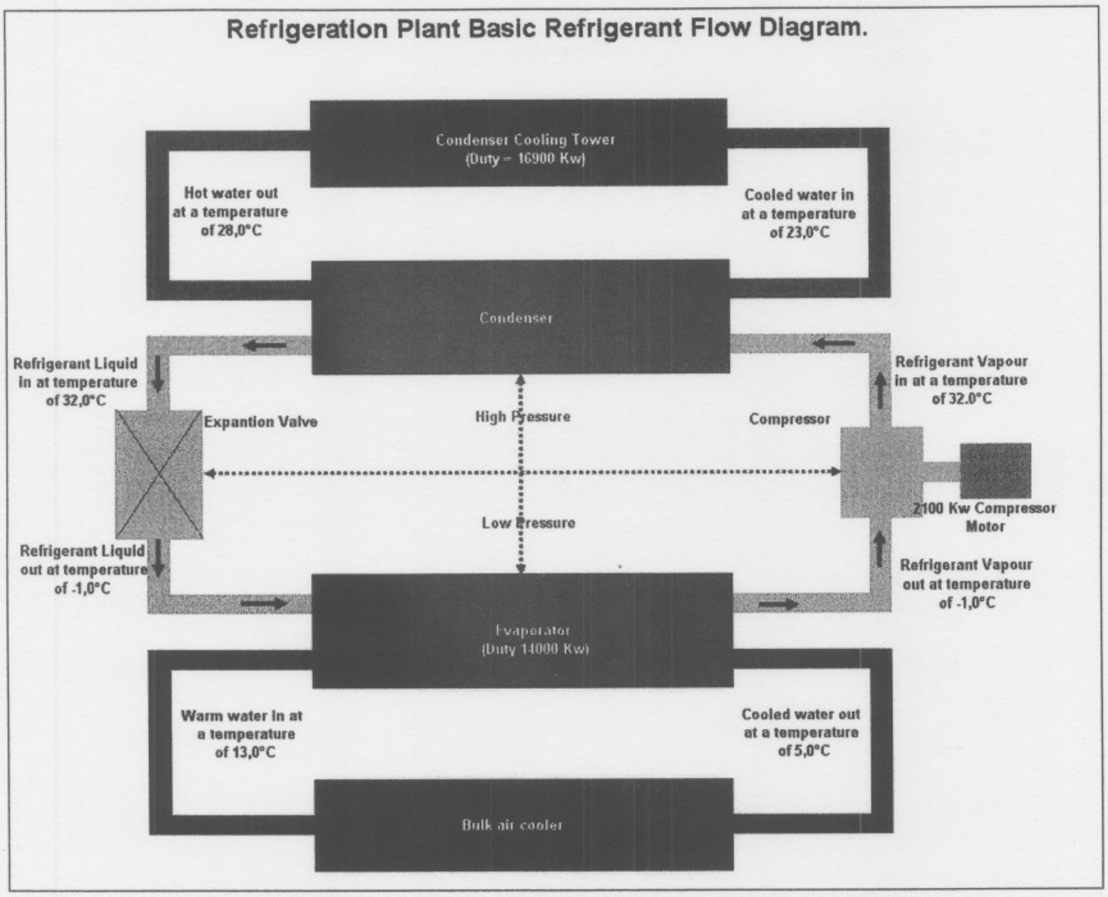


Figure 4.4: Refrigeration plant design specifications at Amandelbult

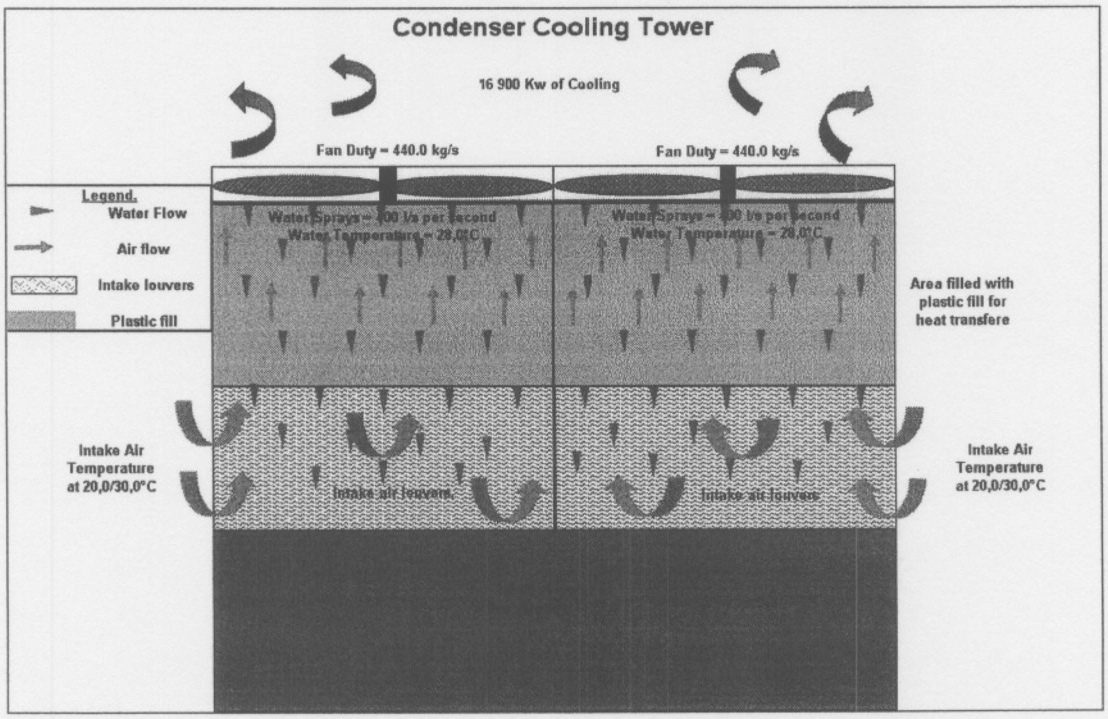


Figure 4.5: Condenser cooling tower design specifications at Amandelbult

The condenser water is pumped to the condenser cooling towers where it is cooled to ±23°C. The condenser flow varies between 400 and 450 kg/s as indicated in Figure 4.5.

4.1.1.3 Electricity audit

There are five main electricity intensive systems namely refrigeration, underground pumping, winding, ventilation and compressors. The contribution of each of these to the total electricity consumption of the mine can be seen in *Figure 4.6*.

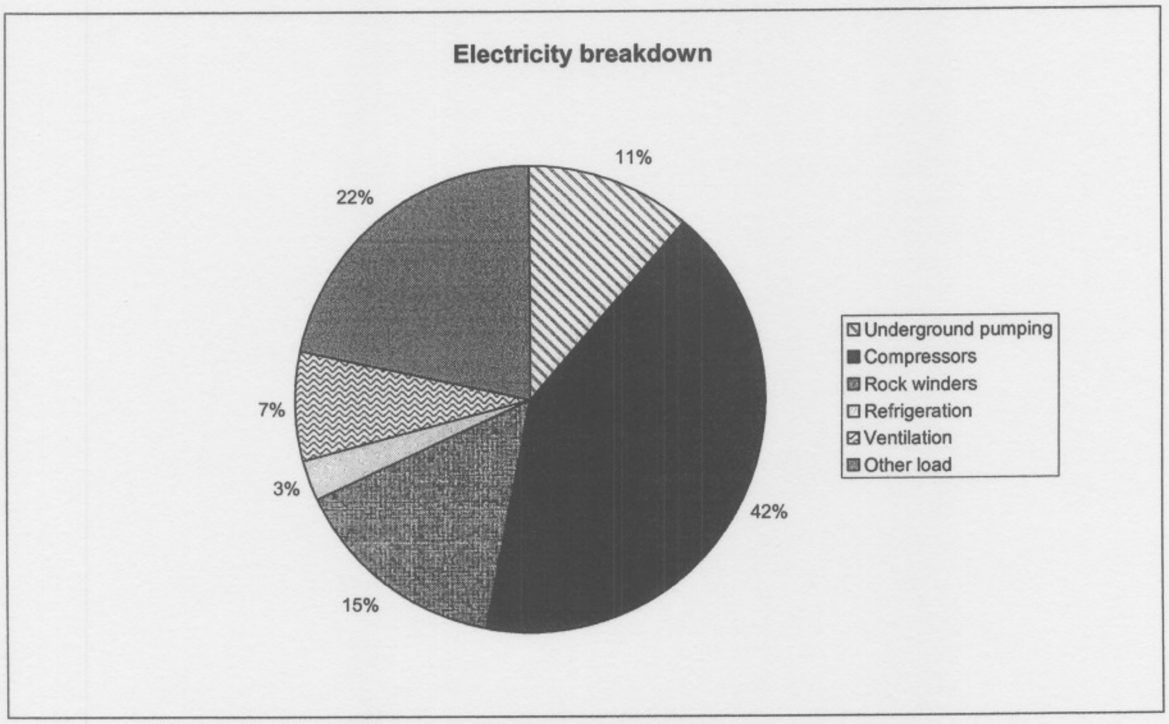


Figure 4.6: Electricity breakdown of Amandelbult

The base load includes the mills, lights, workshops and air conditioning of office buildings. All these systems were not part of the study due to their constant or unpredictable nature. The mills were not considered for the study due to their direct link to production and the mines view that the saving does not warrant the risk of production loss.

Load factors	
Underground pumping	0.40
Compressors	0.81
Rock winders	0.96
Refrigeration	1.00
Ventilation	0.91
Base load	1.00

Table 4.1: Load factors of the different systems at Amandelbult

The load factors in *Table 4.1* give a good indication of the current operation of the systems as well as the presence of surplus capacity. The lower the load factor the greater the potential for DSM or load shifting. When one takes this as well as the operational constraints into consideration the underground pumping system appears to be only system with DSM or load shifting potential.

The compressor and ventilation systems must be active during underground shifts. The surplus capacity at these two sub systems are only backups and may not be used. This means that the compressors and ventilation systems will not form part of the study.

The rock winders operate continuously only stopping for inspections and maintenance. This together with the fact that the winders also directly influence maintenance and the mine's feeling towards the potential loss in production means that this system will also not form part of the study.

The refrigeration plant on the other hand is currently operated fully throughout the year by lowering the evaporator set point to 0.5°C in winter. This is not necessary as an evaporator set point of 5°C is sufficient to handle the underground cooling needs.

Both the underground pumping and refrigeration systems will be studied in detail to assess the potential for DSM and load shifting.

4.1.1.4 Cost

The mine is currently on the urban NIGHTSAVE tariff structure. This tariff consists of two parts namely a maximum demand charge and an electricity charge. The tariff charges in 2002 are indicated in *Table 4.2* and *Table 4.3.*

	High demand season (June-August) 2002	**Low demand season (September-May) 2002**
/kVA	R 26.15	R 10.66
/kW	R 30.77	R 12.54

Table 4.2: NIGHTSAVE maximum demand charge

High demand season (June-August) 2002	**Low demand season (September-May) 2002**
12.42c/kWh	9.16c/kWh

Table 4.3: NIGHTSAVE electricity charge

This tariff structure does not give any incentive for load shifting. The only saving that can be achieved on NIGHTSAVE is electricity savings on the refrigeration plants in winter. In 2001 Amandelbult had an electricity bill of R103 million. Pumping contributed R11.3 million and refrigeration R3.1 million.

The management is currently looking at switching to the MEGAFLEX tariff structure. The tariff consists of the same two parts as NIGHTSAVE with the difference being that the electricity charge consists of different prices for different time of use periods. These time periods are peak, standard and off-peak. The tariff charges in 2002 are indicated in *Table 4.4* and *Table 4.5*.

	2002
/kW	R 8.17

Table 4.4: MEGAFLEX maximum demand charge

	High demand season (June-August)	**Low demand season (September-May)**
Peak	45.49c/kWh	13.92c/kWh
Standard	13.11c/kWh	9.21c/kWh
Off-peak	7.76c/kWh	6.94c/kWh

Table 4.5: MEGAFLEX electricity charge

This time of use tariff lends itself much more towards load shifting and DSM actions, shifting or shedding load from the peak and standard time of use periods to the off-peak time of use period.

4.1.1.5 Data availability

The mine has a comprehensive Supervisory Control and Data Acquisition (SCADA) system monitoring the surface refrigeration plant. All the required water temperatures, flows and electricity consumptions are measured on the refrigeration plant. The underground pumping stations are only monitored by the operator and the total daily flow is logged in a logbook.

Only the maximum demand is monitored continuously as maximum demand control is very important for customers on NIGHTSAVE as this is the main contributor to the electricity account. All other electricity information will be collected from the electricity accounts.

4.1.1.6 Conclusion

The mine is well suited for this case study. The management is very keen on any savings and open to suggestions as long as it has no negative affect on production. The infrastructure is in place to easily automate the surface refrigeration system under investigation. Due to the SCADA system most of the operational condition data are easily available.

The underground pumping system has large dams that can be used for storage. This together with the current operating strategy of the refrigeration plant indicates a good potential for both load shifting and DSM actions on these two systems.

4.1.2 Simulation models

4.1.2.1 Underground pumping system

4.1.2.1.1 Background

The accurate prediction of the power consumption of the pumps is essential for any load shifting calculations. To predict a realistic operation schedule for the pumps the following needs to be accurately predicted.

- Settler flow
- Dam capacities
- Pump flow and electricity consumption

The way each of these where handled in the simulation is shown in section 3.1.2.1.2. No calibration or verification was done on the underground pumping systems due to the lack of suitable measurements.

4.1.2.1.2 Methodology

4.1.2.1.2.1 Settler flow

The total amount of water pumped from every pumping station is logged in a log book daily. The logged flows were used to calculate the amount of water that is pumped to the surface daily for a weekday, Saturday and Sunday. These flows are indicated in *Table 4.6*.

	Weekday	**Saturday**	**Sunday**	
No. 1 shaft	7725	6880	6286	m^3
No. 2 shaft	10000	10000	5000	m^3

Table 4.6: Daily settler flow at Amandelbult

The daily settler flow was used as a constant average hourly flow for simulation purposes.

4.1.2.1.2.2 Dam capacities

The clear water dams at both the shafts have been cleaned recently and the dam's capacities were recalculated. These given capacities are taken as accurate as there are no recorded dam level measurements available to recalculate the capacity. The dam capacities are indicated in *Table 4.7*.

No. 1 shaft	3500 m^3
No. 2 shaft	3600 m^3

Table 4.7: Dam capacities at Amandelbult

These capacities were used for the simulation. The pumps are currently being controlled to keep the dam levels between 60% and 80%.

4.1.2.1.2.3 Pump flow

The pumps are inspected once a week. During these inspections the flow delivered by each pump as well as the electricity demand is measured. The maintenance on the pumps is done according to the flow measurement. This ensures that the flow rate delivered by the pumps will always be above the values listed in *Table 4.8*.

No. 1 shaft	138 kg/s
No. 2 shaft	120 kg/s

Table 4.8: Minimum flow per pump at each pumping station at Amandelbult

These minimum flows will be used for the simulation as these are the more conservative value to use.

4.1.2.1.2.4 Electricity consumption

Just as the flow per pump was taken as constant the electricity consumption per pump at a pumping station was taken as constant. The electricity demand of the pumps is taken as the measured electricity demand at the minimum flow during the routine pumping inspections. The electricity demand of the pumps at the pumping stations is indicated in *Table 4.9*.

No. 1 shaft	1800 kW
No. 2 shaft	2500 kW

Table 4.9: Electricity demand per pump at each pumping station at Amandelbult

4.1.2.2 Surface refrigeration system

4.1.2.2.1 Background

The accurate prediction of the compressor power consumption of chillers is essential for any load shifting calculations. To predict a realistic operation schedule for the chillers the following needs to be accurately predicted:

- Thermal performance of the pre-cooling towers.
- Thermal performance of the BAC.
- Accurate prediction of the climate.

The way each of these was handled in the simulation is shown in section 3.1.2.2.2.

4.1.2.2.2 Methodology

4.1.2.2.2.1 Climate

The climate model predicts the hourly temperature and relative humidity swing using the predicted minimum and maximum temperatures of the day. The fit employs the use of both second and third order polynomials to predict the temperature swing between the maximum and minimum temperatures. The calibration results can be seen in *Figure 3.13*. The temperature error is smaller than 2°C for 83% of the time. On average the simulated and measured temperatures differ by 1°C. An error smaller than 2°C for 80% of the time is taken as the acceptable norm for these types of thermal simulations.

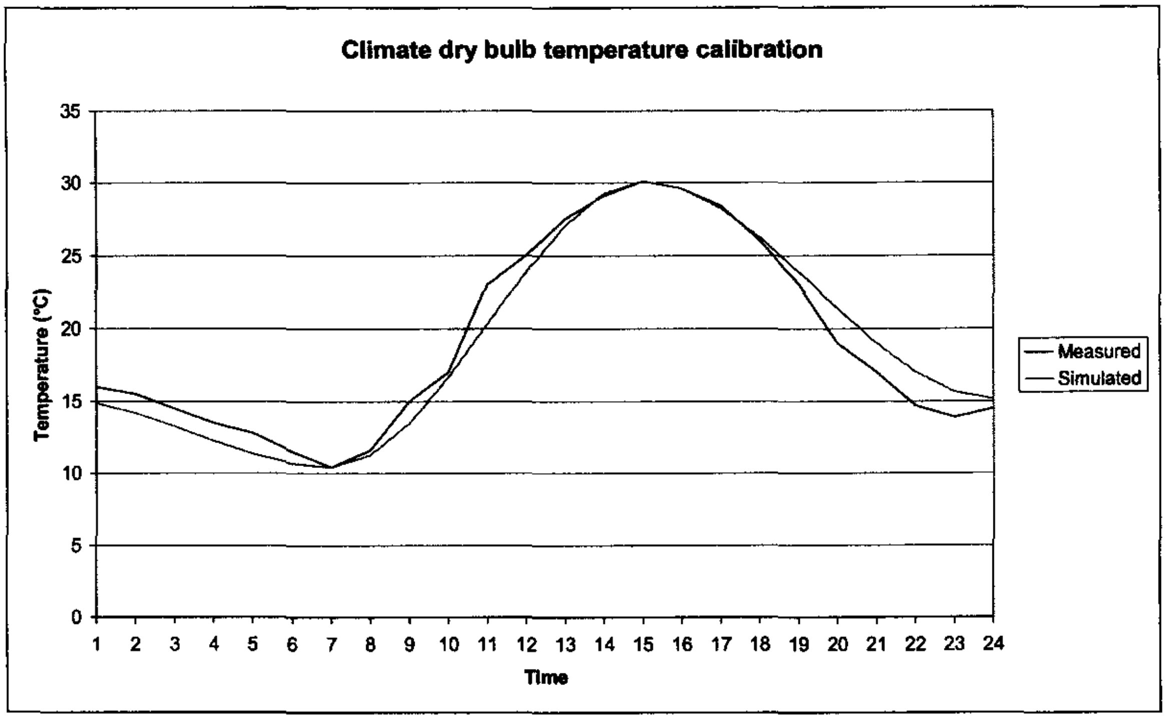


Figure 4.7: Climate temperature calibration at Amandelbult

The relative humidity is calculated as discussed in section 3.1.2.2.2.1. Figure 3.14 shows the calibration results of a week extracted out of the data. The average error in the simulated values was 6.8%. This is acceptable, as any accuracy within 10% is taken as adequate. Furthermore the measurement of relative humidity can have a deviation of 10%.

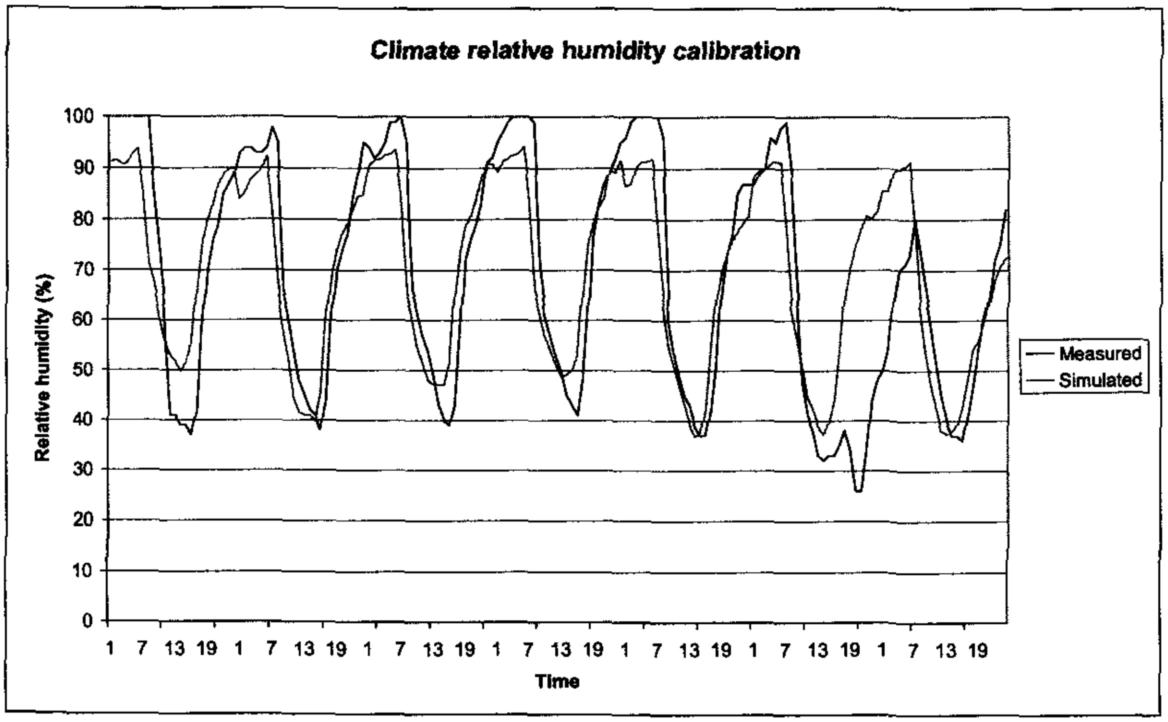


Figure 4.8: Climate relative humidity calibration at Amandelbult

The accurate simulation of the climate wet bulb temperature is more important than the accurate relative humidity prediction. As the wet bulb temperature is used as a direct input to both the cooling tower and bulk air cooler models. The calibration results can be seen in *Figure 4.9*.

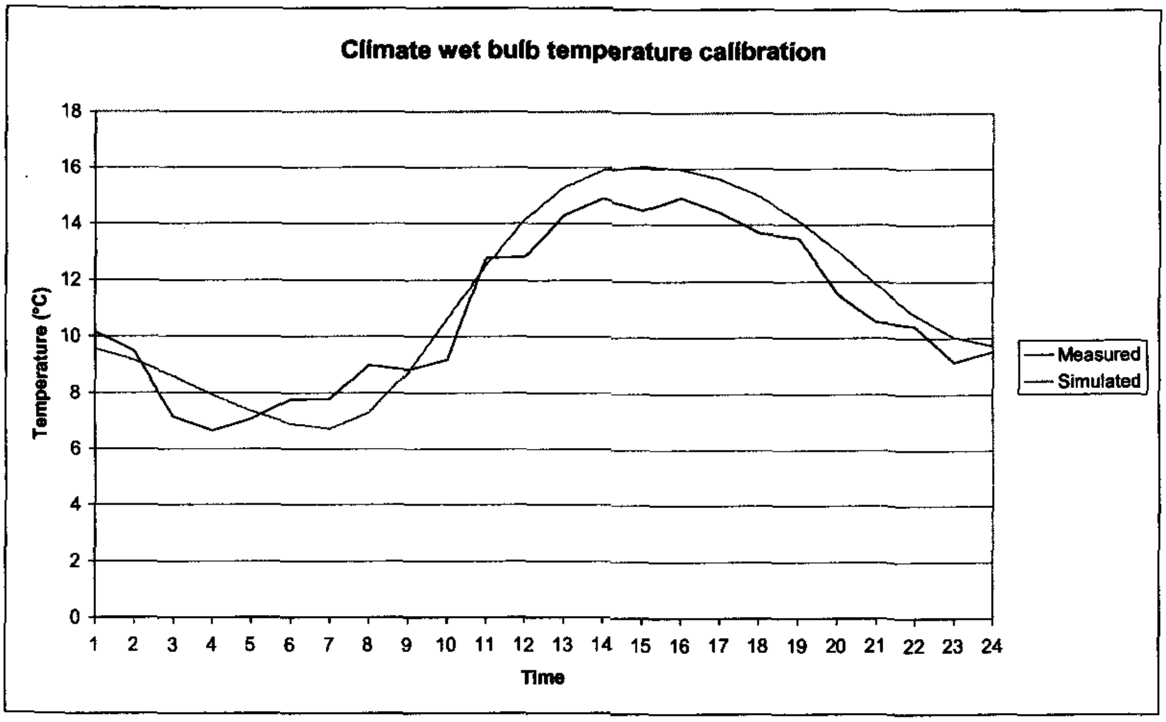


Figure 4.9: Climate wet bulb temperature calibration at Amandelbult

The temperature error is smaller than 1.5°C for 92% of the time. On average the simulated and measured temperatures differ by 0.95°C. An error smaller than 2°C for 80% of the time is taken as the acceptable norm for these types of thermal simulations.

4.1.2.2.2.2 Bulk air coolers

Both the bulk air cooler and cooling towers use the same power function fit to calculate the cooling capacity (Q) as discussed in section 3.1.2.2.2.2. The calibration results are indicated in *Figure 4.10.* The temperature error is smaller than 1.5°C for 92% of the time. On average the simulated and measured temperatures differ by 0.72°C. An error smaller than 2°C for 80% of the time is taken as the acceptable norm for these types of thermal simulations.

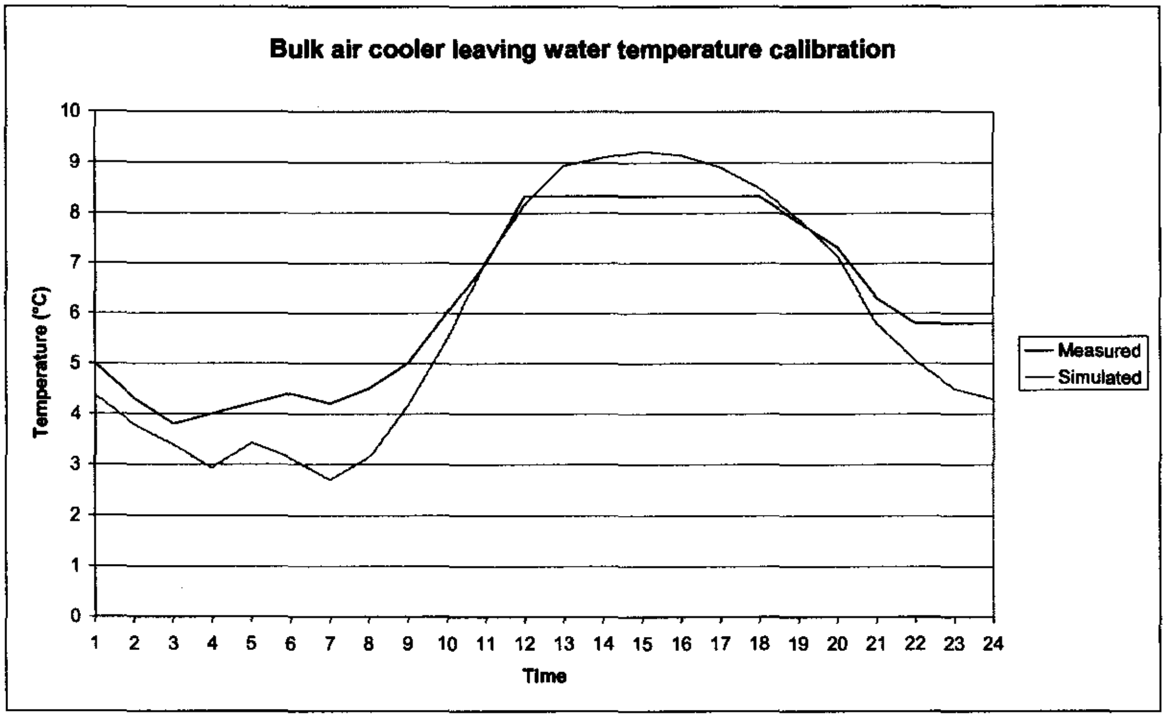


Figure 4.10: Bulk air cooler leaving water temperature calibration at Amandelbult

4.1.2.2.2.3 Chiller compressor power

The compressor power is a function of both the evaporator and condenser outlet temperatures. The compressor power equation looks as follow [12]:

$$Pwr = b_0 + b_1 T_{ce} + b_2 T_{ee}$$

With T_{ce}: Condenser leaving temperature

T_{ee}: Evaporator leaving temperature

$b_{0,1,2}$: Correlation coefficients

Pwr: Compressor power

The correlation coefficients were calibrated using measured data. The calibration of the compressor power can be seen in *Figure 3.15*.

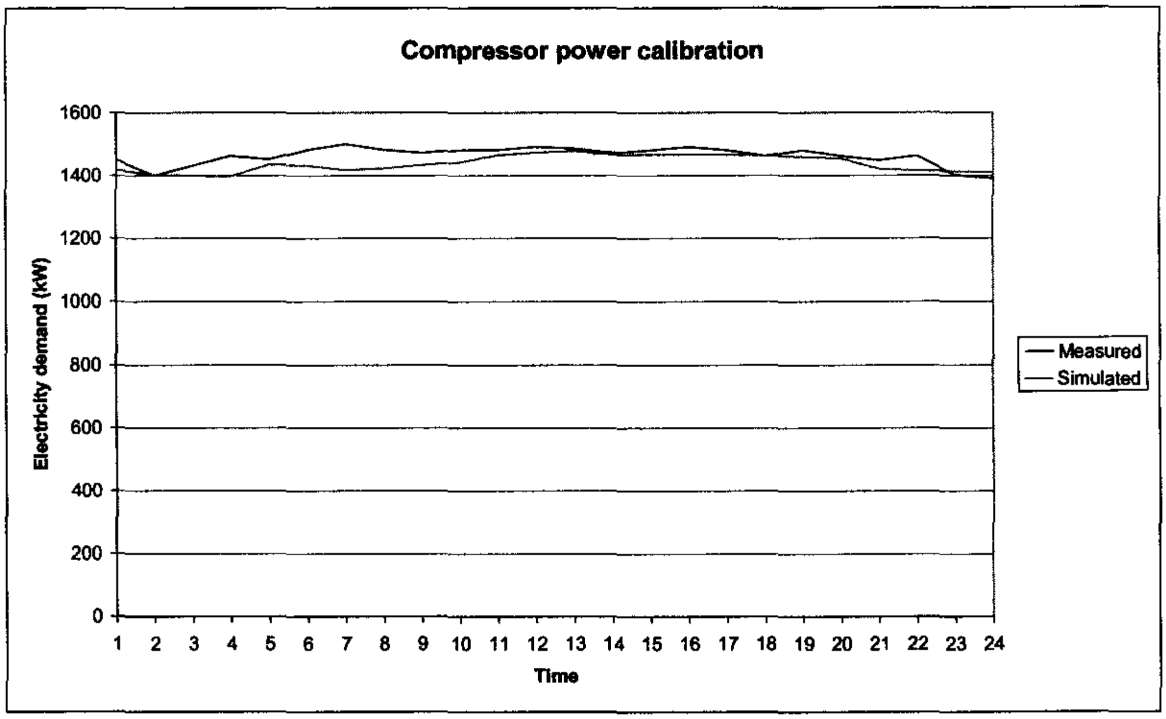


Figure 4.11: Chiller compressor power calibration at Amandelbult

The average error was 2%. The model is within 5% for 96% of the time. This is accurate enough as an error of less than 10% for 80% of the time is taken as the norm.

4.1.2.2.3 Verification

4.1.2.2.3.1 Climate

Using the calibrated model a new day's climate was simulated using the predicted minimum and maximum temperatures of the day. The outputs of this model are then used as inputs to the BAC model.

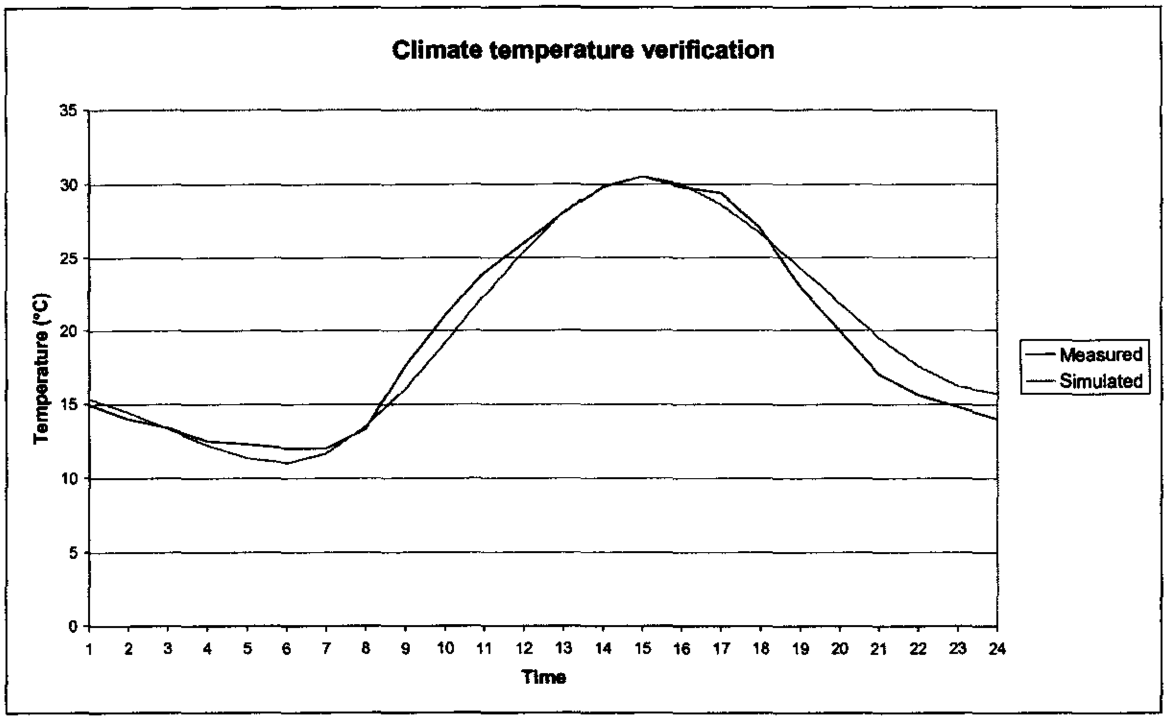


Figure 4.12: Climate temperature verification at Amandelbult

The climate was simulated accurately the error was smaller than 2°C for 96 % of the time (indicated in *Figure 3.16*). This exceeds the norm of less than 2°C for 80 % of the time.

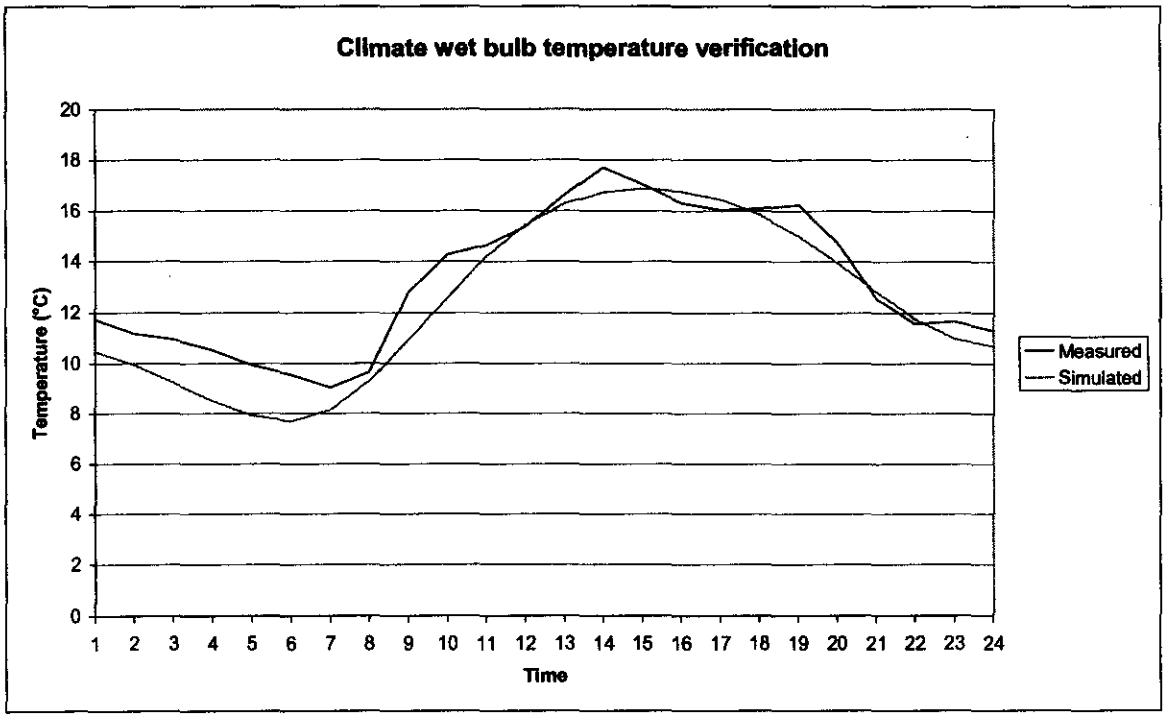


Figure 4.13: Climate wet bulb temperature verification at Amandelbult

The simulated wet bulb temperature shown in *Figure 3.17* has an average absolute error of 0.9°C. The error is smaller than 2°C for 92 % of the time also exceeding the recognised norm.

4.1.2.2.3.2 Bulk air cooler

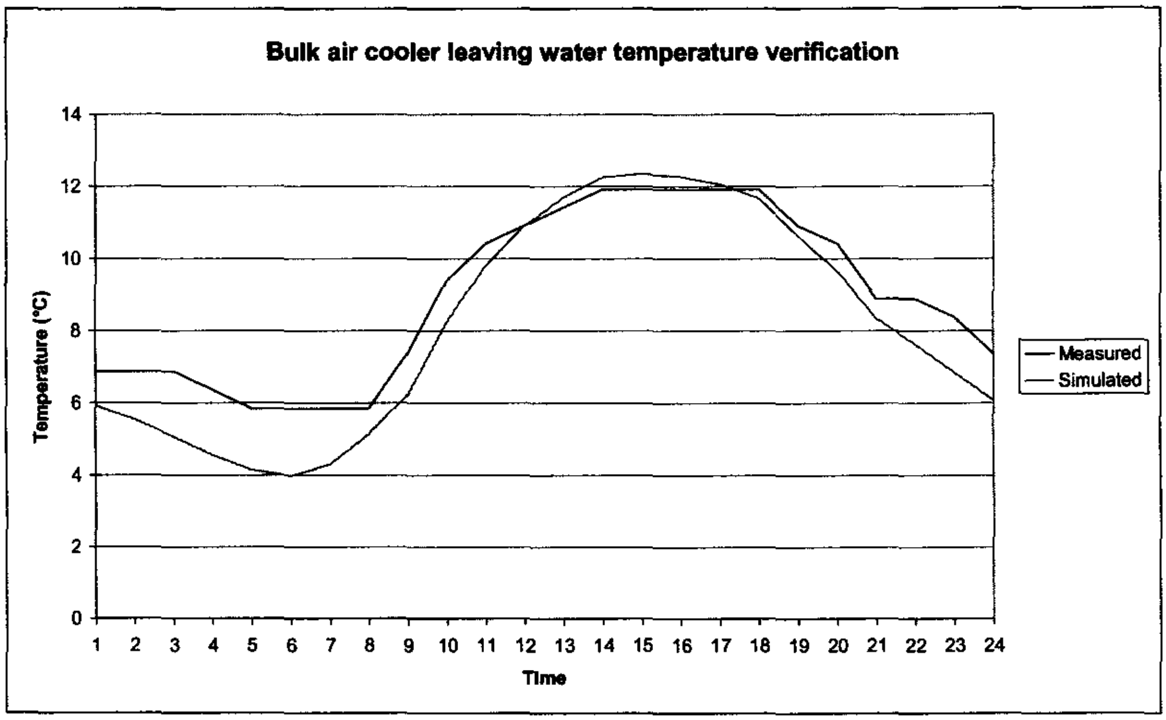


Figure 4.14: Bulk air cooler leaving water temperature verification at Amandelbult

Figure 3.18 shows the verification results of the bulk air cooler outlet water temperature. The error is smaller than 1.5°C for 75% of the time and smaller than 2°C for 100% of the time. This is well within the norm of within 2°C for 80% of the time.

4.1.2.2.3.3 Chiller compressor power

This calibrated chiller model was now verified using the operating conditions (Climate) of another day. The verification showed the following results. The average error was 2.2%. Finally the model's error was smaller than 5% for 100% of the time. Looking at these results and *Figure 3.19* it can clearly be seen that the model is accurate enough for its use in the optimisation.

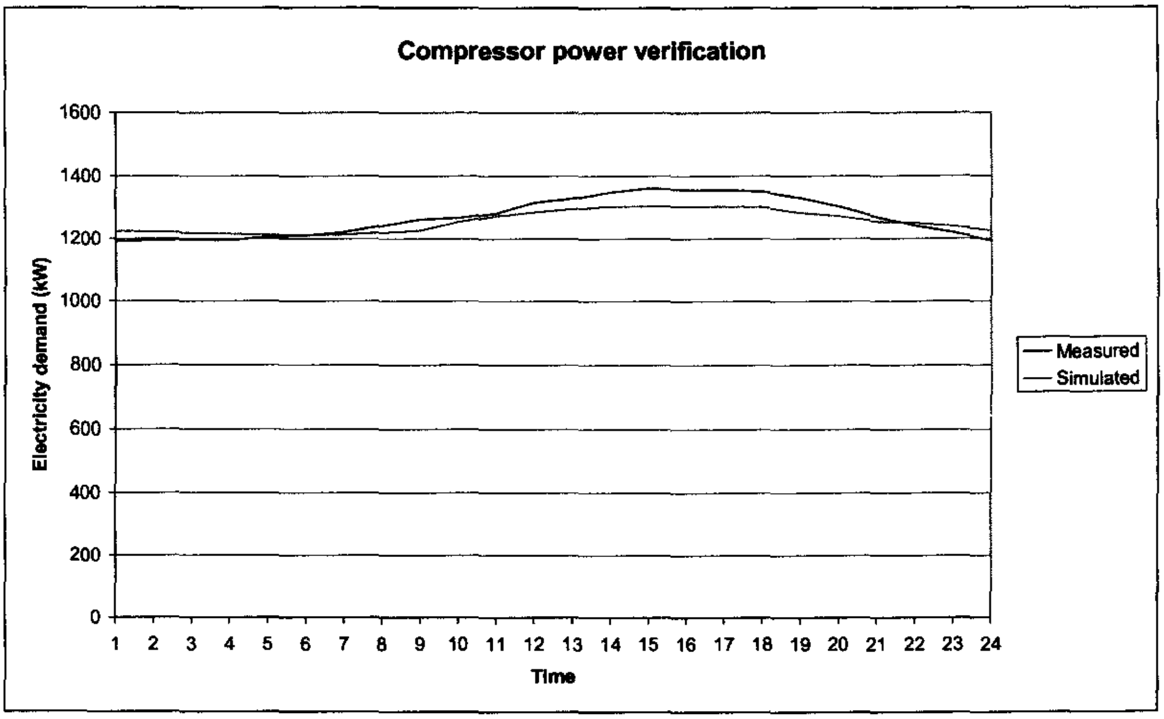


Figure 4.15: Chiller compressor power verification at Amandelbult

4.2 Analysis and optimisation of the electricity costs of each system and system type

4.2.1 Electricity cost analysis

4.2.1.1 Electricity cost of the different systems

In the case of Amandelbult the electricity cost breakdown is exactly the same as electricity usage breakdown due to the fact that NIGHTSAVE does not have a time of use component in the cost calculation.

In 2001 Amandelbult had an electricity bill of R103 million. Pumping contributed R11.3 million and refrigeration R3.1 million.

4.2.2 Objective function

The objective function is the value that is dependent on all the variables that must be optimised. In this case the total daily or weekly electricity cost is the value that must be minimised while still satisfying all of the constraints.

Amandelbult is currently on NIGHTSAVE as electricity tariff. This means that the optimum use of both MEGAFLEX and two-part-RTP needs to be studied. The calculation of the objective function on two-part-RTP is exactly the same as discussed in the same section in chapter 3.

In the case of MEGAFLEX the hourly costs is calculated by multiplying the total load with the tariff the maximum demand is not calculated on a daily basis but monthly. The demand cost is however taken into account while extrapolating the daily optimised cost to a total yearly electricity cost.

4.2.3 Boundaries

The boundaries are those values that are not dependent on any of the outputs of the models, but do influence the models directly or indirectly. The boundaries are also normally one of the values that need to be calibrated from time to time.

The boundaries in this case are the settler flow, minimum and maximum temperatures, base load and price signal.

The settler flow was calculated from measurements taken on the mine. The hourly average for every hour of every day was taken to calculate the weekly boundaries.

The minimum and maximum temperatures are given by the weather forecast of every day. The temperatures drive the optimisation of the cooling systems together with the daily RTP price. The RTP price is downloaded daily for the following day.

4.2.4 Constraints

The constraints are the values that enforce the physical operational limits of the system onto the optimisation. The accurate implementation of these limits is essential to ensure that the outputs of the optimisation are practical and can be implemented.

4.2.4.1 Underground pumping system

There are two types of constraints applicable to this system. These are the available number of pumps and minimum and maximum dam levels on each level.

The pumps at both pumping stations are currently controlled to keep the clear water dams between 60% and 80%. The minimum dam level can be lowered to 40% without any unforeseen problems. The minimum dam levels used for the optimisation will be 40% and the maximum 80%.

There are three pumps installed at both the pumping stations of which currently only one is used at a time per pumping station. There are no operational limits preventing the operators to use two pumps at the same time per pumping station. One pump must always be on standby. The three pumps at shaft 1 has a maximum flow of 120l/s and the pumps at shaft 2 140l/s.

There is no defined maintenance schedule that has to be incorporated using operational constraints.

4.2.4.2 Surface refrigeration system

On the surface refrigeration system the maximum number of chillers available is 2. The chilled water supply must be colder than 5°C and the wet bulb temperature of the air entering the mine (leaving the BAC) should be colder than 10°C. The chillers are capable of 7MW cooling capacity each.

4.2.5 Variables

The variables are the values that are changed to minimise or maximise the objective function while still satisfying the constraints.

On the underground pumping system the number of pumps active every hour on each level is the variables. The total cooling capacity every hour is the variable of the surface refrigeration system.

4.2.6 Optimisation model for each typical day

4.2.6.1 Background

A typical week can be split into three typical day types after looking at the maintenance schedules and typical operating strategies employed on the mine currently. These are a weekday, Saturday and Sunday. The way these were handled in the optimisation is now discussed. An optimisation model for every month for each of these days must be built.

4.2.6.2 Boundaries

The boundaries, of the base load, CBL load, RTP tariff, MEGAFLEX tariff and the minimum and maximum temperatures, for the potential savings calculations are calculated from the previous years' measured data. An hourly average is used to calculate the typical profile for the boundary for each typical day for each month in the case of RTP and for summer and winter for MEGAFLEX.

The boundary of the settler flow is not dependent on the seasons and thus the previous 3 months measured data were used to obtain the boundaries.

4.2.6.3 Constraints

4.2.6.3.1 Weekday

The only constraint that is added during a weekday is that all the pumps must be switched off from 07:00 to 08:00 for routine maintenance inspection.

4.2.6.3.2 Saturday

The last shift leaves the mine a 15:00. No cooling is needed after this on Saturdays.

4.2.6.3.3 Sunday

On Sundays weekly maintenance is performed on the refrigeration plant. The cooling plant must be up and running to ensure the required leaving BAC temperature at 24:00.

4.3 Economic implications of the different DSM alternatives

4.3.1 Comparison of optimised and previous years' loads

4.3.1.1 MEGAFLEX

4.3.1.1.1 Summer

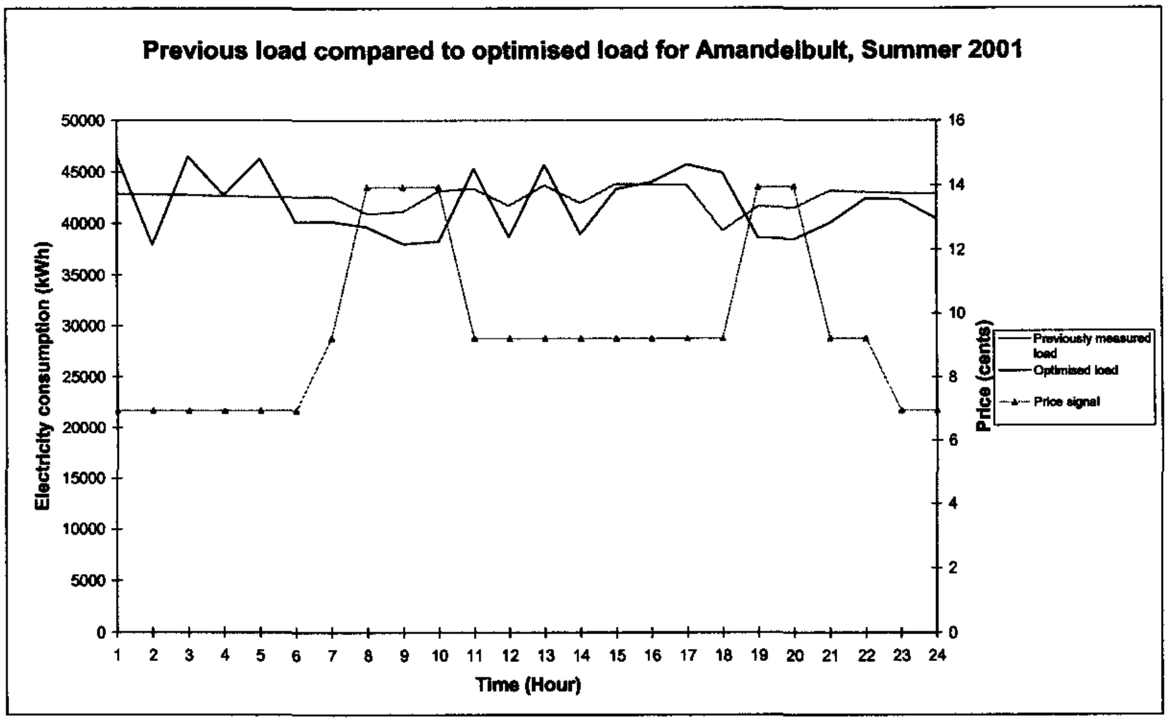


Figure 4.16: Typical weekday, Amandelbult, Summer 2001

During a typical weekday in summer a total of 23MW can be shifted from the morning and afternoon peak price periods. The most of the load is shifted to the early morning and late evening low demand periods as shown in *Figure 4.16.*

On the refrigeration side an average electricity saving of 50% of the refrigeration electricity consumption is achievable. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

4.3.1.1.2 Winter

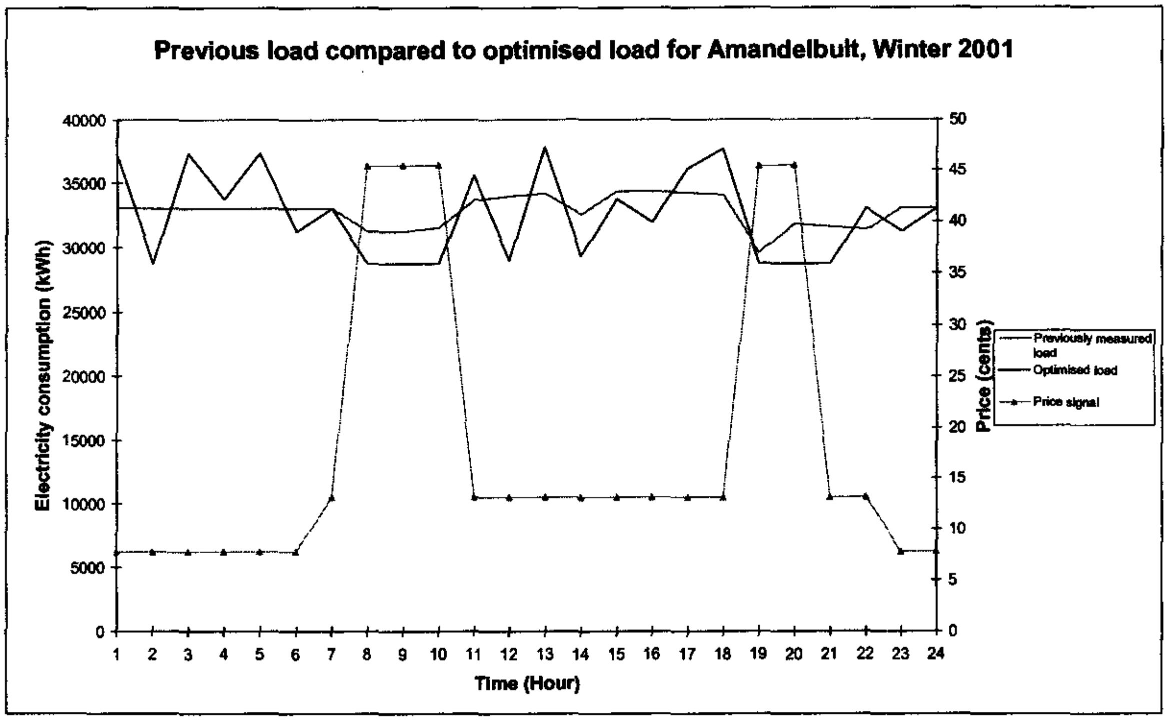


Figure 4.17: Typical weekday, Amandelbult, Winter 2001

During a typical weekday in winter a total of 26.5MW can be shifted from the morning and afternoon peak price periods. The most of the load is shifted to the early morning and late evening low demand periods as shown in *Figure 4.17.*

On the refrigeration side an average electricity saving of 33% of the refrigeration electricity consumption is achievable. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

4.3.1.2 Two part RTP

The previously measure load is compared to the optimised load to calculate both the amount of load shifted and electricity savings for an average weekday for every month.

A short discussion about this comparison for each month is given in appendix B.

These findings are summarised in *Table 4.10*

	Week day	
Month	Shifted load MW	Electricity saving %
January-01	26.5	46
February-01	23.9	43.8
March-01	23.7	49.5
April-01	20	89
May-01	25	50
June-01	27.7	33
July-01	29.5	23.3
August-01	25.5	48
September-01	21	86
October-01	23	62
November-01	23.7	52.5
December-01	25.7	49
Average	24.6	52.7

Table 4.10: Load comparison for Amandelbult

4.3.1.3 Summary

Employing a demand side strategy on the refrigeration system electricity savings of about 50% can be achieved on average in the summer months and 33% on average during typical weekdays in winter.

It seems strange that a bigger electricity savings potential exists in summer than in winter. The reason for this is that the cooler autumn and spring months are included as summer months according to the tariff structures as well as the current control strategy of the mine. In fact these months can be treated almost as winter months if one looks at the cooling demand.

On a typical summer's weekday 23MW of load can be shifted in total mostly on the pumping systems. This figure is a little higher on a typical winter's weekday, 26.5MW.

If one looks at a monthly breakdown as required for a tariff like two-part RTP these figures looks a little different but still in the same order of magnitude. The electricity savings that can be achieved are slightly increased to 58% for a typical summer's day on average. This is largely due to the savings of 89% and 86% in April and September respectively. The electricity saving on a typical winter's weekday increases to 35%.

The amount of load shifted stays almost the same at 23MW on average for summer and 27MW in winter.

4.3.2 Cost savings

4.3.2.1 Background

The mine is currently on NIGHTSAVE [14]. Two part RTP together with one part RTP are the best tariffs when load can be shifted. The saving due to the changing of tariff structure is not taken into affect. Instead only the saving due to load shifting and DSM actions is calculated.

Through the use of simulation models and optimisation the potential sustainable electricity savings through load shifting will be calculated.

4.3.2.2 Savings calculation

The saving calculation procedure stays the same for the three tariff structures. The savings are based on the comparative electricity costs of the current and proposed operating strategies using the tariffs for 2002 for both NIGHTSAVE and MEGAFLEX and the tariffs for 2001 for Real Time Pricing adjusted by the annual price increase of ESKOM.

4.3.2.3 Results

4.3.2.3.1 NIGHTSAVE

The newly proposed strategy on the underground pumping system will not yield any savings for the mine while they are on any tariff without a time of use component. The new operating strategy on the refrigeration system on the other hand can deliver a small saving in the three winter months. This saving is shown in *Table 4.11.*

	Saving
Refrigeration	R 62,461.05
Total	R 62,461.05

Table 4.11: Potential yearly NIGHTSAVE saving at Amandelbult

4.3.2.3.2 MEGAFLEX

A saving of just over R1 million can be achieved using the new operating strategies and the MEGAFLEX tariff. The underground pumping system contributed ±60% of the saving and the refrigeration system the remaining ±40%. The summarised savings are shown in *Table 4.12.*

	Saving
Pumping	R 568,101.87
Refrigeration	R 478,739.21
Total	R 1,046,841.08

Table 4.12: Potential yearly MEGAFLEX saving at Amandelbult

4.3.2.3.3 Real Time Pricing (RTP)

Using two part RTP with the customer base load (CBL) price based on MEGAFLEX an additional R0.5 million can be added to the MEGAFLEX saving. The additional saving is summarised in *Table 4.13*.

	Additional saving
Jan	R 56,396.41
Feb	R 26,860.27
Mar	R 21,792.01
Apr	R 44,337.41
May	R 28,282.79
Jun	R 42,085.11
Jul	R 53,717.82
Aug	R 57,227.08
Sep	R 93,451.15
Oct	R 35,378.59
Nov	R 26,538.66
Dec	R 35,815.21
	R 521,882.49

Table 4.13: Additional RTP saving at Amandelbult

Of this additional saving 44.5% can be achieved on the pumping system and the remaining 55.5% on the refrigeration system.

4.3.3 Infrastructure implications of these alternatives

This analysis is necessary to establish the cost, capital and operating, required for the implementation of the proposed strategies. The main components required are a complete SCADA (supervisory control and data acquisition) system as well as an electricity management system.

A SCADA system is currently implemented. The refrigeration system is controlled from a central control room using the SCADA system. Extra hardware is required to implement a similar process for controlling the underground pumping systems. Due to this initially only the DSM strategy on the refrigeration system will be proposed. The cost saving due to load shifting will not warrant the capital expenditure at present.

A separate piece of software will be implemented that uses the SCADA system to get the required conditional data for the control algorithms and in turn gives back a control signal to the SCADA system that in turn switches the components on and off.

This software will be made available as part of a service agreement in which a percentage of the savings will be paid to the service provider. The provider will be responsible for supply of a daily optimum schedule to the electricity management software. The service provider will also be responsible for the weekly calibration of the optimisation model to ensure accuracy.

This means that the initial implementation on the refrigeration system will only cost a percentage of the savings. This means that the mine will pay less for their electricity consumption even if the service fee is included to the electricity cost.

The implementation on the underground pumps will cost in the region of R1 million. This means that the payback period for the mine would be 2 years using the savings potential on MEGAFLEX. If two-part RTP is used the payback period will be less than a year.

4.4 Conclusion

4.4.1 Summary

Existing simulation models were modified and simplified for their use in optimisation. The simulation models' calibration and verification showed that they were sufficiently accurate to use in the optimisation.

The simulated electricity consumption was always within 10% of the measured values. Simulated temperatures were within 2°C of the measured temperatures for 80% of the time.

On average 3MW of demand can be shifted from the peak periods. During the colder months up to 50% of the electricity consumption of the refrigeration system can be saved.

An analysis of the electricity costs was undertaken. In this analysis the electricity bills for the twelve months preceding the studies were taken. At Amandelbult pumping contributed R11.3 million and refrigeration R3.1 million to the electricity bill.

The complete setup of the optimisation models for each of the mines was discussed in detail. The main components of the optimisation models that were discussed are the boundaries, constraints, variables and the objective function.

After looking at the operating strategies, maintenance schedule and tariff structures the typical day types were selected. At the end there were three typical day types for each mine namely weekday, Saturday and Sunday. The optimisation model for each of these typical days was set up. In the cases where the two-part-RTP tariff is to be optimised an optimisation model for every typical day for every month of the year was built. In the cases where MEGAFLEX was optimised an optimisation model for every typical day for summer as well as winter was built.

The load comparison at Amandelbult can be summarised as follows. Employing a demand side strategy on the refrigeration system electricity savings of about 50% on the refrigeration system can be achieved on average in the summer months and 33% on average during typical weekdays in winter.

The amount of load shifted stays almost the same at 23MW on average for summer and 27MW in winter. The cost savings that this brings is almost R62 500 on NIGHTSAVE, just over a R1 Million on MEGAFLEX and an additional R500 000 can be saved using RTP.

4.4.2 Recommendations

The implementation of one of strategies at one of the mines needs to be negotiated with the mine management and then be implemented for a test period. In this period the actual cost savings must be calculated. This is discussed in chapter 6.

After this phase of the project an implementation strategy must be set up to help in future DSM projects on mines (chapter 7). Lastly a national impact study on the implementation of DSM strategies on mine underground services must be completed (chapter 8).

CHAPTER 5.

TARGET: CASE STUDY 3

In this chapter all the steps in the detailed electricity cost savings calculation process in the case of Target is discussed. This includes the simulation and optimisation models (development, setup as well as verification), proposed DSM and load shifting strategies as well as the calculation of the electricity cost savings potential.

5 TARGET: CASE STUDY 3

5.1 The configuration and verification of the simulation models

5.1.1 Background information

5.1.1.1 General

Target mine is the major asset of Avgold and is situated on the western flank of the Witwatersrand Basin, where most of the world's gold has been mined. Avgold's exploration efforts focused on this area and by 1993 yielded extremely encouraging results. In 1995 feasibility studies for a 45 000 tonnes-a-month mine began and in July 1996 Avgold increased the scope of the project to a 90 000 tonnes-a-month mine.

Target has a mine life of at least 13 years but a resource profile from the areas north of Target shows 65.5 million ounces at an average grade of 6,7 grams/ton which will prolong the Target operations.

The productivity of conventional gold mines equates to a typical value of 20 tonnes milled per man per month. Currently this mine has a productivity figure of 130 tonnes milled per man per month and is looking to improve this figure. The mine's objective is to produce 100 000 tonnes of run-of-mine ore at a cost of less than US$150/oz by 2003.

By making more extensive use of technology the 2.25 km deep gold mine's objectives can be achieved. A detail study on the optimisation of the cooling and fan-power will be done to minimise the electricity cost and, therefore contribute to the mine's low mining cost.

5.1.1.2 System layout

5.1.1.2.1 Underground pumping

Underground water flows through the gullies to gather in the settlers. At the settlers the silt is gravitated out of the water and the clear water is pumped back to the surface via electrical pumps. There are three main pumping stations in the mine. They are on levels 255, 212 and 142 (L 255, L 212, L142).

Clear water from the settlers on level 255 flows to the 6000 kl clear water dam on the same level. From there the water is pumped to the 2100 kl clear water dam on level 212 via level 255 pump station. The clear water is then pumped via pump station 212 to the 1611 kl clear water dam on level 142 and from there to the surface dam via pump station 142.

The whole underground pumping system and the clear water dams are shown in *Figure 5.1*.

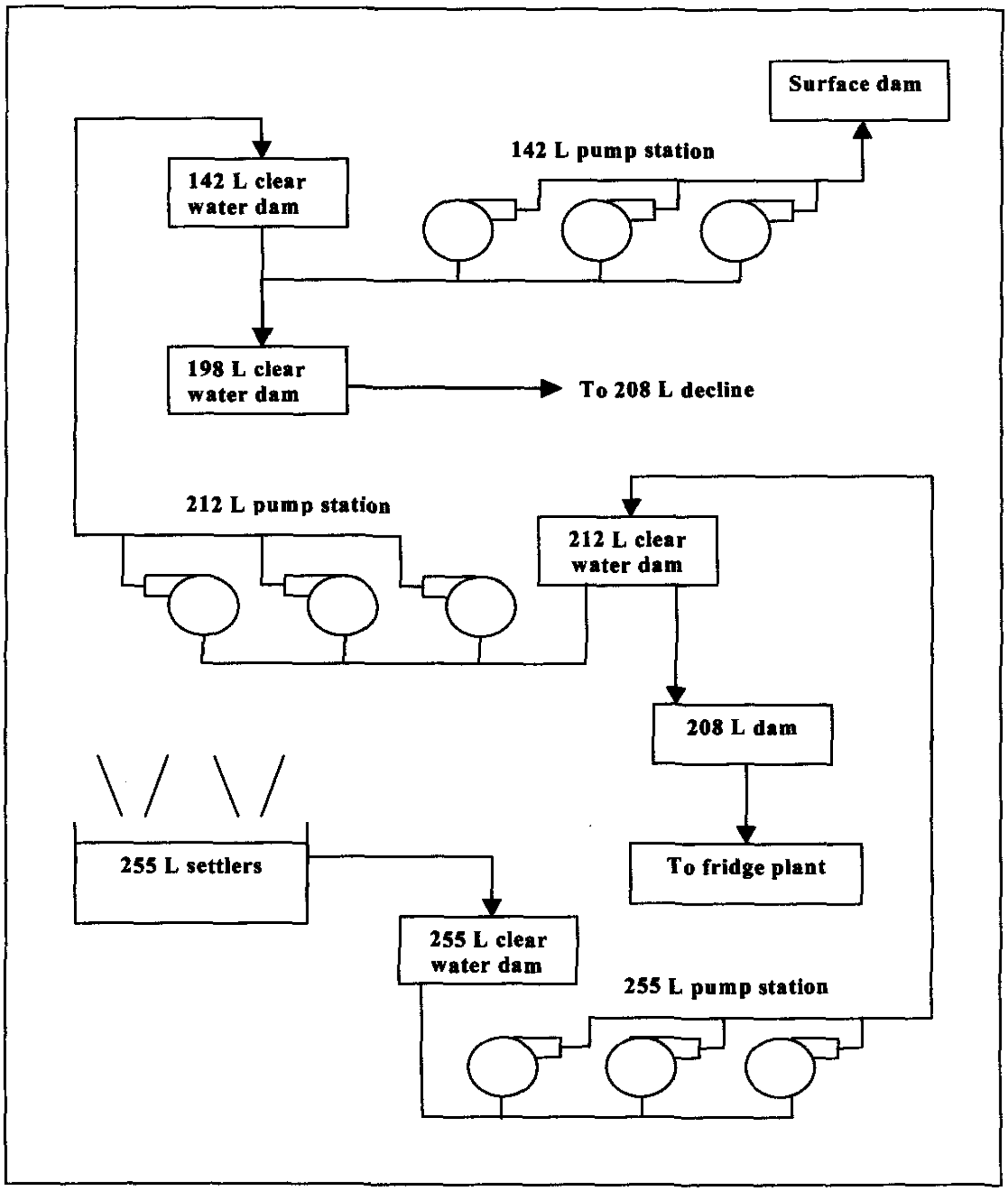


Figure 5.1: Schematic layout of the underground pumping system at Target

Level	Volume	Depth below surface
142	1611 kl	±900 m
212	2100 kl	±1500 m
255	6000 kl	±2200 m

Table 5.1: Underground dam information at Target

5.1.1.2.2 Underground refrigeration

There is no surface refrigeration at Target. All the refrigeration takes place underground. The refrigeration plant is situated on level 255 and consists of 10 refrigeration machines (chillers) each with a cooling capacity of ± 3 MW and a coefficient of performance (COP) of ± 3.5.

The water from the hot dam enters the evaporators at a temperature of 17°C and exits the evaporators at 9°C. This water is then pumped to the evaporator spray ponds at a tempo of 380 kg/s to cool the air that is destined for the workings. There are 4 evaporator spray ponds in parallel on level 255. There are also two smaller secondary evaporator spray ponds on level 276 and 280. The water that exits the evaporator spray ponds gathers in the hot dam before it is again pumped to the refrigeration plant.

From the condenser side of the chillers, water flowing at 740 kg/s, is pumped to the condenser spray ponds. There are four condenser spray ponds in parallel. The water enters the spray ponds at 46°C and is cooled by the return air from the workings to 41°C.

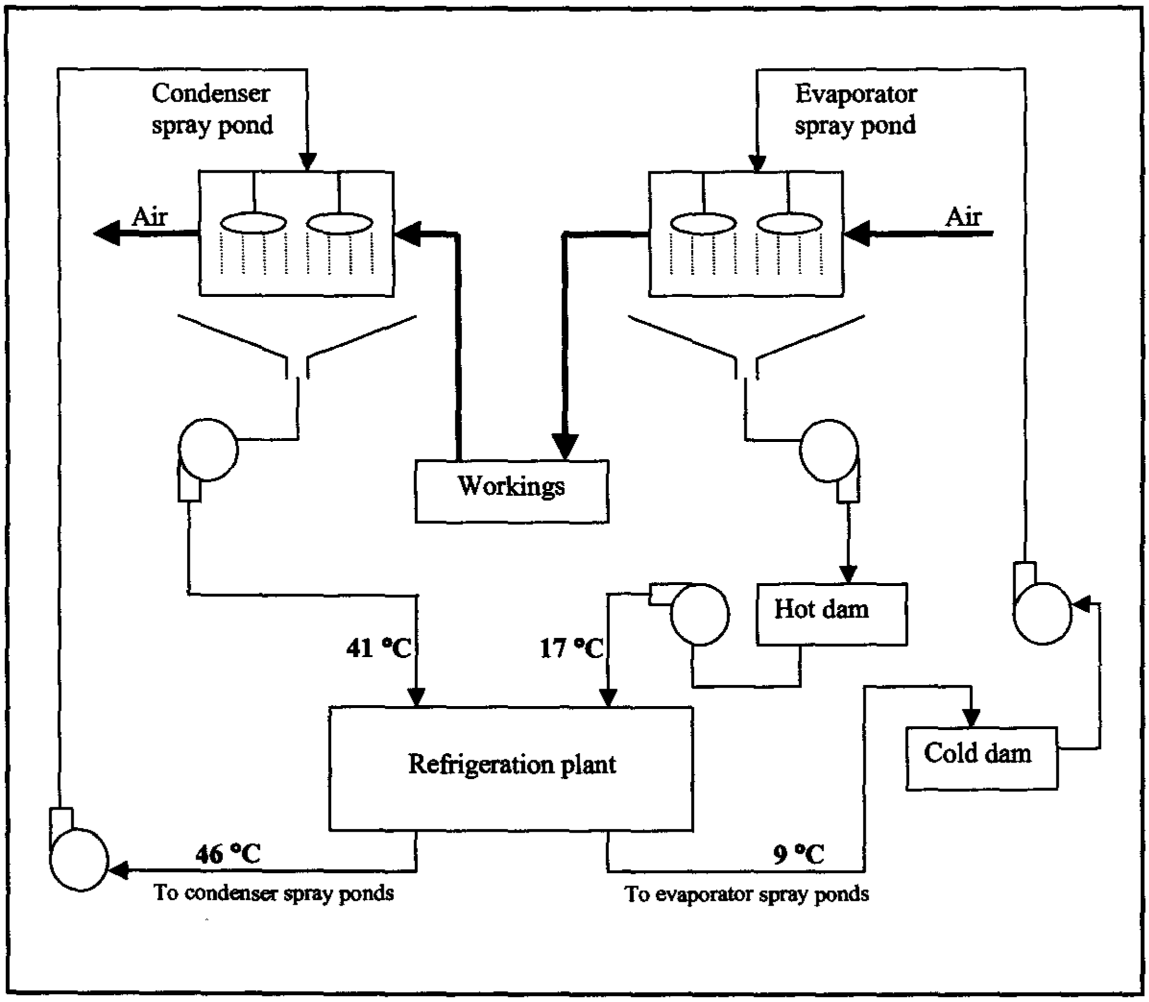


Figure 5.2: Schematic layout of the underground refrigeration system at Target

The exit water from the condenser spray ponds is then pumped back to the condenser side of the refrigeration plant for the next cycle. As shown in *Figure 5.2*

5.1.1.2.3 Underground ventilation system

A surface fan, driven by a 2100 kW electric motor, is mainly responsible for the ventilation requirements in the mine. This fan can extract air at 400 m^3/s at a pressure of 3.5 kPa. There is also one main fan on standby. The main fan is supported by two 275 kW booster fans on level 208 and four 445 kW booster fans on level 255. The schematic layout of the mine ventilation system can be seen in *Figure 5.3*.

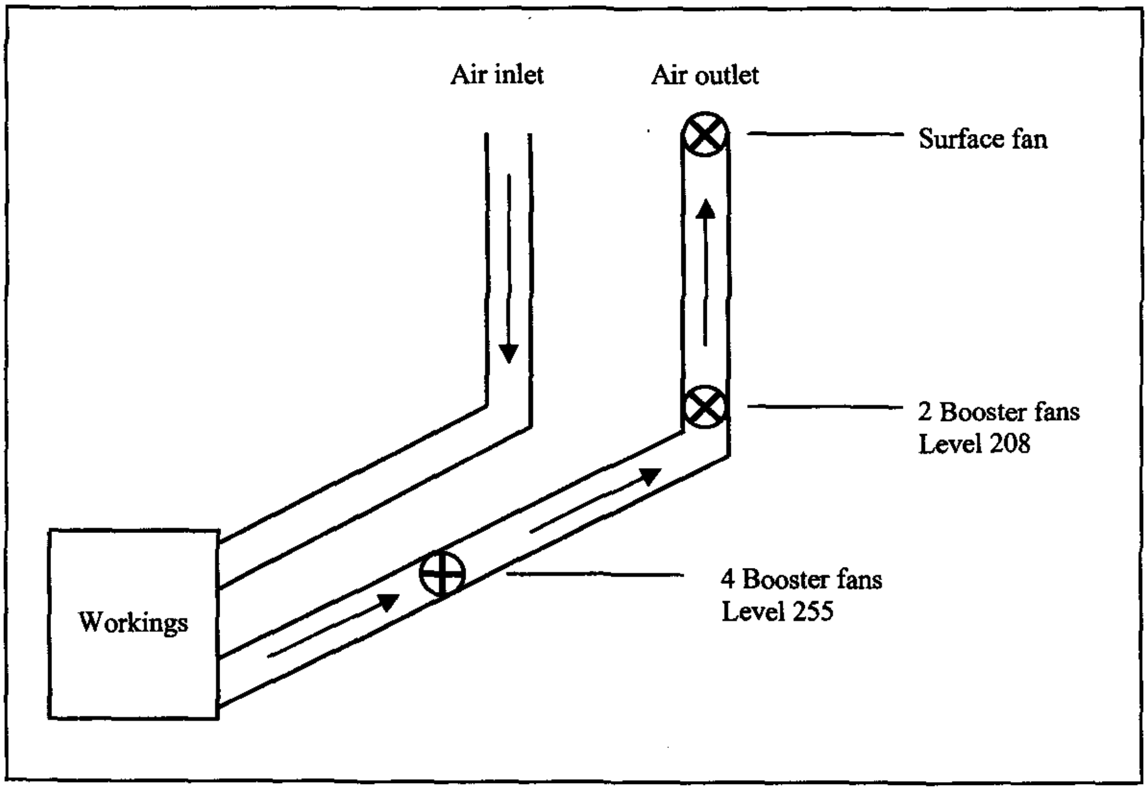


Figure 5.3: Schematic layout of the mine ventilation system at Target

5.1.1.3 Energy audit

There are three main energy intensive systems namely refrigeration, underground pumping and ventilation. Refrigeration includes all the compressors and pumps in the refrigeration plant as well as the fans and pumps at the condenser and evaporator ponds. The contribution of each of these to the total electricity consumption of the mine can be seen in Figure 5.4.

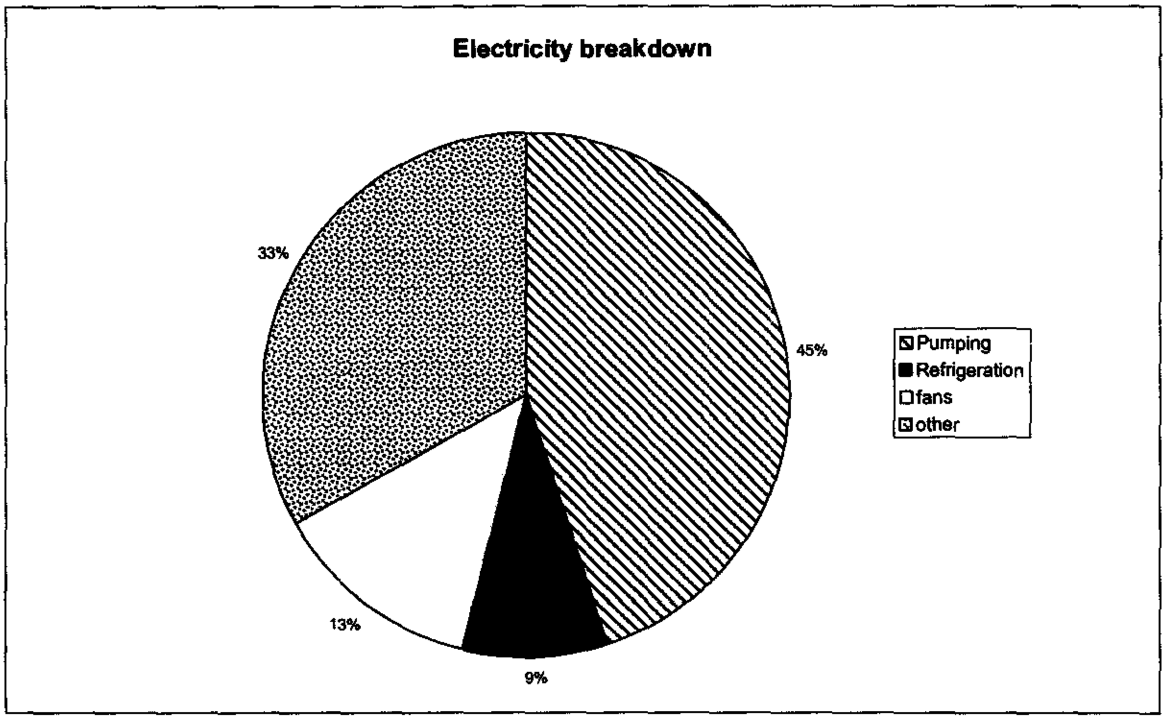


Figure 5.4: Electricity breakdown at Target

Other load includes all the winders, general surface electricity use, drills and rigs, crushers, and conveyor systems. These systems will not be part of the study due to their constant or unpredictable nature. Rock winding, at first, will not be made part of the study due to its direct link with production.

The effect of load shifting and DSM will be studied on the refrigeration and ventilation systems. These three systems account for ± 58% of the mine's mining activities' electricity bill.

5.1.1.4 Pricing structure

The mine is currently on the urban NIGHTSAVE tariff structure. This tariff consists of a demand and energy charge. The demand charge is only applicable during peak periods where the mine is billed per kW of maximum demand on a monthly cycle. The energy charge is calculated by taking the total energy (kWh) consumed by the mine for the month and multiply that with the c/kWh NIGHTSAVE urban energy tariff.

The possibility to shift energy load from peak to off-peak times will ensure a lower electricity cost when the mine shifts to the Megaflex or Real Time Pricing tariff structure. These tariff structures implicate lower tariffs during off-peak times and higher electricity tariffs during peak times. ESKOM's peak periods at present are between 07:00 and 10:00 in the morning and between 18:00 and 20:00 in the afternoon.

One of the objectives of this study will be to analyse the mine with the Real Time Pricing (RTP) tariff structure namely two part RTP. This tariff consists of a Customer Base Line (CBL) load cost and a RTP cost. The CBL load is calculated from historic measured data. This load is then used to calculate the unit cost of electricity for the NIGHTSAVE tariff. The CBL cost is a fixed cost even if no electricity is used.

The RTP part of the tariff has a debit and credit price for every hour of every day. This price is calculated by ESKOM everyday for the next day. The RTP cost is calculated as follow: If the mine use more energy than the mine's CBL the mine will be billed on the amount exceeding the CBL with the RTP debit price. When the mine use less than the CBL load they will be credited with the amount of load less than the CBL times the RTP credit price.

5.1.1.5 Data availability

The mine has a comprehensive Supervisory Control And Data Acquisition (SCADA) system. All underground dam levels and operational pumps are logged. At the refrigeration plant the entering and leaving water temperatures, water mass flows and compressor power are logged for each chiller. For the ventilation system all active fans are logged. Logged data are available at short intervals (few seconds) or longer intervals (per minute or hour).

During the study the air temperature and relative humidity was measured at all the crucial points in the mine. Measurements were taken every minute for a period of 4 days.

5.1.1.6 Conclusion

The mine is well suited for this case study. The management is very keen on any savings and open to suggestions, especially as they have very challenging cost targets. The infrastructure is in place to automate the systems under investigation. Due to the SCADA system most of the operational condition data are easily available.

The refrigeration plant, as well as the underground pumping system, have large dams that can be used for storage. This is a pre-requisite for load shifting.

5.1.2 Simulation models

5.1.2.1 Underground pumping

Due to the experience from other case study mines it was assumed that there is enough water storage capacity underground to do the necessary load shifting. The study could be done without a detail simulation model of the underground pumping system.

A detail simulation model will be needed to implement the findings of the study and such a model is currently being developed.

5.1.2.2 Underground refrigeration system

5.1.2.2.1 Background

The simulation model must predict the inlet and outlet water temperatures to and from the refrigeration plant accurately. To assure accurate predictions it is necessary to develop an integrated simulation model. This model will include different smaller models that will each characterise one of the components in the refrigeration system.

These components are the refrigeration machines (chillers) and the condenser and evaporator spray ponds. The compressors, which are part of the refrigeration machines, are the only simulation component that consumes electrical energy. The water pumps in the system will be neglected during the simulation.

The prediction of the compressor power consumption of chillers is essential for any load shifting calculations. To predict a realistic operating schedule for the chillers the following have to be simulated.

- Thermal performance of the evaporator spray ponds
- Thermal performance of the condenser spray ponds.

The way each of these where handled in the simulation is shown in the following section.

5.1.2.2.2 Methodology

5.1.2.2.2.1 Chiller compressor power

The schematic layout of the refrigeration, evaporator and condenser spray ponds is shown in *Figure 5.5*.

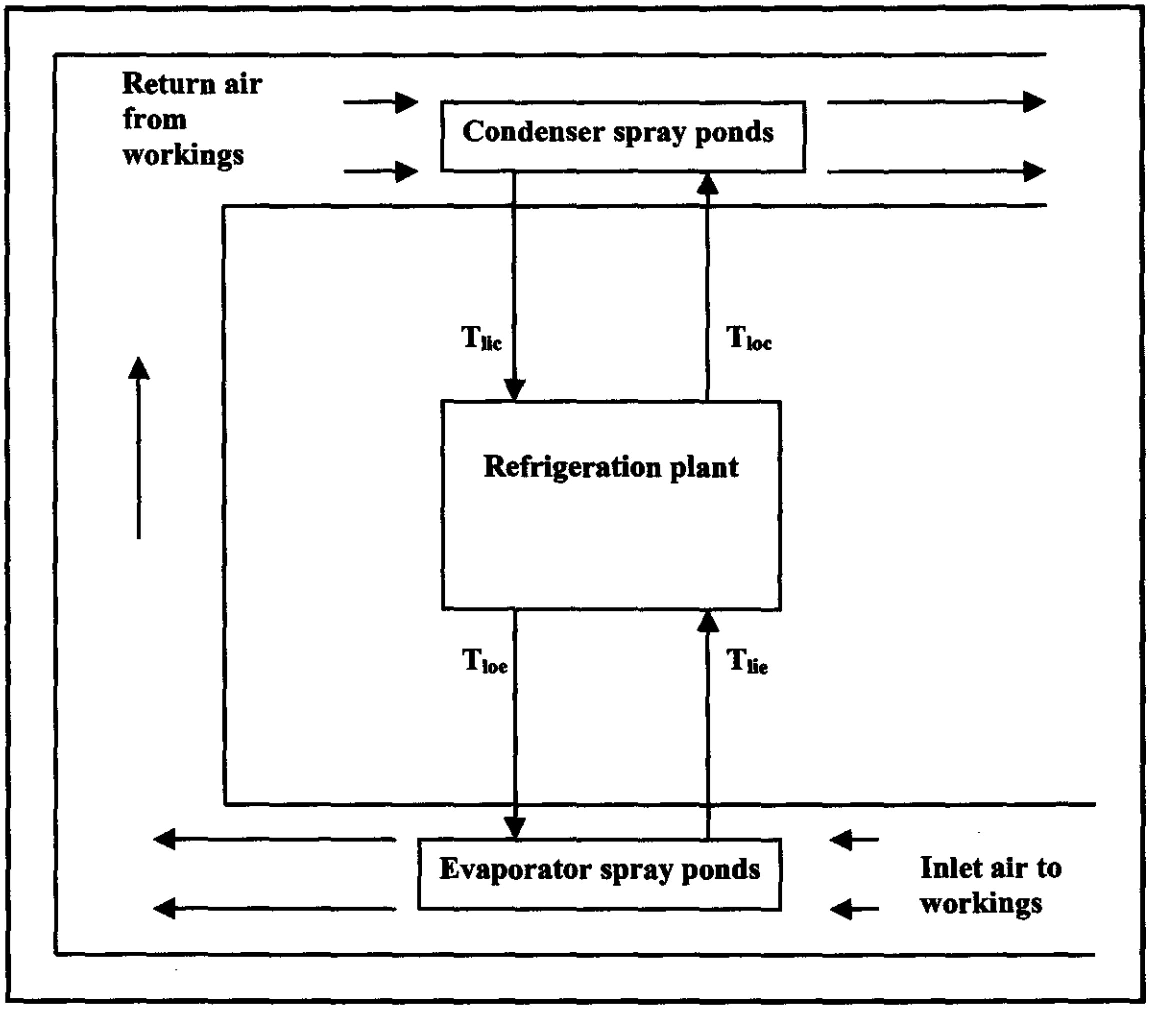


Figure 5.5: Schematic layout of the refrigeration plant, evaporator and condenser spray ponds at Target

First the cooling capacity of the evaporator spray ponds is predicted with the following function [11]:

$$Q_e = \left(\left(b_1 t_{loe} + b_2\right) t_{wb} + b_3 t_{loe} + b_4\right) m_{\max}{}^{0.37} \left(\frac{m_{sp}}{m_{\max}}\right)$$

With:

Q_e = Cooling capacity of the evaporator spray ponds (kW)

m_{max} = Maximum water flow through the spray ponds (kg/s)

m_{sp} = Water flow through the spray ponds (kg/s)

t_{loe} = Temperature of the water leaving the evaporator (°C)

t_{wb} = Wet bulb temperature of the air through the spray ponds (°C)

b = Correlation coefficients derived for cooling capacity

Then the compressor power is calculated with the following function [12]:

$$P_{wr} = \frac{m_{lie} m_{lic} c_p \left(a_0 + a_1 t_{lic} + a_2 t_{lie}\right) - Q_e \left(m_{lic} c_p m_{lie} - m_{lie} a_1 - a_2 m_{lic}\right)}{m_{lie} a_1}$$

With:

P_{wr} = Compressor power (kW)

m_{lie} = Mass flow of the water that enters the evaporator (kg/s)

m_{lic} = Mass flow of the water that enters the condenser (kg/s)

t_{lie} = Temperature of the water that enters the evaporator (°C)

t_{lic} = Temperature of the water that enters the condenser (°C)

a = Correlation coefficients derived for compressor power

c_p = Specific heat capacity of the water (J/kgK)

To complete the cycle the cooling capacity of the condenser spray ponds is calculated as follows [11]:

$$Q_c = \left(\left(c_1 t_{loc} + c_2\right) t_{wb} + c_3 t_{loc} + c_4\right) m_{\max}{}^{0.525} \left(\frac{m_{sp}}{m_{\max}}\right)$$

Q_c = Cooling capacity of the condenser spray ponds (kW)

m_{max} = Maximum water flow through the spray ponds (kg/s)

m_{sp} = Water flow through the spray ponds (kg/s)

t_{loc} = Temperature of the water leaving the condenser (°C)

t_{wb} = Wet bulb temperature of the air through the spray ponds (°C)

c = Correlation coefficients derived for cooling capacity

With the outlet water temperature from the condenser [12]:

$$t_{lec} = t_{lic} - \frac{Q_e + Pwr}{m_{lic} c_p}$$

and the outlet water temperature from the evaporator [12]:

$$t_{lee} = t_{lie} - \frac{Q_e}{m_{lie} c_p}$$

The correlation coefficients were calibrated using measured data. The simulation results of the compressor power can be seen in *Figure 5.6.*

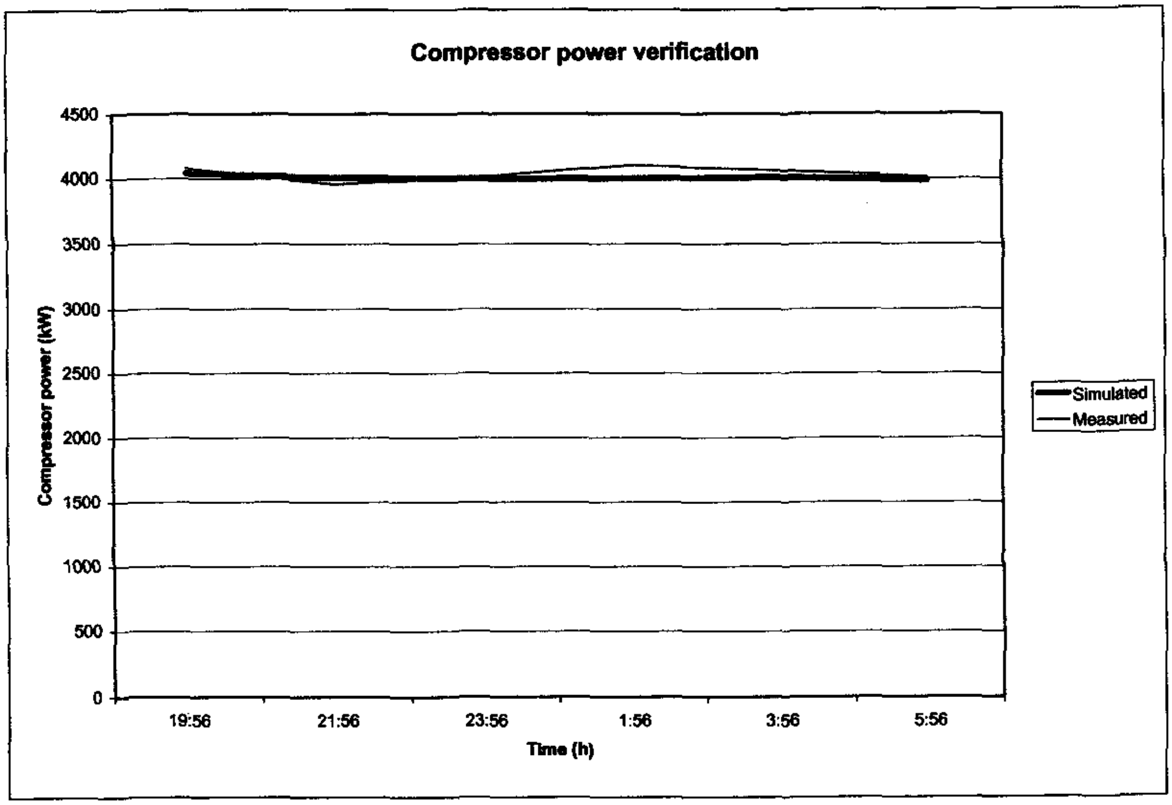


Figure 5.6: Chiller compressor power verification at Target

The average error was 1.15%. The maximum error was 2.58%. This is sufficiently accurate as an error of less than 10% for 80% of the time is taken as the norm.

5.1.2.3 Underground cooling model

5.1.2.3.1 Background

The rock temperature as well as the diesel equipment underground heats the air that flows through the mine. The underground supply air temperatures at the mine depend on the cooling capacity of the chillers and the air flow supplied by the ventilation fans. The combination of fan and cooling power can be controlled to supply air at the correct flow and temperature at the minimum energy cost.

The accurate prediction of the wet bulb temperature at the outlet of the workings is essential to be able to control fan and cooling power. The maximum allowable temperature at the outlet of the workings will determine the fan speeds and compressor power needed to maintain that temperature.

5.1.2.3.2 Methodology

A schematic layout of the mine can be seen in *Figure 5.7*.

The mine is divided into 4 critical parts:

Node 1 – node 2: Represents the shaft from surface to the intake of the evaporator spray ponds.

Node 2 - node 3: Represents the shaft from the outlet of the evaporator spray ponds to the intake of the workings.

Node 3 – node 4: Represents the workings area. From intake of the workings to the outlet of the workings.

Node 4 – node 5: Represents the shaft from the outlet of the workings to the inlet of the condenser spray ponds.

R1 – R4: The heat flow resistances between every set of nodes.

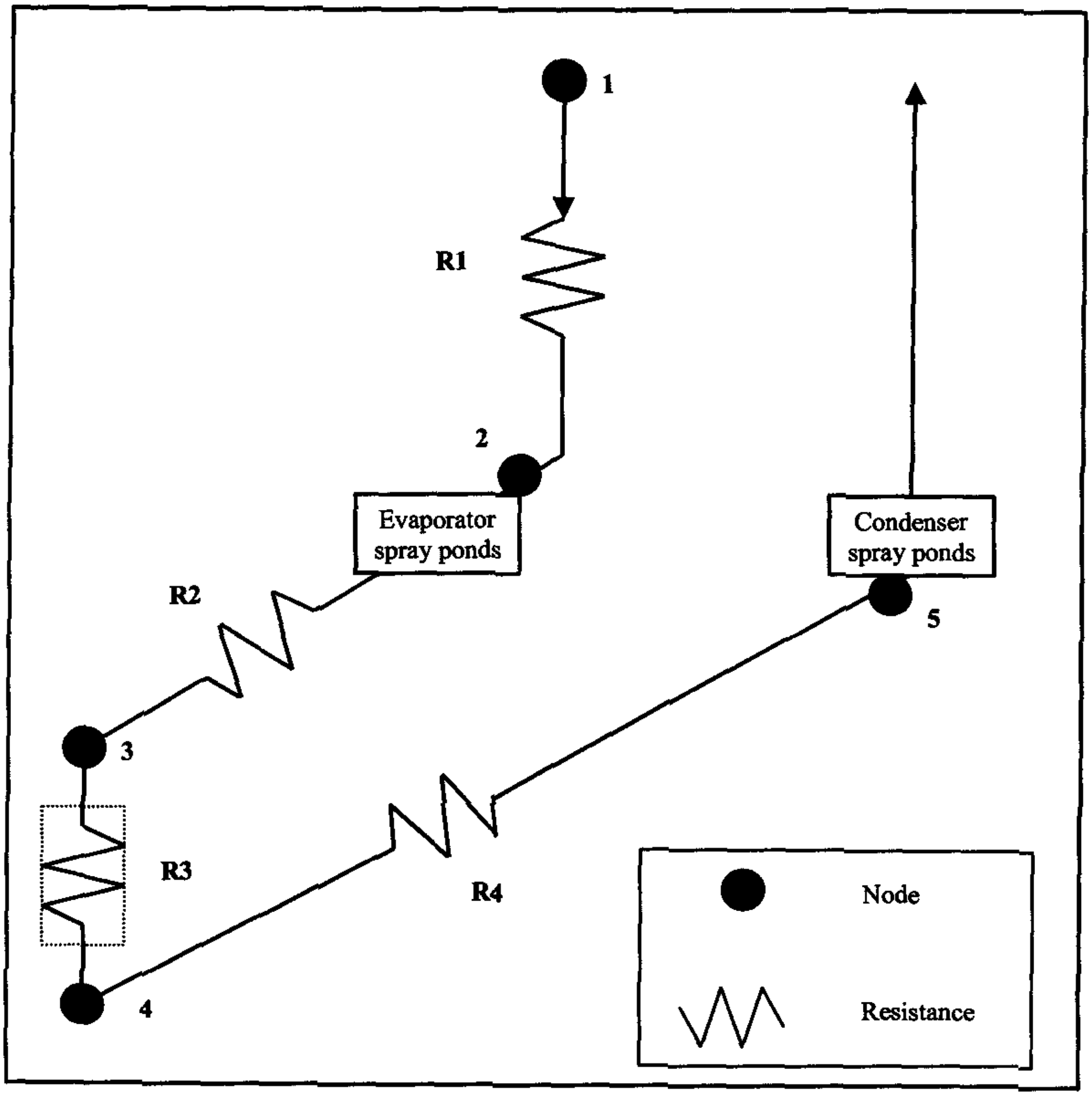


Figure 5.7: Schematic layout of the mine underground at Target

The thermal performance of each shaft mentioned above will be simulated using energy balance equations. The basic thermal model of the shaft is shown in *Figure 5.8.*

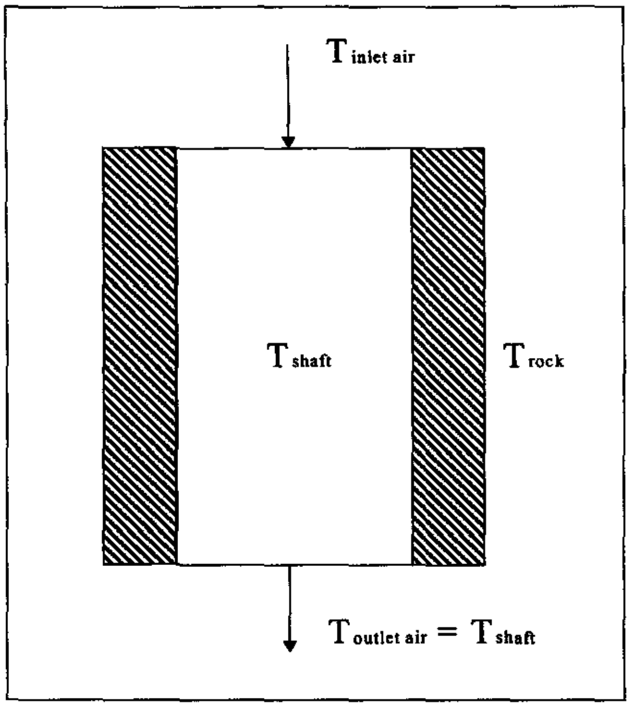


Figure 5.8: Schematic layout of the thermal model of the shaft at Target

The energy balance of the system in *Figure 5.8* can be written as [13]:

$$C\frac{dT_{shaft}}{dt} = U_{shaft}A_{shaft}\left(T_{rock} - T_{shaft}\right) + m_{air}cp_{air}\left(T_{inletair} - T_{shaft}\right)$$

Separating the variables and using the initial values $T_{shaft} = T^0_{shaft}$ at $t = 0$ the shaft temperature can be solved using the following equation.

$$T_{shaft} = \frac{1}{a}\left[\left(aT^0_{shaft} - b\right)\exp\left(\frac{-a\delta t}{C}\right) + b\right]$$

Where $a = U_{shaft}A_{shaft} + m_{air}cp_{air}$

And $b = U_{shaft}A_{shaft}T_{rock} + m_{air}cp_{air}T_{inletair}$

The shaft between each node set is divided into 3 separate segments (models) as seen in *Figure 5.9*

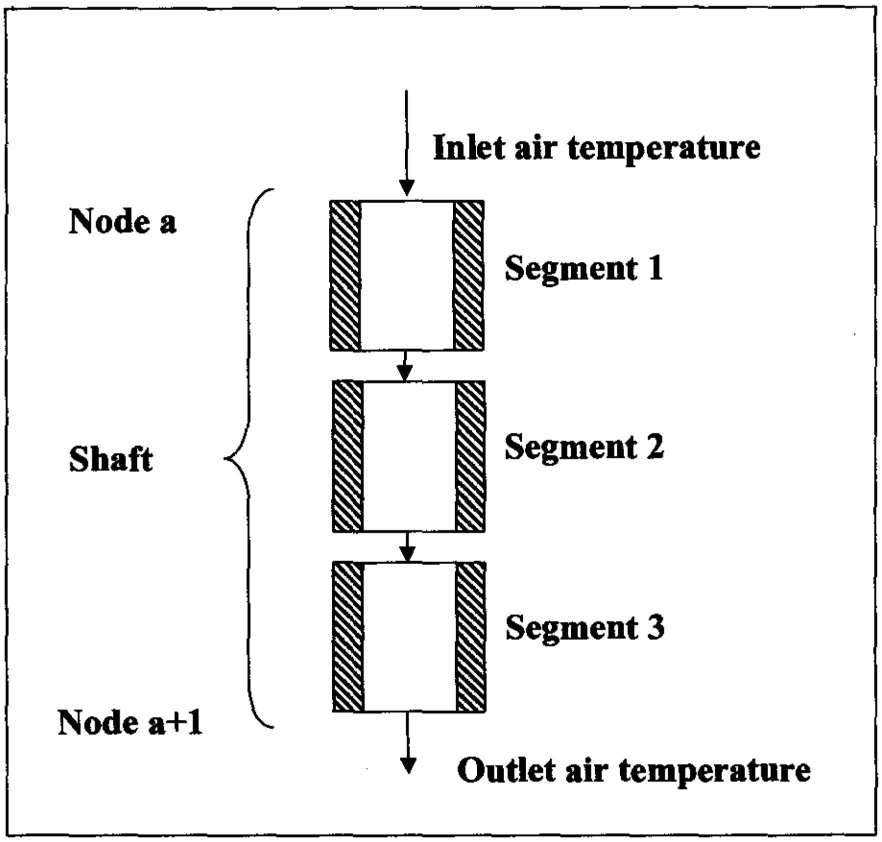


Figure 5.9: Schematic layout of the underground cooling model for each of the shafts at Target

The models are interconnected through the air temperature that is passed from one model to the other, starting with the inlet air temperature at the first segment right through to the leaving air temperature of the third segment. This leaving temperature will then be the inlet temperature to the next set of nodes.

The values of the thermal capacity (C) and the heat transfer coefficient ($U_{shaft}A_{shaft}$) can be calibrated using the measured temperature profiles for each shaft. The workings model (between node 3 and node 4) in *Figure 5.7* was set up differently than the shaft models. See the schematic layout of the workings area in *Figure 5.10.* The Q represents the heat that is generated by mining activities as well as the heat transfer from the surrounding rock to the air in the workings. Q will change throughout the day, depending on mining activities, but a standard daily profile exists.

Q consists of two parts, q_s and q_l with q_s the sensible and q_l the latent heat transfer [13].

$$Q = q_s + q_l$$

With:

$$q_s = mc_p(t_o - t_i)$$

and

$$q_l = m(W_o - W_i)i_{fg}$$

with

m = Mass flow of the air through the workings (kg/s)

c_p = Heat capacity of the air (KJ/kg.K)

t_o = Temperature of the air at the outlet of the workings (°C)

t_i = Temperature of the air at the inlet of the workings (°C)

W_o = Humidity ratio of the air at the outlet of the workings (kg/kg)

W_i = Humidity ratio of the air at the inlet of the workings (kg/kg)

i_{fg} = Enthalpy of the air (KJ/kg)

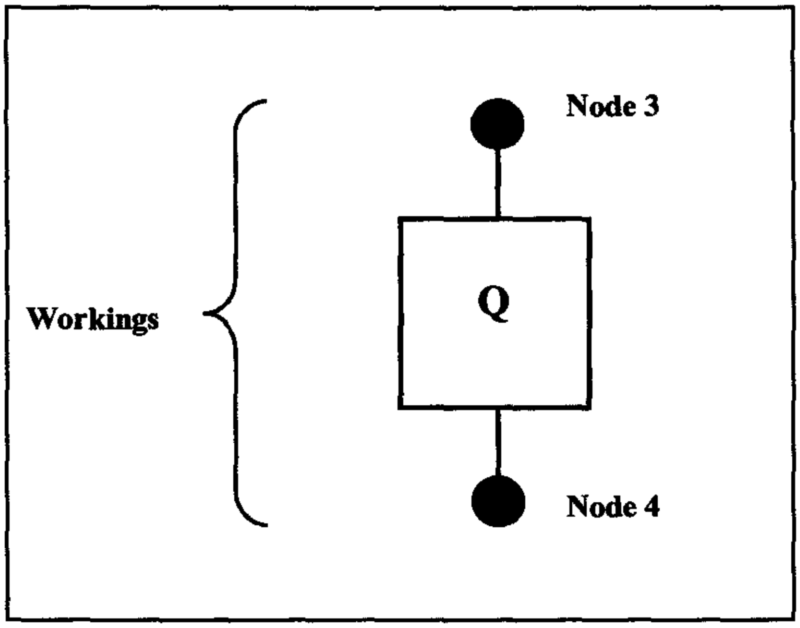


Figure 5.10: Schematic layout of the workings area at Target

By calculating a suitable daily average q_s and q_l from the measured data it is possible to predict the average outlet dry bulb and wet bulb temperatures of the workings. The inlet temperatures and humidity ratio are known from the shaft model between nodes 2 and 3. With q_s and q_l known it is possible to calculate t_o and W_o. With the help of the psychometric formulas the wet bulb temperature at the outlet can now be calculated. It is assumed that no mass transfer takes place.

5.1.2.4 Airflow model

5.1.2.4.1 Background

A certain amount of airflow is needed in the mine to maintain the correct amount of fresh air for a suitable working environment. The ventilation fans are responsible for the airflow through the mine. To be able to calculate the potential energy saving of fan power it is necessary for a simulation model to be developed that can predict underground airflow at changing fan conditions.

5.1.2.4.2 Methodology

The airflow network underground has to be simplified and represented by a flow diagram. This flow diagram will work on the same principle as an electrical circuit. The electrical resistances will be replaced by the air flow resistances through the shafts and airways. The power sources are replaced by the pressure created by the fans. See the layout of the airflow circuit in *Figure 5.11*.

P1 = Pressure difference created by the surface fan.

P2 = Pressure difference created by the 255 level booster fans at the evaporator spray ponds.

P3 = Pressure difference created by the 208 level booster fans.

a = The airflow resistance of the airway between each node in the circuit.

(A node is where two or more of the airways come together at one point)

Like in any electrical circuit it is now possible to generate a series of equations which can be solved simultaneously and so calculate all the airflows and fan pressures in the circuit. This is done by using Kirchhoff's current laws but revised for airflow and air pressures.

Airflow: The algebraic sum of all the airflows at any node in a circuit equals zero.

Air pressure: The algebraic sum of all the pressure differences around any closed path in a circuit equals zero.

The pressure drop through each airway is a function of the resistance of the airway and the amount of air that flows through the airway.

Pressure drop:

$$\Delta P = aQ^2$$

with :

a = Resistance of the airway

Q = Amount of airflow through the airway (kg/s)

The resistances (a1 – a7) were calculated using measured and design ΔP and Q values for each of the airways.

There will be a pressure drop through each airway. These pressure drops must then be overcome by the pressure created by the ventilation fans. The pressure difference created by the ventilation fans were calculated by using a known fan model for each of the ventilation fans.

Fan model [11]:

$$P = K_h N^2 D^2$$

With:

P = Pressure created by the fan (kPa)

N = Rotational speed of the fan (r.p.m)

D = Impeller diameter of the fan (m)

K_h = Dimensionless pressure head coefficient

and

$$K_h = a_0 + a_1 K_f + a_2 K_f^{\ 2}$$

$$K_f = \frac{m_a}{ND^3}$$

with

a = Correlation coefficients for K_h

K_f = Dimensionless flow coefficient

m_a= Massflow of the air (kg/s)

and the fan efficiency

$$\eta = b_0 + b_1 K_f + b_2 K_f^{\,2}$$

with

b = Correlation coefficients for fan efficiency

Then for fan power

$$Pwr = \frac{m_a P}{\eta}$$

The airflow and air pressures at all the strategic places in the mine can now be solved by using Kirchhoff's laws on the circuit shown in *Figure 5.11*.

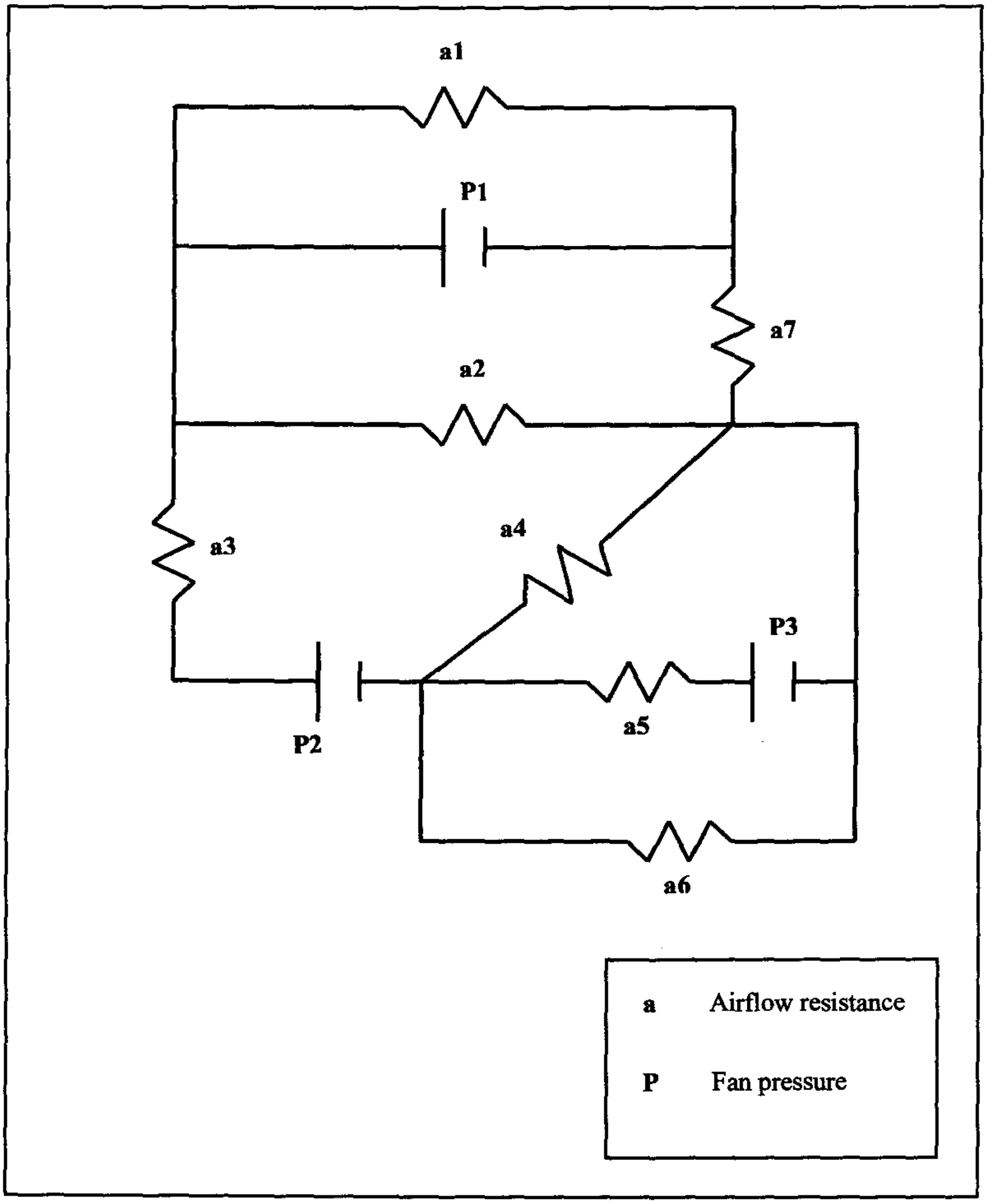


Figure 5.11: Layout of the underground airflow simulation model at Target

5.1.2.5 Simulation results

5.1.2.5.1 Background

The cooling plant at the case study mine is situated ± 2 km underground. This means that the air from outside must travel ± 2km through the airways before it can be cooled by the spray ponds. Due to the relative high rock temperatures (sides of the airways) the air reaches the evaporator spray ponds at a constant temperature, no matter what the outside air temperature are. This was also confirmed by the temperature readings taken underground.

By knowing this the simulation model could be simplified to be a steady state model. This means that the simulation needs to be done only once in a day to predict a certain temperature underground. This temperature will then be constant throughout the day.

Small changes in the wet bulb temperature will occur at the outlet of the workings. This is due to the mining activities in the workings. For the purpose of the simulations a constant temperature throughout the day is assumed.

The simulation was done during the time that one of the condenser spray ponds was shut down. This was an ideal time to test the model as the underground conditions were different than normal. The model was calibrated with measurements taken at normal conditions and then verified under unique underground conditions.

5.1.2.5.2 Results

The whole purpose of this study is to simulate the air temperature at the outlet of the workings correctly. This temperature is a function of the airflow model and temperature model. The two models were integrated after it was calibrated with measured data.

After the calibration and integration of the models the following simulation results were found and were compared with new measured data. *Figure 5.12* and *Figure 5.13* show the simulated values compared with the real measured values at the outlet of the workings.

The comparison was made for 3 hours (because the conditions underground are steady state). The maximum deviation was 1.01 °C which is equal to an error of 2.8%. This shows that the dry bulb temperature was simulated accurately.

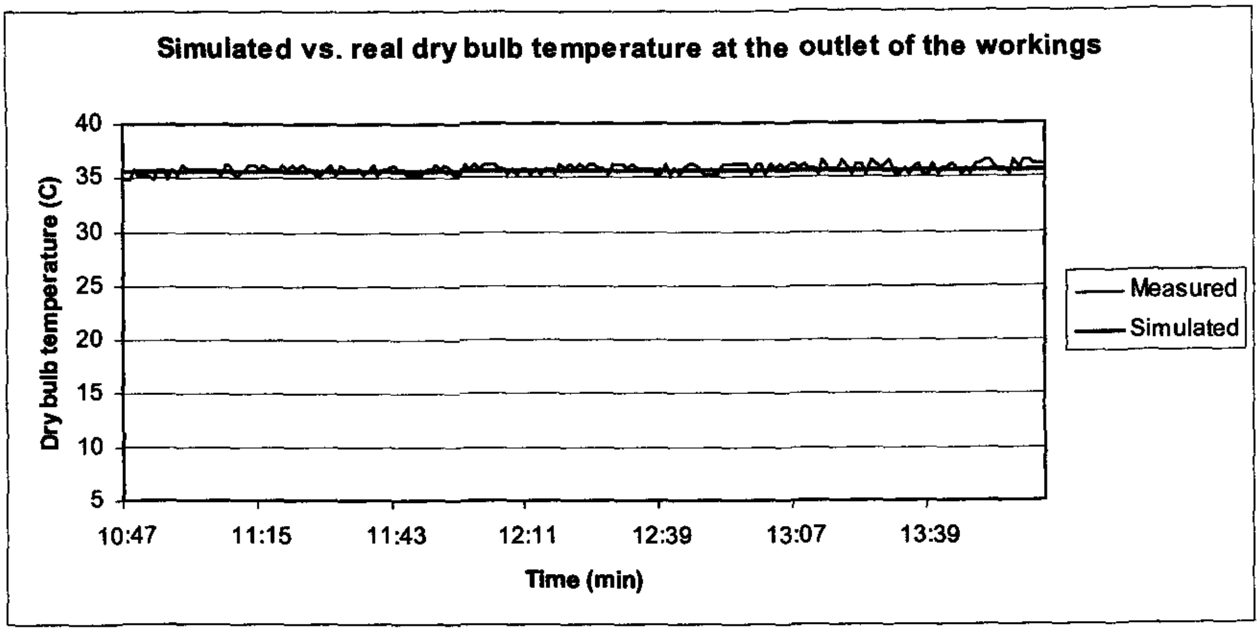


Figure 5.12: Simulated vs. real dry bulb temperature at the outlet of the workings at Target

Figure 5.13 shows the simulated vs. measured results of the wet bulb temperature at the outlet of the workings. This comparison was made for 3 hours. The maximum deviation was 1.8 °C which is equal to an error of 5.6 %.

The simulation model predicted the outlet dry bulb temperature well but was on average a little lower than what was measured as can be seen in *Figure 5.13.*

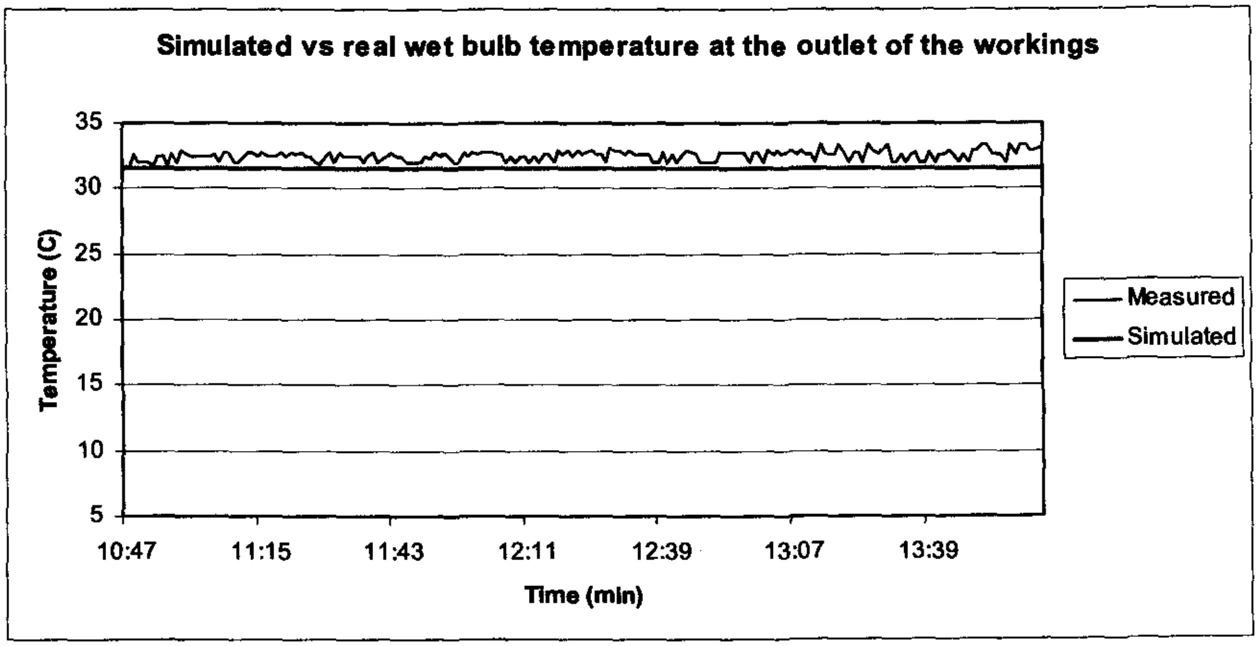


Figure 5.13: Simulated vs. real wet bulb temperature at the outlet of the workings at Target

The above wet bulb and dry bulb temperatures were all predicted at an airflow of 190 m^3/s through the workings, which is the same airflow that was measured at the specific time as the temperature data.

5.2 Analysis and optimisation of the electricity costs of each system and system type

5.2.1 Electricity cost analysis

5.2.1.1 Electricity cost of the different systems

Target had an electricity bill of ±R35.3 million in the twelve months prior to the commencement of the study on NIGHTSAVE. Of this pumping contributed about 45%, refrigeration 9% and fans 13% on average.

This means that pumping contributed almost R16 million to the electricity bill. Refrigeration contributed almost R3.2 million and ventilation fans R4.6 million.

The use of optimum scheduling of the pumping systems using MEGAFLEX or two-part-RTP as the tariff could produce substantial cost savings. On the Refrigeration and ventilation sides DSM as well as electricity efficiency measures will be studied

Month	Year	Cost			Pumping	Refrigeration	Fans
		Electricity	MD	Total	Total	Total	Total
December	2000	R 1,482,996.82	R 1,528,299.94	R 3,011,296.75	R 1,355,083.54	R 271,016.71	R 391,468.58
January	2001	R 1,438,381.53	R 1,404,602.21	R 2,842,983.74	R 1,279,342.68	R 255,868.54	R 369,587.89
February	2001	R 1,438,381.53	R 1,404,602.21	R 2,842,983.74	R 1,279,342.68	R 255,868.54	R 369,587.89
March	2001	R 1,521,174.33	R 1,485,122.69	R 3,006,297.02	R 1,352,833.66	R 270,566.73	R 390,818.61
April	2001	R 1,547,392.23	R 1,464,669.38	R 3,012,061.60	R 1,355,427.72	R 271,085.54	R 391,568.01
May	2001	R 1,154,482.73	R 1,335,698.10	R 2,490,180.83	R 1,120,581.37	R 224,116.27	R 323,723.51
June	2001	R 1,154,482.73	R 1,335,698.10	R 2,490,180.83	R 1,120,581.37	R 224,116.27	R 323,723.51
July	2001	R 1,251,512.70	R 1,328,587.92	R 2,580,100.62	R 1,161,045.28	R 232,209.06	R 335,413.08
August	2001	R 1,264,049.85	R 1,327,248.99	R 2,591,298.84	R 1,166,084.48	R 233,216.90	R 336,868.85
September	2001	R 1,633,934.18	R 1,781,958.85	R 3,415,893.04	R 1,537,151.87	R 307,430.37	R 444,066.09
October	2001	R 1,677,667.55	R 1,810,630.42	R 3,488,297.97	R 1,569,734.09	R 313,946.82	R 453,478.74
November	2001	R 1,681,503.95	R 1,859,247.43	R 3,540,751.39	R 1,593,338.12	R 318,667.62	R 460,297.68
			Total	R 35,312,326.38	R 15,890,546.87	R 3,178,109.37	R 4,590,602.43

Table 5.2: Electricity cost breakdown at Target

5.2.2 Objective function

The objective function is the value that is dependent on all the variables that must be optimised. In this case the total daily or weekly electricity cost is the value that must be minimised while still satisfying all of the constraints.

Target is currently on NIGHTSAVE as electricity tariff. This means that the optimum use of both MEGAFLEX and two-part-RTP needs to be studied. The calculation of the objective function is the same as discussed in chapter 3.

The only difference being the components that is used to calculate the total electricity consumption. These are the underground pumps, chillers, and ventilation fans.

5.2.3 Boundaries

The boundaries are those values that are not dependent on any of the outputs of the models, but do influence the models directly or indirectly. The boundaries are also normally one of the values that need to be calibrated from time to time.

The boundaries in this case are the amount of air leaks through the airways settler flow every hour minimum and maximum climate temperature and the electricity price from ESKOM.

5.2.4 Constraints

The constraints are the values that enforce the physical operational limits of the system onto the optimisation. The accurate implementation of these limits is essential to ensure that the outputs of the optimisation are practical and can be implemented.

5.2.4.1 Underground pumping

There are two types of constraints applicable on this system. These are the available number of pumps and minimum and maximum dam levels on each level.

All dam levels must be controlled to ensure dam levels of between 20% and 80%. On level 255 3 underground pumps are installed of which one must always be on standby (maximum flow of 80l/s per pump). On level 212 4 pumps are installed of which 2 must always be on standby (maximum flow of 100l/s per pump).

5.2.4.2 Underground refrigeration plant

The constraints on the refrigeration plant are the number of chillers available and the cooling capacity of the chillers. Other constraints are the maximum water flow and airflow through the spray ponds.

There are currently 5 chillers active in the underground refrigeration plant of the mine. The total maximum cooling capacity of the chillers is 18 MW. The maximum water flow through the evaporator spray ponds is 380l/s. The maximum water flow through the condenser spray ponds is 740l/s. There are 4 condenser spray ponds and 4 evaporator spray ponds available.

5.2.4.3 Underground conditions

The ideal wet bulb temperature at the outlet of the workings is 25.5 °C. The maximum temperature at the outlet of the workings is 27.5 °C. The ideal airflow through the workings is $240m^3/s$. The minimum airflow through the workings is $225m^3/s$. The minimum air cooling power at the outlet of the workings is 300 W/m^2.

5.2.5 Variables

The variables are the values that are changed to minimise or maximise the objective function while still satisfying the constraints.

In the optimisation model the fan speeds and the set point of the chillers are variables on the underground refrigeration system. On the underground pumping system the number of pumps active every hour on each level is the variables.

5.2.6 Optimisation model for each typical day

5.2.6.1 Background

Target is operating 7 days a week. After looking at the operating strategies and maintenance schedules no distinct day types could be identified. Looking at the tariff structures it was however decided to use three typical days: a weekday, Saturday and Sunday. The constraints remain the same for all of the typical days.

5.2.6.2 Boundaries

The boundaries, of the base load, CBL load, RTP tariff, MEGAFLEX tariff and minimum and maximum temperatures, for the potential savings calculations are calculated from the previous year's measured data. An hourly average is used to calculate the typical profile for the boundary for each typical day for each month. Just as with Amandelbult the boundaries will also be calculated for summer and winter for optimisation using MEGAFLEX.

The boundary of the settler flow is not dependent on the seasons and thus the previous 3 months' measured data was used to obtain the boundaries.

5.3 Economic implications of the different DSM alternatives

5.3.1 Comparison of optimised and previous years loads

5.3.1.1 Background

The refrigeration plant is totally submerged underground. This means that the cooling demand is not affected by climatic conditions. The pumping demand is also almost constant during the year. Due to these factors the load comparison was done on the summer MEGAFLEX profile. All the other optimisations were done for the cost saving calculation but just not discussed in this section.

5.3.1.2 MEGAFLEX

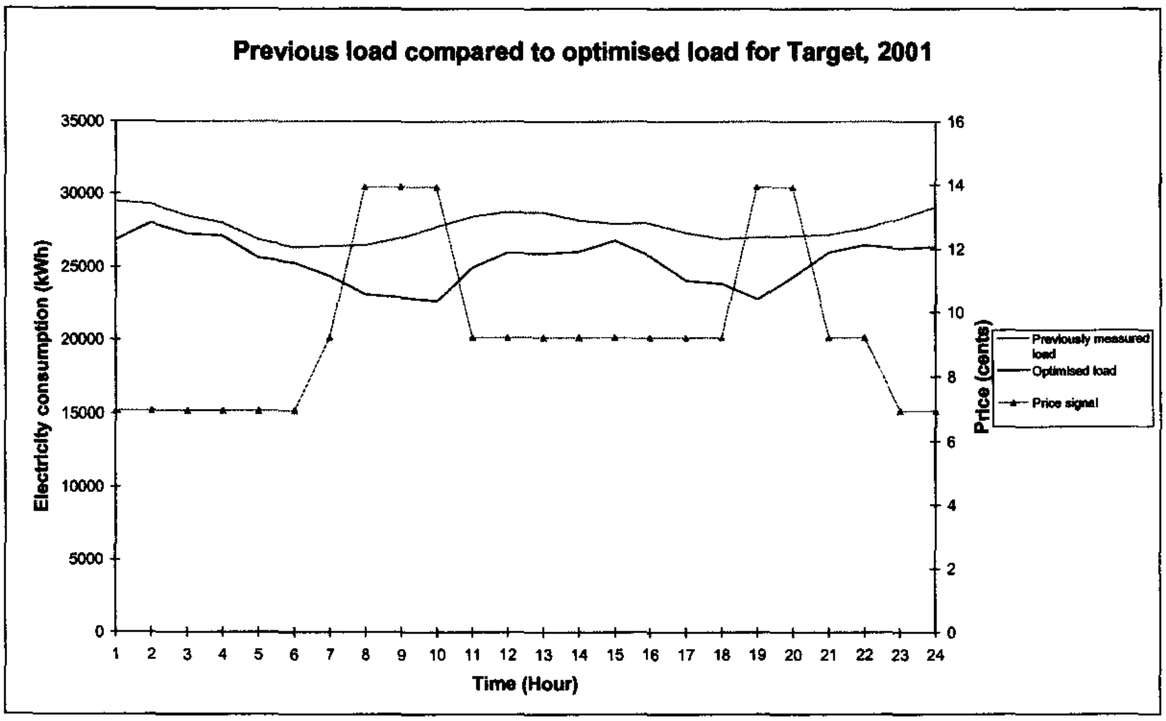


Figure 5.14: Typical weekday, Target, 2001

During a typical weekday a total of 8MW can be shifted from the morning and evening peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure 5.14*.

On the refrigeration side an average electricity saving of 40.9% of the refrigeration electricity consumption is achievable. This is done by changing the control strategy from supplying a constant amount of cooling to a strategy that ensures just enough cooling to ensure acceptable temperatures in the working areas.

5.3.2 Cost savings

5.3.2.1 Background

Through the use of simulation models and optimisation the potential sustainable electricity savings through the minimisation of electricity will be calculated.

5.3.2.2 Savings calculation

All the savings calculations will be based upon the NIGHTSAVE electricity tariff from ESKOM. The optimum cost is now compared to the cost on the actual daily electricity profile measured in 2002. These savings are then extrapolated to calculate the monthly savings. The monthly savings are then added together to get the potential yearly saving.

First, the simulation model was set up to simulate the mine underground operations exactly. The current cost of electricity was then calculated. After the optimisation study the cost of electricity was again calculated. These two calculated costs were compared and the difference was taken as the savings potential.

5.3.2.3 Results

5.3.2.3.1 NIGHTSAVE

The load shifting on the underground pumping system will not yield any savings for the mine while they are on any tariff without a time of use component. The new operating strategy on the refrigeration system on the other hand can deliver a substantial saving. This saving is shown in *Table 5.3*.

	Saving
Refrigeration	R 1,480,236.00
Total	R 1,480,236.00

Table 5.3: Potential yearly NIGHTSAVE saving at Target

5.3.2.3.2 MEGAFLEX

A saving of R2.55 million can be achieved using the new operating strategies and the MEGAFLEX tariff. The underground pumping system contributed ±13% of the saving and the refrigeration system the remaining ±87%. The summarised savings is shown in *Table 5.4*.

	Saving
Pumping	R 331,550.31
Refrigeration	R 2,218,836.69
Total	R 2,550,387.00

Table 5.4: Potential yearly MEGAFLEX saving at Target

5.3.2.3.3 Real Time Pricing (RTP)

	Additional savings
Jan	R 55,268.48
Feb	R 26,323.07
Mar	R 21,356.17
Apr	R 43,450.66
May	R 27,717.13
Jun	R 41,243.41
Jul	R 52,643.46
Aug	R 56,082.54
Sep	R 91,582.12
Oct	R 34,671.02
Nov	R 26,007.88
Dec	R 35,098.91
Total	R 511,444.84

Table 5.5: Additional RTP saving at Target

Using two part RTP with the customer base load (CBL) price based on MEGAFLEX an additional R0.5 million can be added to the MEGAFLEX saving. The additional saving is summarised in *Table 5.5*.

5.3.3 Infrastructure implications of these alternatives

This analysis is necessary to establish the cost, capital and operating, required for the implementation of the proposed strategies. The main components required is a complete SCADA (supervisory control and data acquisition) system as well as an electricity management system.

Currently a SCADA system is implemented. None of the systems are controlled using the SCADA system. No actual extra hardware is required to implement the remote control of the systems.

A separate piece of software will be implemented running on top of the SCADA system to get the required conditional data for the control algorithms and in turn gives back a control signal to the SCADA system that in turn switches the components on and off. Only minor alterations will be required to the SCADA software.

This software will be made available as part of an service agreement in which a percentage of the savings will be paid to the service provider. The provider will be responsible for supply of a daily optimum schedule to the electricity management software. The service provider will also be responsible for the weekly calibration of the optimisation model to ensure accuracy.

The controls on the pumping and refrigeration systems will not require any extra costs. The implementation on the ventilation system requires the implementation of variable speed drives for the fans. The estimated cost of this is R2 million. This means a pay back period of 2 years based on the contribution of the ventilation systems to the savings on MEGAFLEX.

5.4 Conclusion

5.4.1 Summary

The integrated simulation model combined underground airflow and cooling to predict the air temperatures at various underground positions. The most important of them is the air temperature at the outlet of the workings. The simulation model managed to predict the air temperature at the outlet of the workings accurately. The dry bulb temperature was always simulated within 2.8 % of the measured and the wet bulb temperature within 5.6% of the measured temperature. The simulation model used the same airflow as was measured at that time.

By using optimisation the simulation model showed that there is a significant energy saving potential at the mine. The mine wants to maintain a wet bulb temperature of 25.5°C at the outlet of the workings. The optimisation model showed that this can still be achieved by decreasing the airflow through the mine and increasing the amount of cooling done by the refrigeration plant. An electricity cost saving of R1.48 million per year can be achieved.

If the mine can be convinced to maintain an air cooling power of 300 W/m^2 at the outlet of the workings it is possible to reduce the fan motor power as well as the compressor power of the chillers. This can result in an energy cost saving of R2.55 million per year.

If Target's electricity tariff can be changed to the MEGAFLEX tariff further load shifting can be realised. A possible 6 MWh on the pump system can be shifted daily which will result in an extra R 800 000 saved every year. Preliminary studies also shows that a further 20 MWh can be shifted daily on the refrigeration plant alone.

An analysis of the electricity costs was undertaken. In this analysis the electricity bills for the twelve months preceding the studies were taken. Pumping contributed almost R16 million, refrigeration contributed almost R3.2 million and ventilation fans R4.6 million to Target's electricity bill.

The complete setup of the optimisation models for each of the mines was discussed in detail. The main components of the optimisation models that were discussed are the boundaries, constraints, variables and the objective function.

After looking at the operating strategies, maintenance schedule and tariff structures the typical day types were selected. At the end there were three typical day types for each mine namely weekday, Saturday and Sunday. The optimisation model for each of these typical days was set up. In the cases where the two-part-RTP tariff is to be optimised an optimisation model for every typical day for every month of the year was built. In the cases where MEGAFLEX was optimised an optimisation model for every typical day for summer as well as winter was built.

On Target 8MW of load can be shifted daily on the pumping system on a typical day. On the underground cooling 40.9% of the current electricity consumption of these systems can be saved.

This means that a cost saving of almost R1.5 million can be achieved on NIGHTSAVE. This figure is substantially increased on MEGAFLEX to R2.55 Million. A further increase in the cost savings can be achieved by using two-part RTP with the CBL base on the optimum MEGAFLEX profile. This further saving amounts to another R0.5 million.

5.4.2 Recommendations

The implementation of the strategies at one of the mines needs to be negotiated with the mine management and then be implemented for a test period. In this period the actual cost savings must be calculated. This is discussed in chapter 6.

After this phase of the project an implementation strategy must be setup to help in future DSM projects on mines (chapter 7). Lastly a national impact study on the implementation of DSM strategies on mine underground services must be completed (chapter 8).

CHAPTER 6.

IMPLEMENTATION OF THE PROPOSED STRATEGIES

The practical viability of the proposed strategies is tested on Kopanang. The complete implementation process is discussed in this chapter. This includes the negotiations with mine management, implementation and measured savings.

6 IMPLEMENTATION OF THE PROPOSED STRATEGIES ON KOPANANG

6.1 Implementation negotiations with mine management

6.1.1 Background

Before these studies were conducted it was agreed that the mines were under no obligation to implement the proposed strategies. It was however agreed that at the end of the study the mine management would meet with representatives from TEMM International to discuss the proposed strategies and the possible implementation of these on the mine for a trial period [15].

6.1.2 Kopanang

After the initial presentation of the results and proposed strategies the mine management agreed to the implementation of the strategies for a trial period of three months.

The agreement stipulates that the operator will still control the equipment according to the optimum operating strategy supplied to him daily. He does however have the final say in following the schedule or not if the agreed operating limits are reached.

The implementation will work as follows. A daily operating schedule will be faxed and emailed to the operator telling them how many and which components of each of the sub systems will be active each hour. A cost model will be developed that will predict the electricity cost according to the previous operating strategies as well as the tariff and climate. The actual electricity account will then be compared to the cost model to calculate the saving.

During this time a complete record must be kept of the amount of time the schedule was followed and the reasons why it was not followed. All these results must be sent through in the form of a report to the mine representatives. This trail period will be from September 2001 to November 2001.

At the end of the three month period the results will be analysed and a final decision will be made on the continuation of the service and possible extensions of the system to the point where control is done automatically.

6.1.3 Amandelbult

The representatives of the mine were impressed by the results but felt that the risk still outweighs the possible savings. They felt that they would be more at ease if the successful implementation of the proposed strategies can be proven with measured results.

They were open to be approached again once this measured proof of success is available. At this stage no trial implementation on the mine will be done.

6.1.4 Target

The mine representatives were very interested to find out if we could achieve these savings. They were however sceptical about the saving calculation using typical days. They decided that they would agree to a trial implementation if we can proof sufficient savings in a three month period where the optimisation is run concurrently with the current operating system. The electricity cost of the optimised load is then compared to the actual measured load to calculate the possible savings.

Due to this being done currently no physical implementation will be done at the mine during the current time frame of this project.

6.2 Implementation of proposed strategies

6.2.1 Background

In this section the main steps during the initial implementation on the mine itself will be discussed. These include the placing and identifying of the necessary infrastructure to implement the delivery and control according to the daily operating schedule, the implementation of all the required software to be able to deliver the schedule and retrieve measured data remotely as well as the calibration of the optimisation model for the current specifications of the different sub systems.

6.2.2 Infrastructure

To deliver the daily operating schedules a dedicated phone line is required. In the control room an extra phone line was available for this purpose. A modem was also connected to the operator's computer to allow secure remote access to the computer to download condition data from the SCADA system to check the performance continually during the implementation period.

Lastly a fax machine was also placed in the operating room as a backup for the e-mail.

6.2.3 Software implementation

To accomplish all these functions a few pieces of software was also installed on the operator's computer. The first was a program that securely grants remote access to this computer and gives the user the option to take complete control of the keyboard remotely. The remote control functionality is turned off by default and will only be used in the case where some maintenance to the software needs to be done. This piece of software will also be used to download SCADA data weekly to use for ongoing calibration of the optimisation model and reporting on the operator's ability to follow the daily operating schedule.

The second piece of software that was implemented was a small program added to the SCADA system that displays the operating schedule for the current day on the computer. This program also highlights the current hour and shows in red where there are deviations from the operating schedule. This is done to help the operators to comply with the operating schedule if possible.

This piece of software also records al the relevant SCADA measurements on a five minute interval basis in a text file that is remotely downloaded once a week for calibration and reporting.

6.2.4 Optimisation model calibration

The optimisation model needed to be recalibrated to ensure accuracy due to the time span between the simulation model calibration and the actual implementation. To do this a day calibration was done using the measured condition data as well as the on/off status of each of the components. Only slight adjustments to the models were required. It however became apparent that the settler flow boundary needs to be adjusted weekly due to unpredictable underground production. This boundary will thus be calibrated once a week for the following week during the trial period. The other components will only be calibrated once a month. The calibration results of the underground pumping system can be seen in *Figure 6.1, Figure 6.2, Figure 6.3* and *Figure 6.4*.

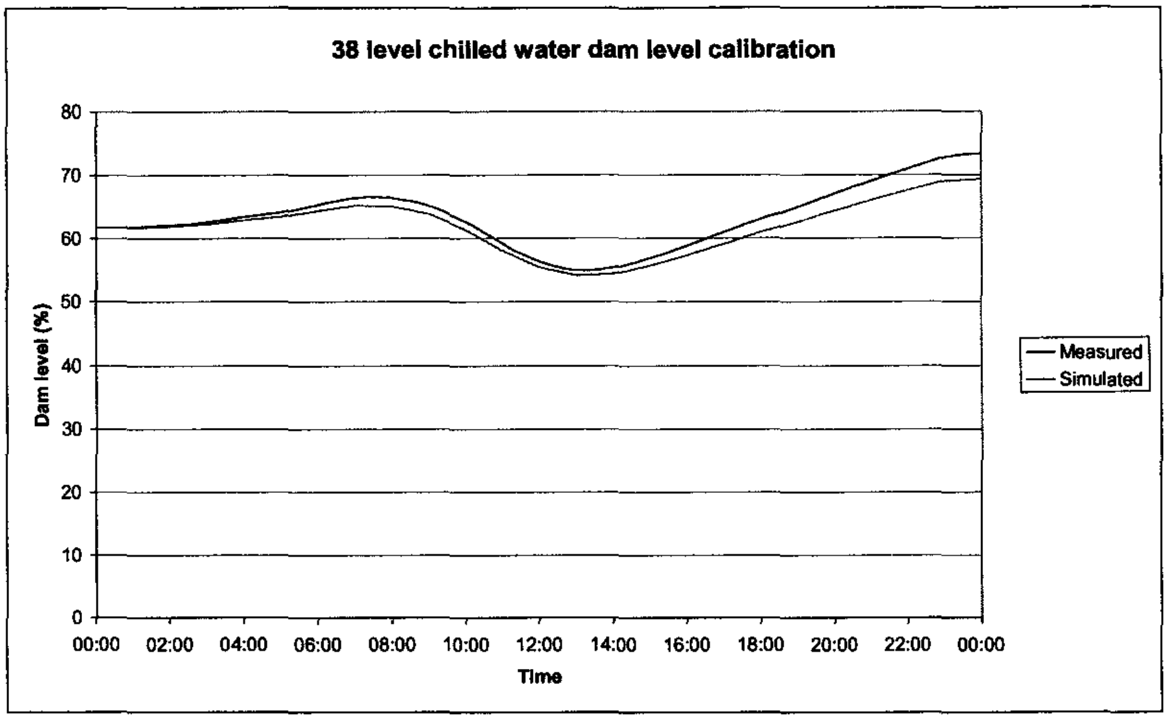


Figure 6.1: Kopanang level 38 chilled water dam calibration

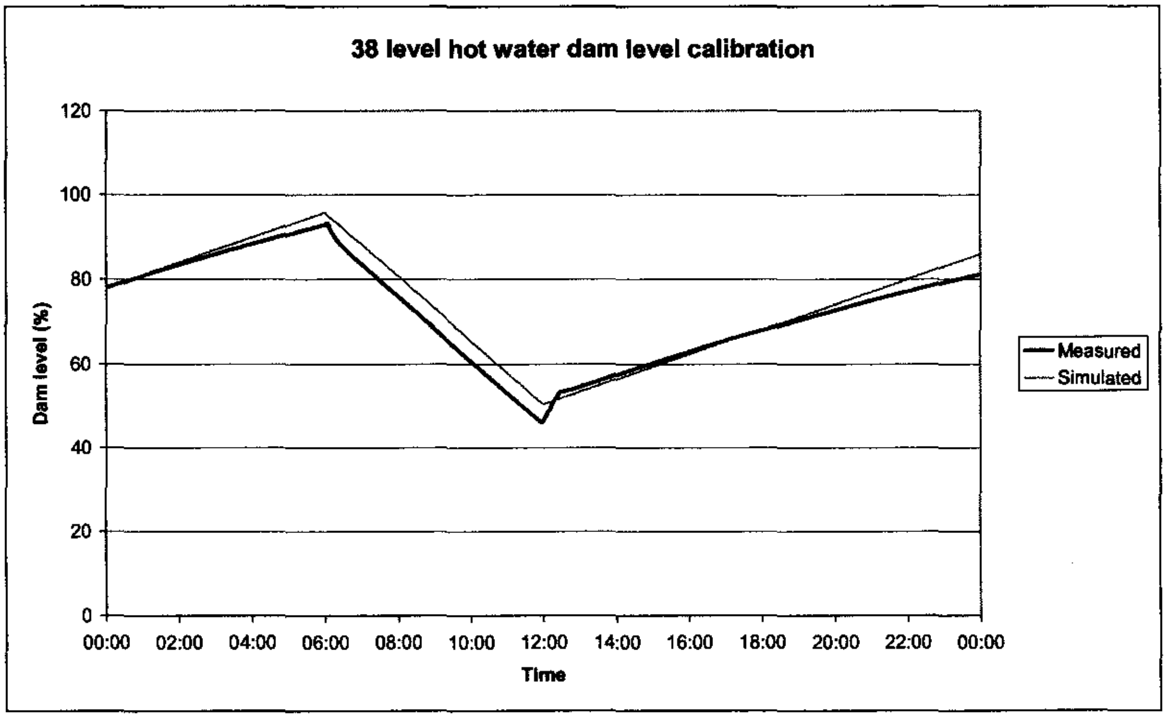


Figure 6.2: Kopanang level 38 hot water dam calibration.

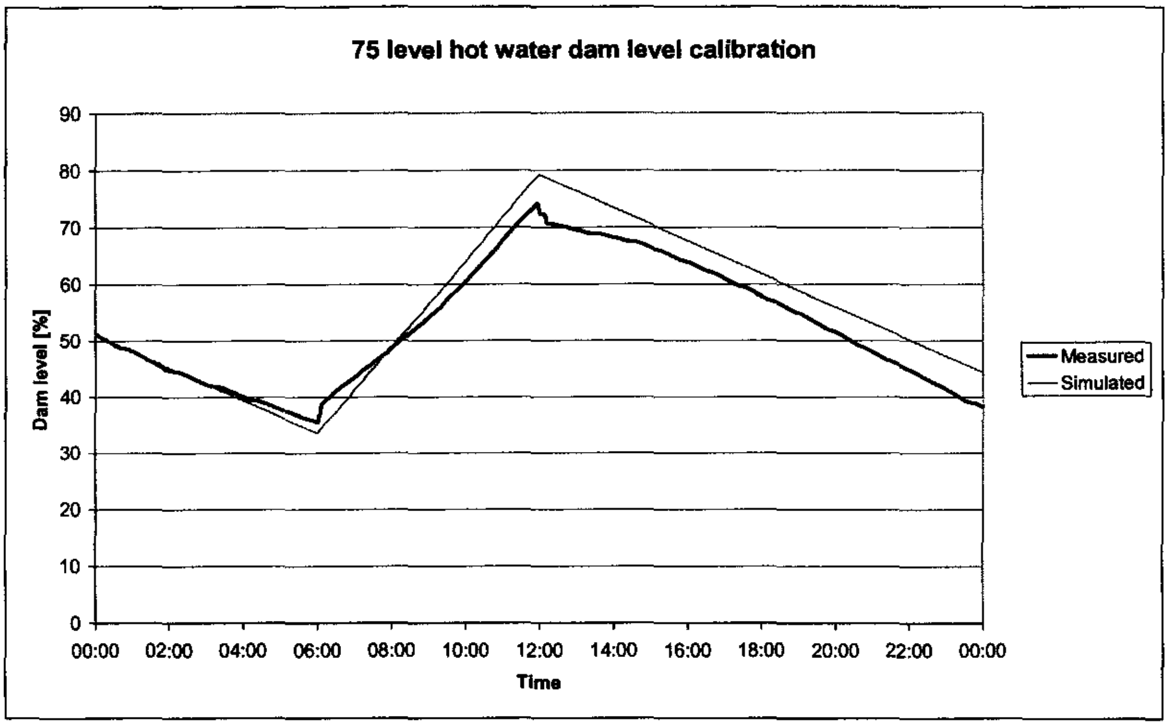


Figure 6.3: Kopanang level 75 hot water dam calibration.

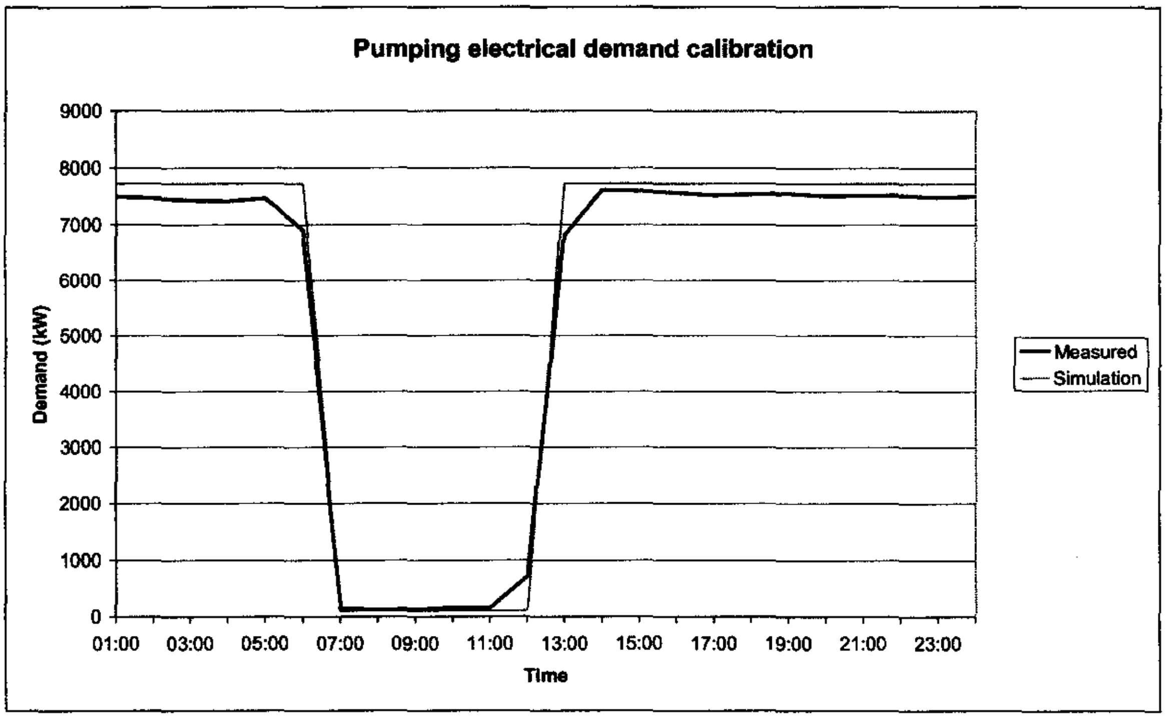


Figure 6.4: Kopanang underground pumping electricity calibration

The chiller's compressor power also needed some calibration the result is shown in *Figure 6.5*.

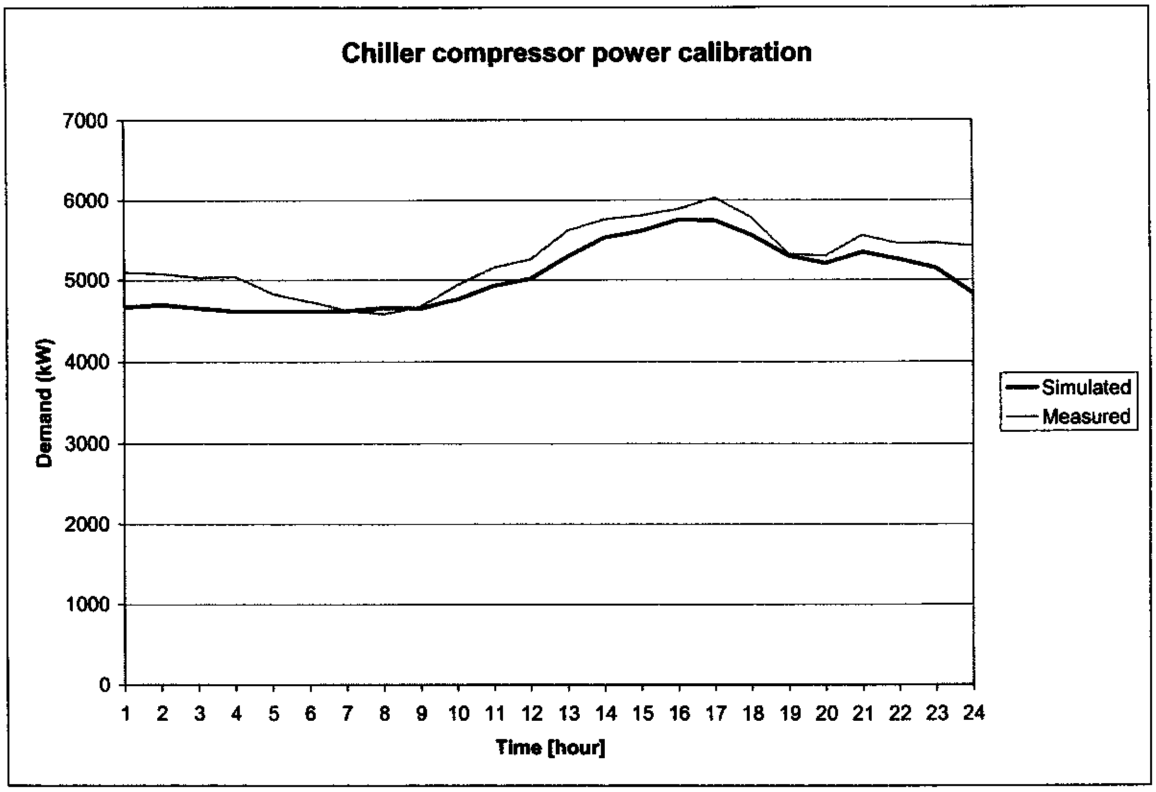


Figure 6.5: Kopanang chiller compressor calibration

The underground cooling model was the last to be calibrated the results of both the wet bulb and dry bulb temperatures on level 64 are shown in *Figure 6.6* and *Figure 6.7.*

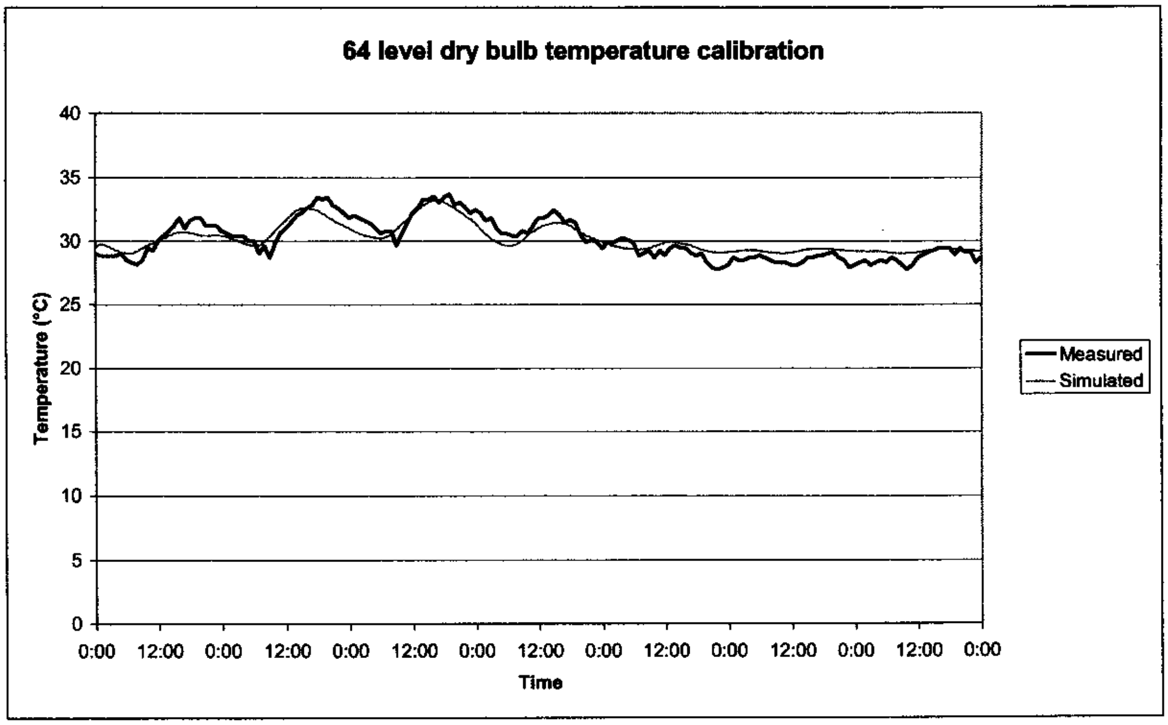


Figure 6.6: Kopanang 64 level dry bulb temperature calibration

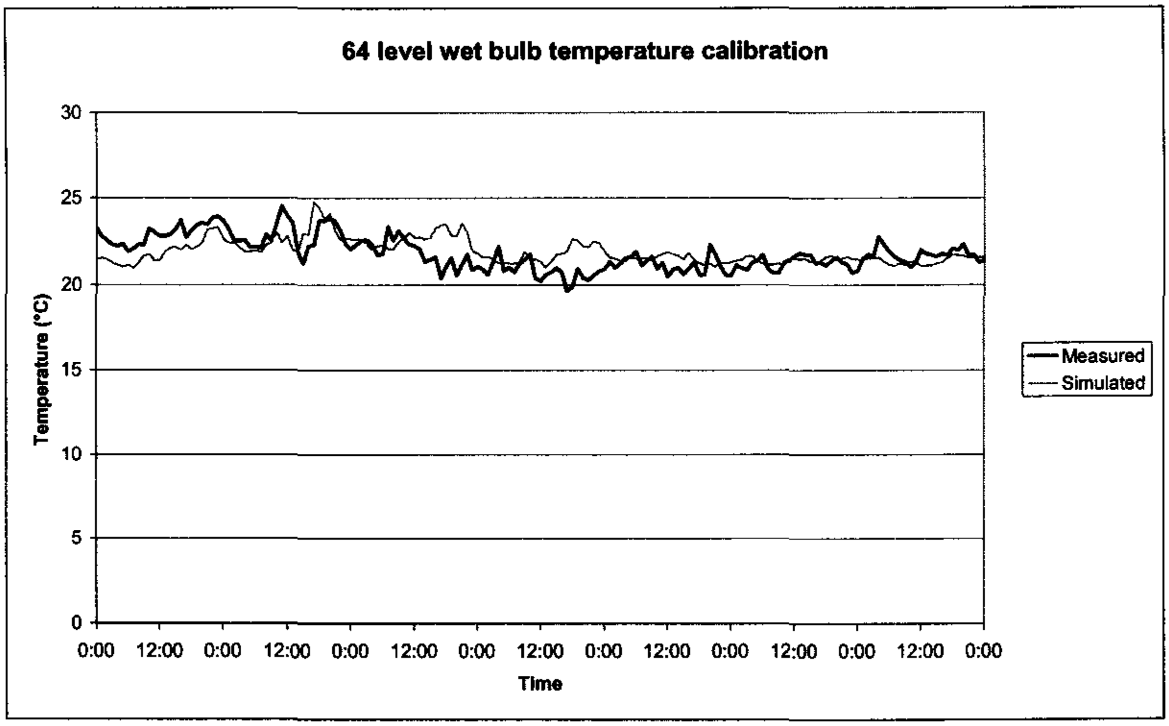


Figure 6.7: Kopanang 64 level wet bulb temperature calibration

The optimisation model is now calibrated to be used to generate the optimum daily operating schedule that must be sent to the mine everyday during the trial period.

The delivery of the daily service and all it's components is discussed in detail in section 6.3.2

6.3 The trial period

6.3.1 Background

After the results of the study were shown to the mine management of Kopanang they decided to agree to the implementation of the proposed strategies for a trial period of three months. During this time a daily operating schedule will be given to the operators on the mine to follow.

The electricity cost will then be compared to the cost of a cost model predicting the electricity cost on the old operating strategy for the same operating conditions. A monthly report on the cost saving as well as the ability to follow the schedules must be created and sent to the mine's representative. All these findings will be evaluated at the end of the three month period to decide on the continuation of the service.

The basic components of the trial period are discussed in this section. The cost prediction model will be discussed on its own in section 6.4.

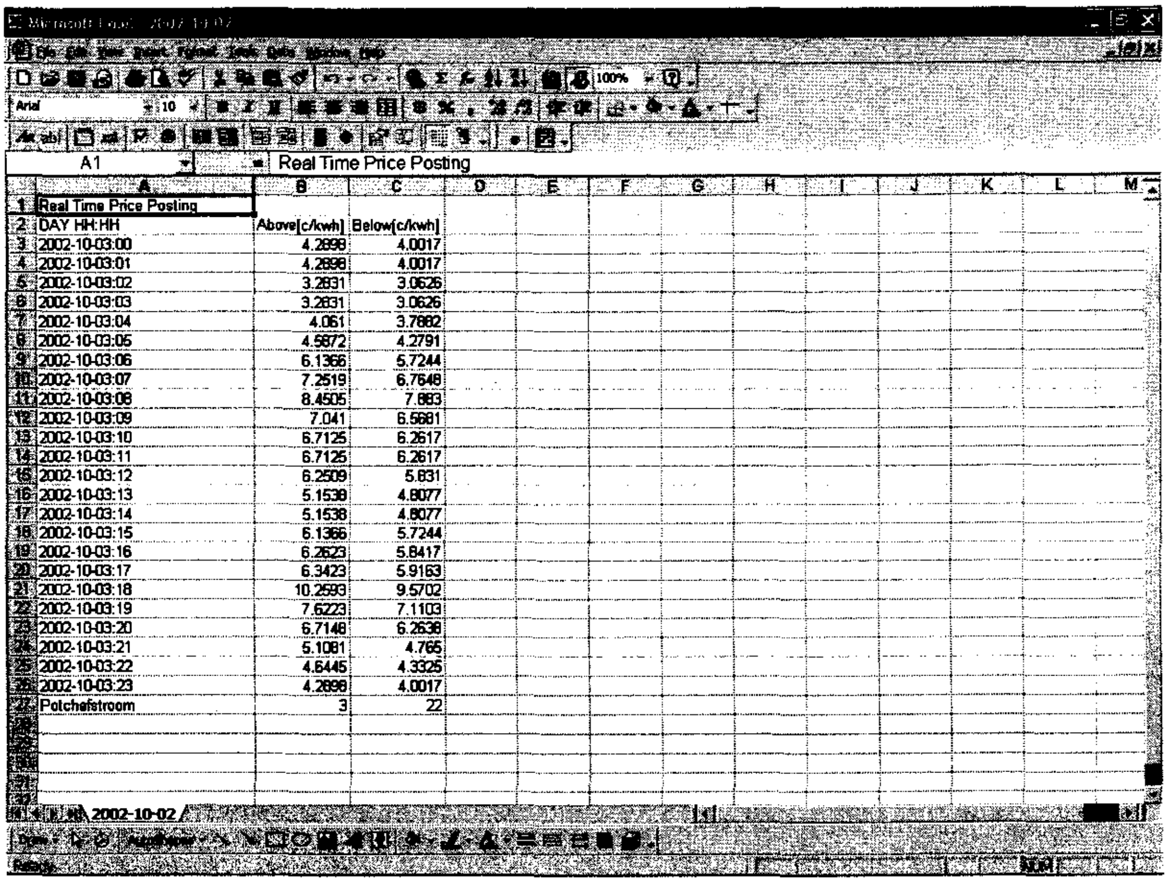
6.3.2 Daily operating schedules

A daily optimisation must be done to calculate the optimum operating strategy for the day. To deliver this service an optimum schedule must be calculated in advance to enable the operators to follow the schedule from the start of the day. The daily RTP price signal is available from ESKOM from 16:00 the day before. This means that the optimum operating schedule for the next day can be generated after 16:00 and then be sent to the operators.

The generation of the optimum operating schedule consists of the following steps:

6.3.2.1 Downloading price and weather information

The RTP price is downloaded daily, anytime after 14:30, from the following website: http://www.enerweb.co.za/ftp/pub/ftp/rtp2p/latest_rtp2p.csv. The predicted minimum and maximum temperatures must also be downloaded, anytime after 16:00, from the following website: http://www.weathersa.co.za/fcast/maxmin.htm. This data must now be combined in one file to ease the use of the data in the optimisation. This is done by pasting the downloaded data into an EXCEL sheet and saving it as "The current date".xls for example if the current date is 2002-10-02 the file's name will be 2002-10-02.xls as indicated in *Figure 6.8.*



A1 Real Time Price Posting

Real Time Price Posting		
DAY HH:HH	Above[c/kwh]	Below[c/kwh]
2002-10-03:00	4.2898	4.0017
2002-10-03:01	4.2898	4.0017
2002-10-03:02	3.2831	3.0626
2002-10-03:03	3.2831	3.0626
2002-10-03:04	4.061	3.7882
2002-10-03:05	4.5872	4.2791
2002-10-03:06	6.1366	5.7244
2002-10-03:07	7.2519	6.7648
2002-10-03:08	8.4505	7.883
2002-10-03:09	7.041	6.5681
2002-10-03:10	6.7125	6.2617
2002-10-03:11	6.7125	6.2617
2002-10-03:12	6.2509	5.831
2002-10-03:13	5.1538	4.8077
2002-10-03:14	5.1538	4.8077
2002-10-03:15	6.1366	5.7244
2002-10-03:16	6.2623	5.8417
2002-10-03:17	6.3423	5.9163
2002-10-03:18	10.2593	9.5702
2002-10-03:19	7.6223	7.1103
2002-10-03:20	6.7148	6.2638
2002-10-03:21	5.1081	4.765
2002-10-03:22	4.6445	4.3325
2002-10-03:23	4.2898	4.0017
Potchefstroom	3	22

Figure 6.8: Storing of the downloaded data

6.3.2.2 Calculation of the climate data

From the downloaded minimum and maximum temperatures the hourly dry bulb and wet bulb temperatures must be calculated. This is done using the climate model derived during the calibration and verification of the simulation models [16].

6.3.2.3 Boundary data

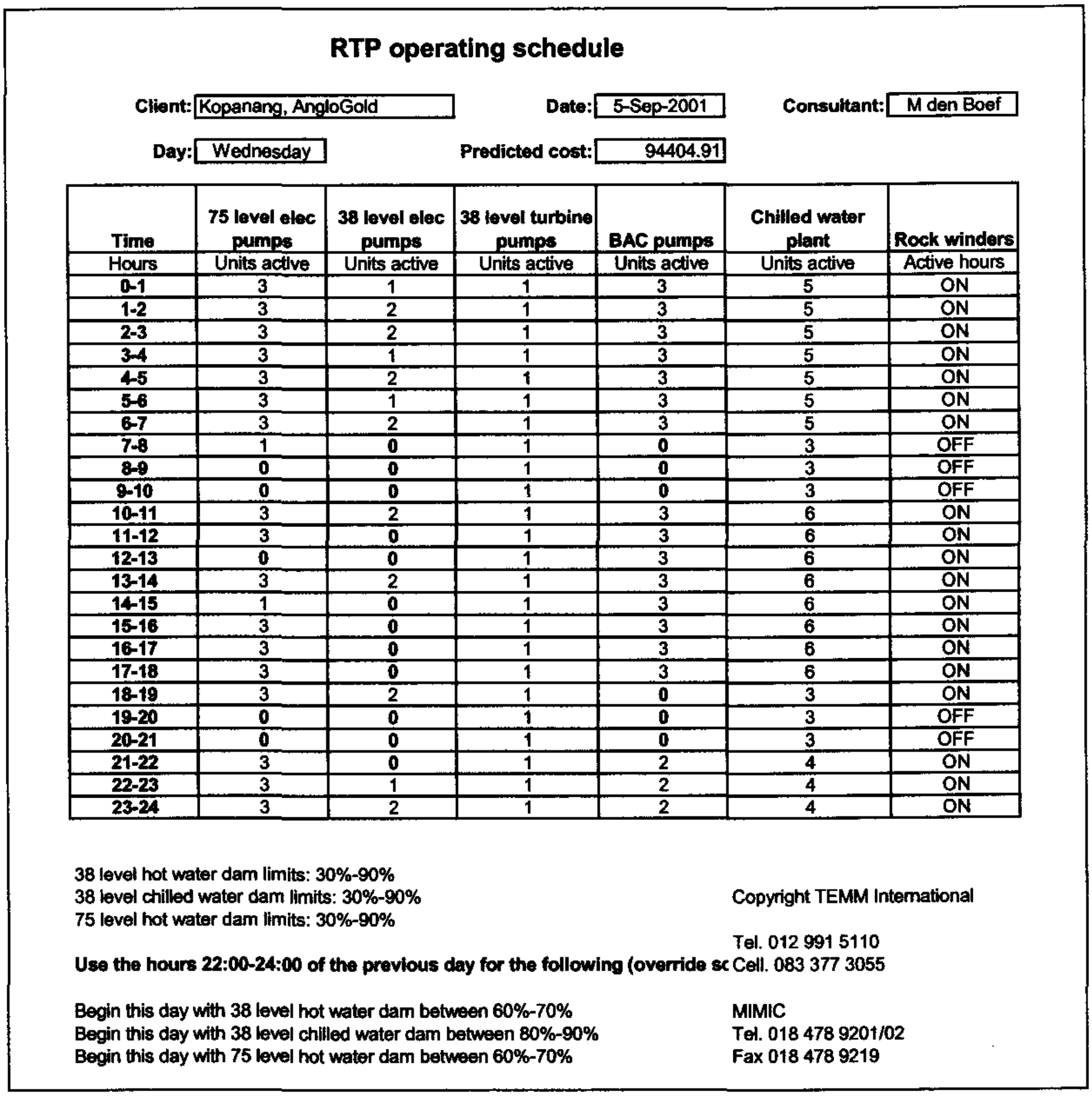
The newly calibrated boundary values which are discussed in section 6.3.3 must also be pasted into the boundary sheet.

6.3.2.4 Optimisation

All the variables are now reset to zero and the optimisation of each of the subsystems is done. After the optimisation the number of components active every hour needs to be rounded down or up to integer values.

6.3.2.5 The final operating schedule

This calculated number of components active every hour is now summarised in a report that is sent to the mine. In *Figure 6.9* an example of such a report is shown.



RTP operating schedule

Client: Kopanang, AngloGold **Date:** 5-Sep-2001 **Consultant:** M den Boef

Day: Wednesday **Predicted cost:** 94404.91

Time	**75 level elec pumps**	**38 level elec pumps**	**38 level turbine pumps**	**BAC pumps**	**Chilled water plant**	**Rock winders**
Hours	Units active	Units active	Units active	Units active	Units active	Active hours
0-1	3	1	1	3	5	ON
1-2	3	2	1	3	5	ON
2-3	3	2	1	3	5	ON
3-4	3	1	1	3	5	ON
4-5	3	2	1	3	5	ON
5-6	3	1	1	3	5	ON
6-7	3	2	1	3	5	ON
7-8	1	**0**	1	**0**	3	OFF
8-9	**0**	**0**	1	**0**	3	OFF
9-10	**0**	**0**	1	**0**	3	OFF
10-11	3	2	1	3	6	ON
11-12	3	**0**	1	3	6	ON
12-13	**0**	**0**	1	3	6	ON
13-14	3	2	1	3	6	ON
14-15	1	**0**	1	3	6	ON
15-16	3	**0**	1	3	6	ON
16-17	3	**0**	1	3	6	ON
17-18	3	**0**	1	3	6	ON
18-19	3	2	1	**0**	3	ON
19-20	**0**	**0**	1	**0**	3	OFF
20-21	**0**	**0**	1	**0**	3	OFF
21-22	3	**0**	1	2	4	ON
22-23	3	1	1	2	4	ON
23-24	3	2	1	2	4	ON

38 level hot water dam limits: 30%-90%
38 level chilled water dam limits: 30%-90%
75 level hot water dam limits: 30%-90%

Use the hours 22:00-24:00 of the previous day for the following (override sc

Begin this day with 38 level hot water dam between 60%-70%
Begin this day with 38 level chilled water dam between 80%-90%
Begin this day with 75 level hot water dam between 60%-70%

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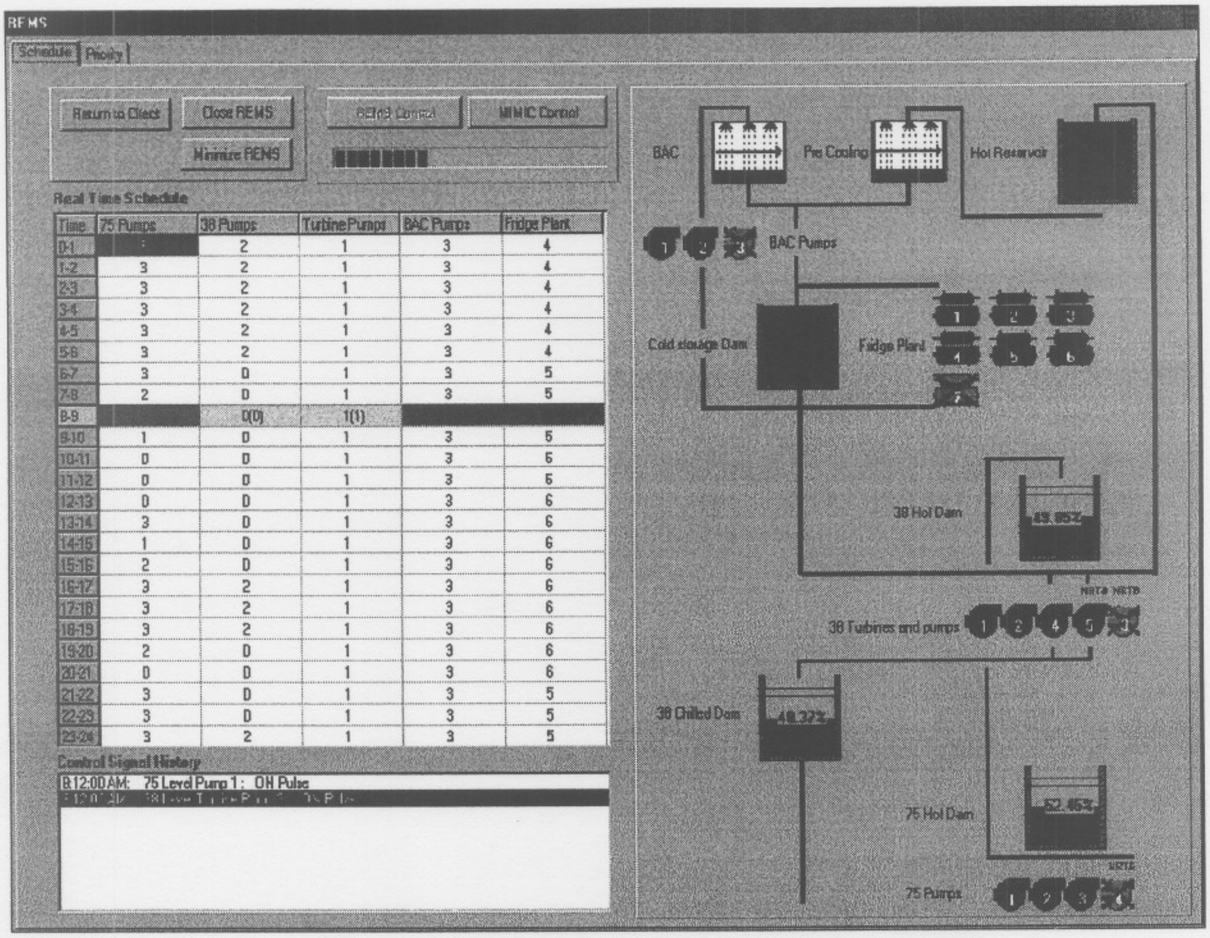
Fax 018 478 9219

Figure 6.9: Optimum operating schedule as faxed to the operator



Real Time Schedule

Time	75 Pumps	38 Pumps	Turbine Pumps	BAC Pumps	Fridge Plant
0-1	[illegible]	2	1	3	4
1-2	3	2	1	3	4
2-3	3	2	1	3	4
3-4	3	2	1	3	4
4-5	3	2	1	3	4
5-6	3	2	1	3	4
6-7	3	0	1	3	5
7-8	2	0	1	3	5
8-9		0(0)	1(1)		
9-10	1	0	1	3	5
10-11	0	0	1	3	6
11-12	0	0	1	3	6
12-13	0	0	1	3	6
13-14	3	0	1	3	6
14-15	1	0	1	3	6
15-16	2	0	1	3	6
16-17	3	2	1	3	6
17-18	3	2	1	3	6
18-19	3	2	1	3	6
19-20	2	0	1	3	6
20-21	0	0	1	3	6
21-22	3	0	1	3	5
22-23	3	0	1	3	5
23-24	3	2	1	3	5

Control Signal History

8:12:00 AM: 75 Level Pump 1 : Off Pulse

Figure 6.10: The display of the operating schedule on the SCADA interface

A comma separated text file is also uploaded to the operator's computer where it is used by the software to display the optimum operating schedule on the computer screen in the SCADA system as seen in *Figure 6.10*.

6.3.3 Weekly calibration of boundaries

Normally calibration is done on a weekly basis depending on the sensitivity of the boundaries and components to wear and tear over time. The most important part of calibration is data validation. The validation is included in the calibration process at different stages.

The data is checked for completeness. Blank data is used to replace missing data. This is done to ensure that they are not taken into account when averages are calculated. Most of the calibration of boundaries is merely the calculation of the hourly averages of the measured boundary values. The boundaries are not always explicitly measured. In these cases a backward engineering approach can be used. This can best be explained through the use of an example.

Consider the calibration of a pumping system consisting of two dams and two pumping stations, as typically found at Kopanang, as indicated in *Figure 6.11*.

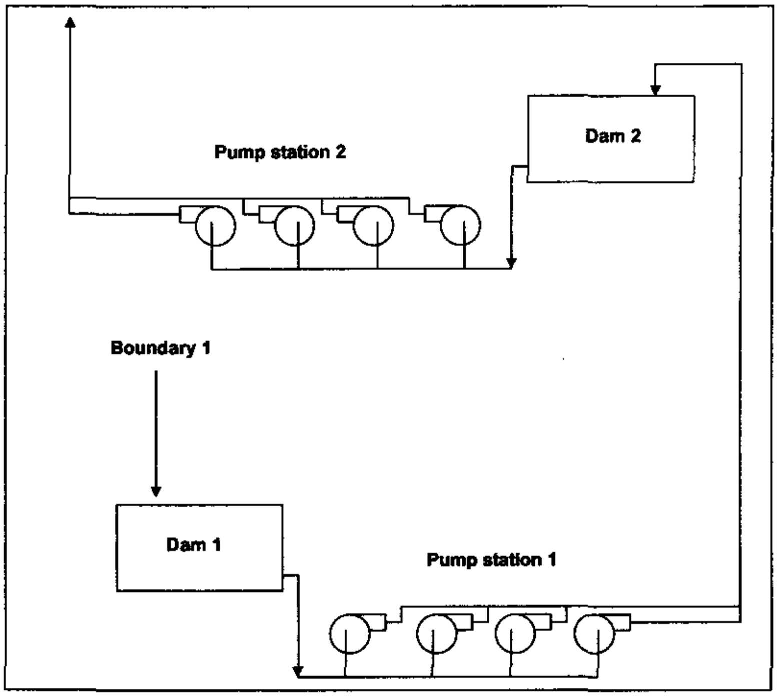


Figure 6.11: Pumping system layout

In the example we want to calibrate the flow of the pumps in each of the two pumping stations as well as the hourly flow profile of boundary 1. To do this we simplify the calibration by assuming that all the pumps at a pumping station deliver the same flows.

The calibration procedure is as follows:

- We use validation to search for times where only one pump is active at pumping station 2 and none at pumping station 1.
- This set of measurements is now further validated using only data where the pump was active for the whole hour.
- The flow per hour is now calculated using the measured dam levels of dam 2 in the new set of data. This is now the newly calibrated pump flow for pumping station 2.
- The whole set of data is now used to calibrate the pump flow of pumping station 1.

- The data is validated to use only data where an integer number of pumps are active per hour for both pumping stations.
- The flow per hour is now calculated using the measured dam levels of dam 2 in the new set of data. This is now the newly calibrated pump flow for pumping station 1.
- Lastly the hourly flow of boundary 1 is calculated from the dam levels of dam 1 and the newly calibrated flows of pump station 1.

This procedure depends on the availability of enough valid data to produce accurate results. It is suited for weekly, monthly or seasonal calibration.

This process is followed to calculate the settler flow boundary at level 75.

6.3.4 Reports

At the end of each month a cost savings report is given to the mine. In this report the amount of time that the schedule was followed for the underground pumps, rock winders and the refrigeration and BAC components as well as the lost savings due to not following the optimum profile is given in a table like the one in *Table 6.1*.

Time on or below the operating schedule:

	Hours on/below	**Total hours**	**% on/below**
Pumps	555	720	77
Fridge plants	560	720	78
Rock winders	4	7	57
Unrealised Potential ®	41677.45		

Table 6.1: Ability to follow operating schedules and unrealised potential

The second table in the report summarises the savings achieved in the particular month as seen in the example *Table 6.2*.

Model cost ®	2618879.00
Actual cost ®	2549628.16
Actual saving ®	69250.83
% saving	2.6

Table 6.2: Example of a cost savings summary

October 2001

Date	CBL cost	Model cost	Actual cost	Predicted cost	Actual savings	Predicted savings	Unrealised potential
22/09/01	73997.07	80317.04	80567.28	73019.54	-250.24	7297.50	7547.74
23/09/01	73997.07	67296.23	69141.42	67027.13	-1845.19	269.10	2114.29
24/09/01	73997.07	71789.62	70178.16	79695.75	1611.46	-7906.13	-9517.59
25/09/01	90590.62	84365.56	85704.77	82998.20	-1339.21	1367.36	2706.57
26/09/01	90245.49	90606.18	90894.08	91251.63	-287.89	-645.45	-357.56
27/09/01	93116.71	91697.67	89996.39	89925.15	1701.28	1772.53	71.25
28/09/01	91681.64	90824.29	83267.90	77144.92	7556.39	13679.37	6122.98
29/09/01	88380.20	89680.49	84941.19	78147.11	4739.30	11533.38	6794.08
30/09/01	66597.66	62102.33	55760.36	44124.51	6341.97	17977.81	11635.84
1/10/2001	89135.11	91295.19	90592.87	88347.24	702.32	2947.94	2245.63
2/10/2001	90590.62	95187.44	92294.04	89803.96	2893.40	5383.48	2490.08
3/10/2001	90245.49	95280.13	92983.54	92118.94	2296.59	3161.19	864.59
4/10/2001	93116.71	94610.53	91647.94	94143.63	2962.59	466.90	-2495.69
5/10/2001	91681.64	94459.85	89792.56	90897.99	4667.29	3561.86	-1105.43
6/10/2001	88380.20	89326.88	86330.00	83534.72	2996.88	5792.16	2795.28
7/10/2001	66597.66	65222.73	65281.89	62881.83	-59.16	2340.90	2400.06
8/10/2001	89135.11	94749.75	92943.31	88549.85	1806.44	6199.90	4393.46
9/10/2001	90590.62	93920.41	92124.73	91990.82	1795.68	1929.59	133.91
10/10/2001	90245.49	96062.98	93317.14	93440.01	2745.83	2622.96	-122.87
11/10/2001	93116.71	95696.50	93413.54	92823.45	2282.97	2873.06	590.09
12/10/2001	91681.64	93959.11	91188.86	90769.76	2770.25	3189.35	419.10
13/10/01	88380.20	90193.11	86684.90	86874.21	3508.21	3318.90	-189.31
14/10/01	66597.66	68591.08	66947.83	64193.15	1643.25	4397.93	2754.68
15/10/01	89135.11	94209.67	90081.62	90041.16	4128.05	4168.51	40.47
16/10/01	90590.62	93392.01	90510.14	92137.48	2881.86	1254.53	-1627.34
17/10/01	90245.49	94452.17	91343.13	92919.15	3109.04	1533.02	-1576.02
18/10/01	93116.71	95286.18	93521.83	92055.21	1764.35	3230.98	1466.62
19/10/01	91681.64	92738.95	91087.39	89320.39	1651.56	3418.57	1767.01
20/10/01	88380.20	94701.69	90273.19	85227.09	4428.51	9474.61	5046.10
21/10/01	66597.66	66863.24	66816.17	72546.74	47.06	-5683.50	-5730.56
22/10/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2571845.83	2618879.00	2549628.16	2507950.71	69250.83	110928.29	41677.45

Table 6.3: Example of the daily cost savings summary

Lastly the daily savings results is summarised in a table like *Table 6.3*.

6.4 Calculation of the actual savings achieved

6.4.1 Background

The mine is currently on the two-part RTP electricity tariff. As a result of this dynamic tariff structure it is not possible to just compare the previous years electricity costs with the current months electricity costs to calculate the cost savings.

A load prediction model must be derived to predict what the daily electricity costs would have been for the current climate conditions and the previous operating strategies. The electricity cost associated with this predicted load is compared to the actual electricity cost to calculate the cost savings.

6.4.2 Load prediction model

6.4.2.1 Previous operating strategy pumping profiles

Average daily pumping profiles were calculated for each day of the week for the summer and winter seasons form the 2000 data supplied. The same philosophy was utilised in calculating the daily CBL profiles [14]. The profiles can therefore be seen as pumping CBL's. *Figure 6.12* and *Figure 6.13* show these profiles.

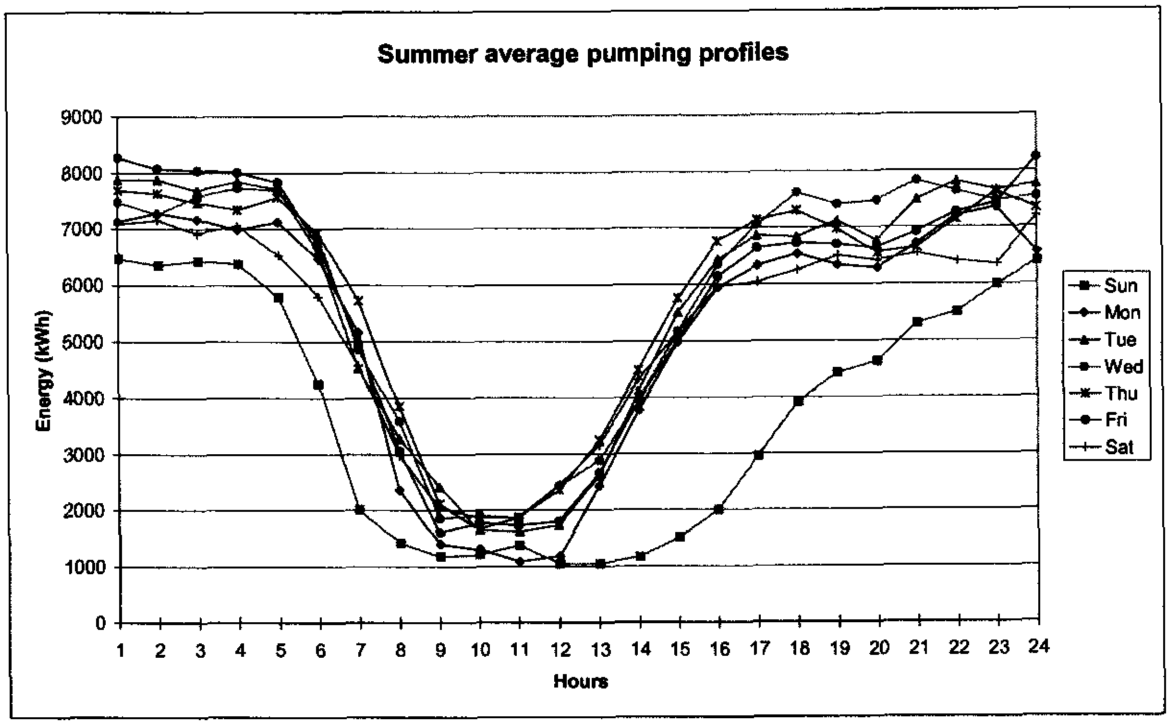


Figure 6.12: Summer pumping CBL's for Kopanang

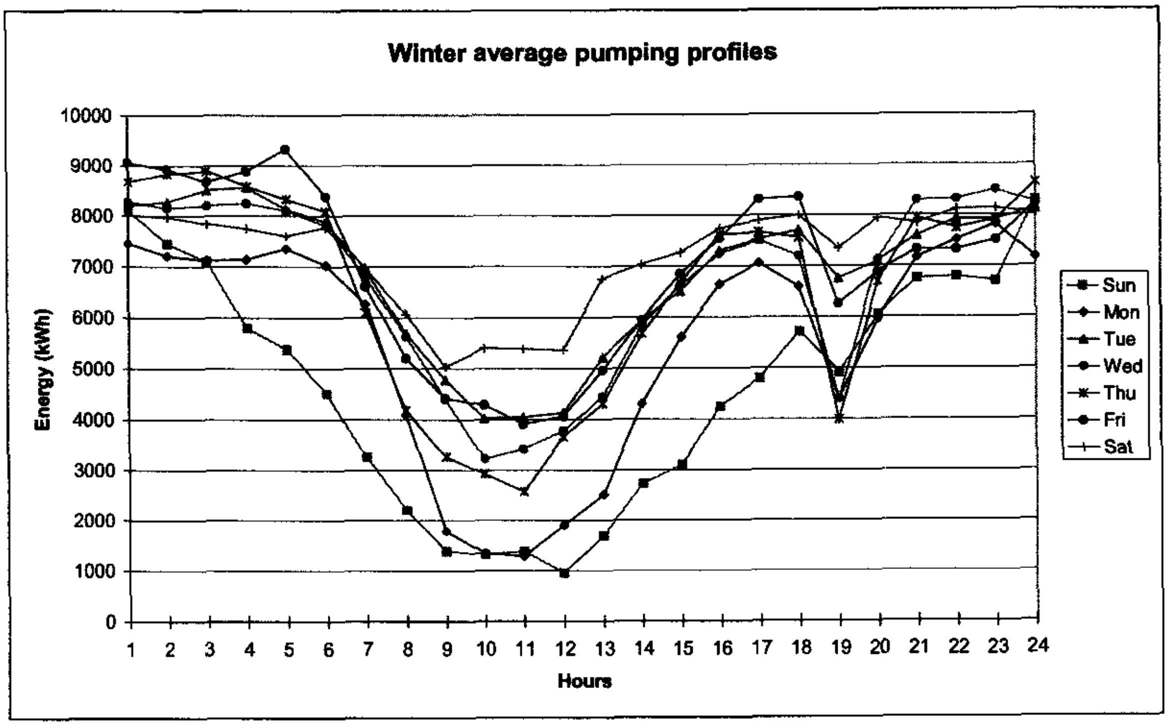


Figure 6.13: Winter pumping CBL's for Kopanang

6.4.2.2 Previous operating strategy refrigeration profiles

Daily summer and winter refrigeration profile equations were derived from 2000 data as a function of daily minimum and maximum ambient temperatures. (Hourly energy = f(T_{min}, T_{max})). *Figure 6.14* and *Figure 6.15* displays the measured and predicted profiles.

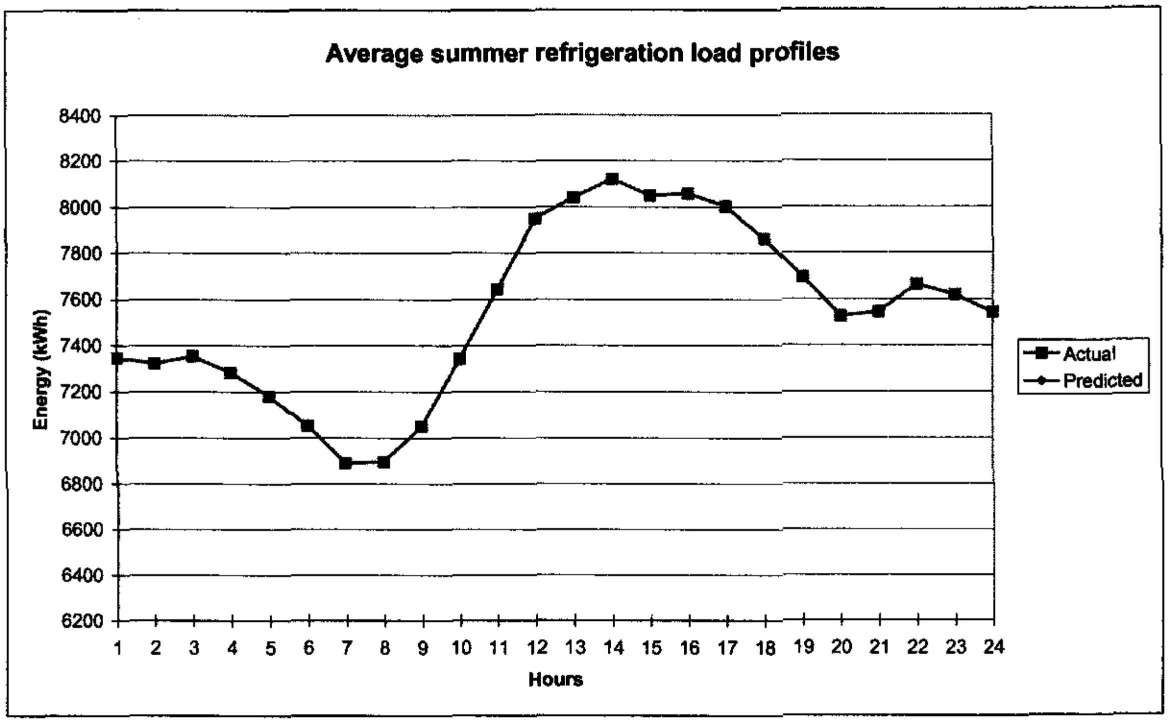


Figure 6.14: Refrigeration load model verification for summer at Kopanang

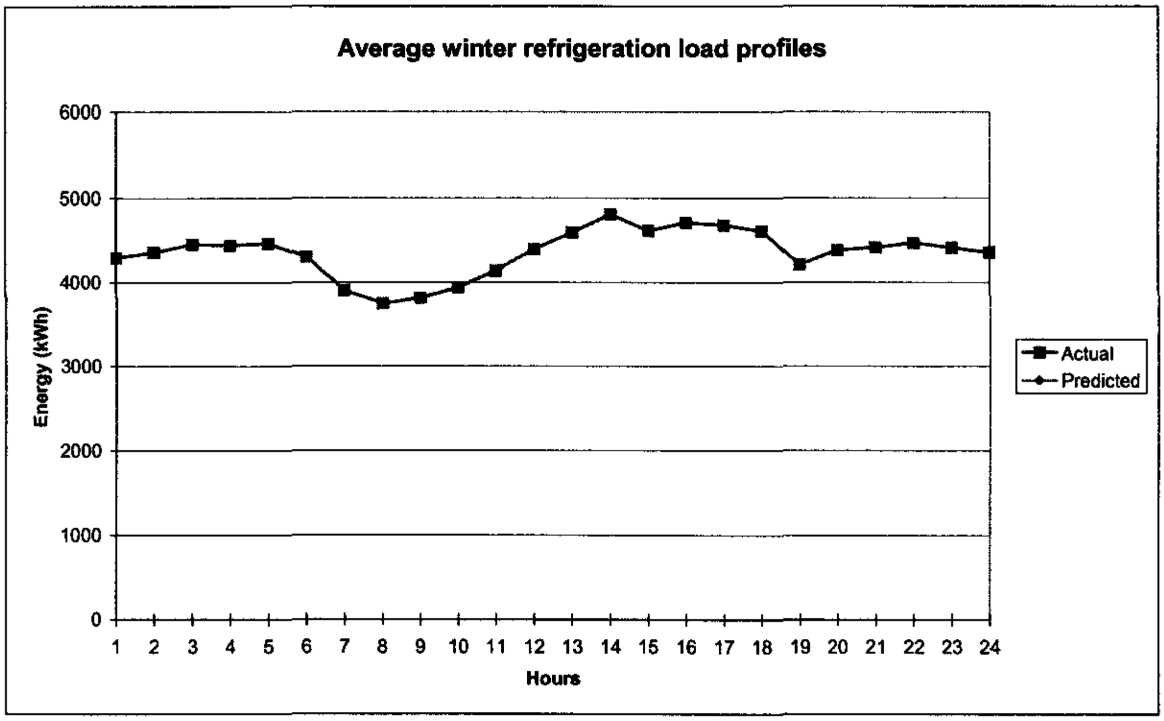


Figure 6.15: Refrigeration load model verification for winter at Kopanang

6.4.2.3 Actual measured total load

The actual cost is calculated on the actual total load profile supplied. *Figure 6.16* displays such a profile.

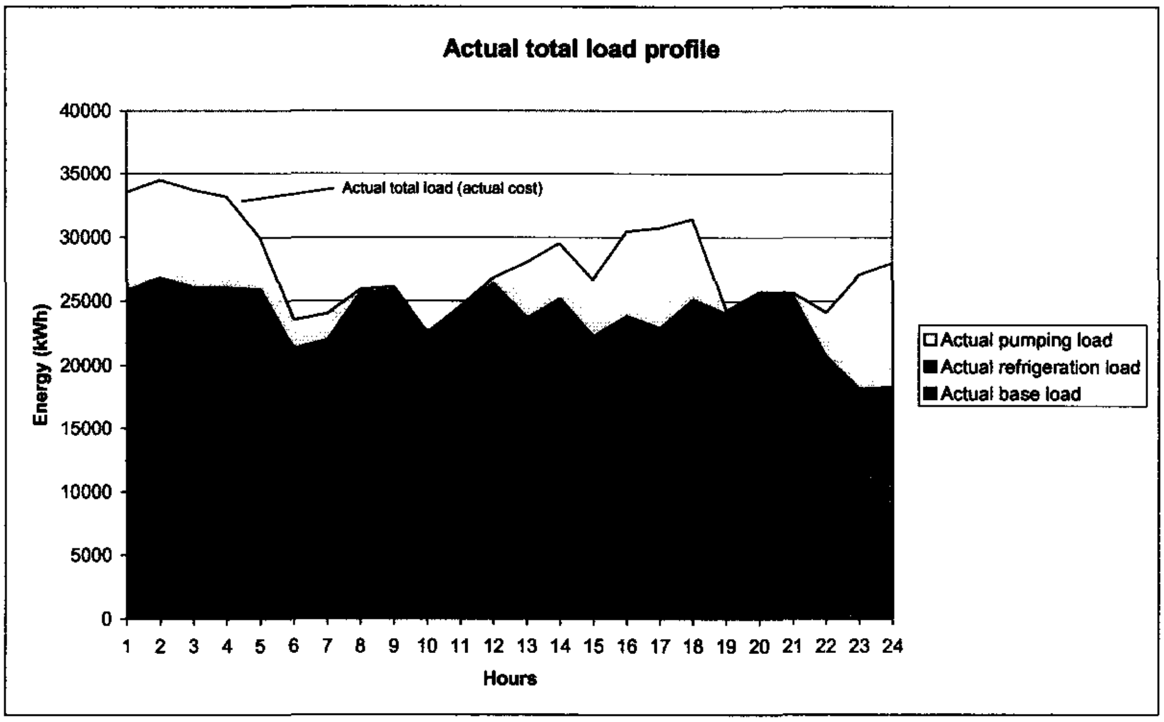


Figure 6.16: The composition of the actual total load profile at Kopanang

6.4.2.4 Predicted total load

The predicted pumping profiles are scaled up or down to match the electricity consumption of the respective daily actual electricity consumption of the pumps. This scaled predicted pumping profile and the predicted refrigeration profile is now added to the actual base load profile to obtain the predicted total profile.

The predicted profile cost is now calculated on this predicted total load profile. *Figure 6.17* illustrates this calculation.

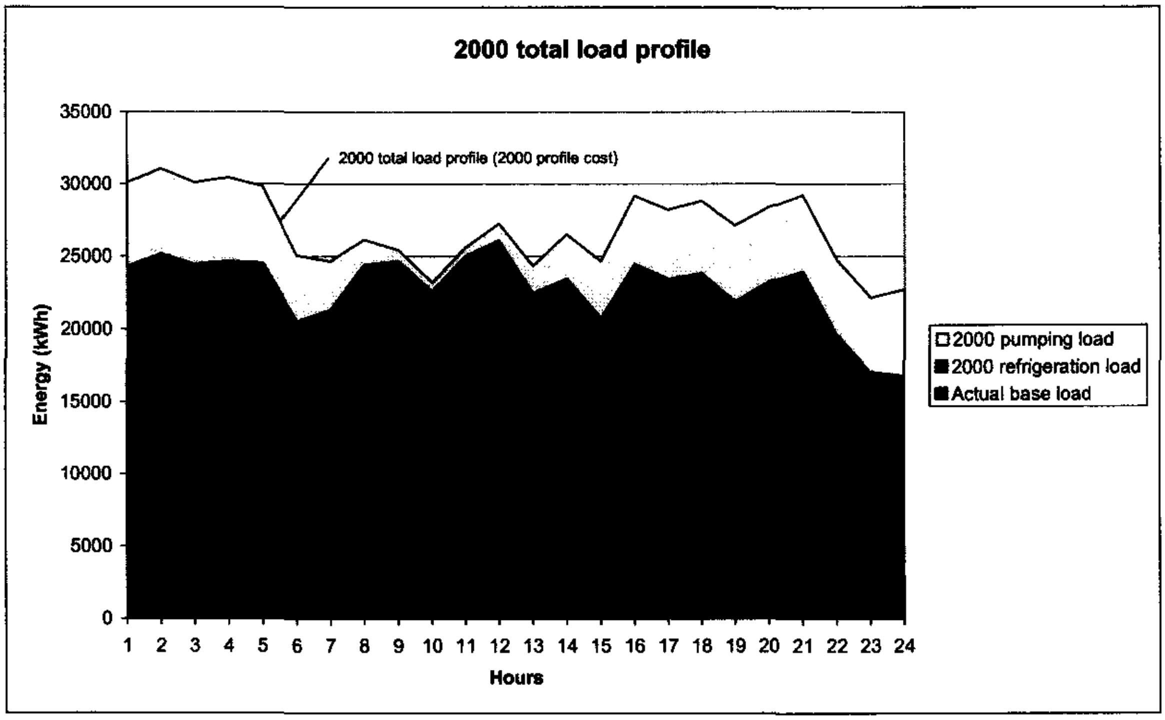


Figure 6.17: The composition of the predicted total load profile at Kopanang

6.4.3 Calibration and verification of model

This model was then used to predict the electricity load for each of the months of 2000. The predicted load is then compared to the actual measured load to test the accuracy of the prediction model. The total daily electricity costs of the predicted and measured load profiles were compared to gauge the accuracy of the load prediction profile. *Figure 6.18* shows an extract of the daily electricity cost verification done on the load prediction model. The figure shows a stretch of 90 days extracted from the complete year 2000 verification.

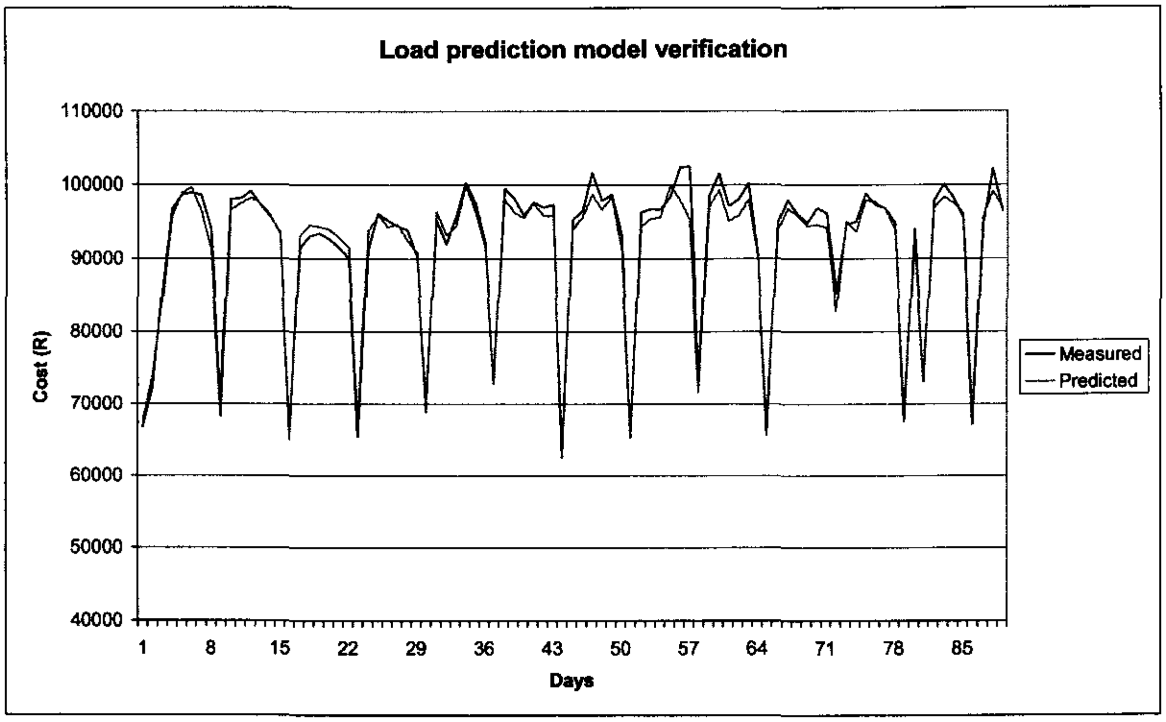


Figure 6.18: Load prediction model verification at Kopanang

The absolute average error between the actual electricity cost and the modelled electricity cost was smaller than 1%. The load prediction model was accepted to be accurate enough to prove the actual cost savings during the trial period by the mine management.

6.4.4 Calculated savings

The calculated savings achieved during the trial period is summarised in *Table 6.4*, *Table 6.5* and *Table 6.6*. In total R335 416 was saved in the three month period.

An additional R273 101 could have been saved if the operating schedules were followed 100% of the time. The biggest amount of this unrealised potential occurred in the first month due to insufficient contact between the operators that had the schedules and the operators that had to control the refrigeration plant and the BAC's. After this was resolved there was a steady decrease in the unrealised potential during the next 2 months.

September 2001							
Date	CBL cost	Model cost	Actual cost	Predicted cost	Actual savings	Predicted savings	Unrealised savings
22/08/2001	86159.10	99918.79	97978.28	86001.59	1940.51	13917.20	11976.69
23/08/2001	85736.26	99186.33	99850.29	82070.84	-663.96	17115.49	17779.46
24/08/2001	85206.27	102285.62	97693.06	78859.22	4592.55	23426.39	18833.84
25/08/2001	82911.42	89887.35	88487.62	78239.39	1399.73	11647.96	10248.23
26/08/2001	58312.62	58328.73	56192.87	56300.84	2135.86	2027.89	-107.97
27/08/2001	82259.45	88296.42	83830.91	81574.86	4465.50	6721.55	2256.05
28/08/2001	85888.85	92862.81	85572.31	83177.94	7290.50	9684.87	2394.37
29/08/2001	86159.10	92042.85	81813.92	82352.06	10228.92	9690.78	-538.14
30/08/2001	85736.26	94666.80	84877.28	84231.06	9789.52	10435.74	646.22
31/08/2001	85206.27	85815.37	82409.11	81022.37	3406.26	4793.00	1386.74
01/09/2001	85902.52	68947.29	65672.43	35114.39	3274.87	33832.90	30558.03
02/09/2001	64730.65	56233.48	50380.41	43989.57	5853.07	12243.91	6390.84
03/09/2001	86636.28	86958.06	83419.30	83724.08	3538.76	3233.98	-304.78
04/09/2001	88050.97	85460.62	67035.95	54394.20	18424.67	31066.43	12641.76
05/09/2001	87715.53	81078.29	77743.58	80712.29	3334.72	366.01	-2968.71
06/09/2001	90506.25	86573.94	79194.52	74164.59	7379.43	12409.35	5029.92
07/09/2001	89111.41	82313.35	76686.73	70874.91	5626.62	11438.44	5811.82
08/09/2001	85902.52	77395.33	58984.96	39404.08	18410.37	37991.25	19580.88
09/09/2001	64730.65	64981.74	58651.24	49519.60	6330.50	15462.14	9131.64
10/09/2001	86636.28	91925.29	87253.13	85637.49	4672.16	6287.80	1615.64
11/09/2001	88050.97	93169.47	87586.92	86430.14	5582.55	6739.33	1156.78
12/09/2001	87715.53	87776.87	83807.05	88679.84	3969.81	-902.97	-4872.79
13/09/2001	90506.25	91852.80	86354.25	83560.81	5498.56	8291.99	2793.43
14/09/2001	89111.41	99899.23	85205.66	65220.80	14693.57	34678.43	19984.86
15/09/2001	85902.52	81559.38	69487.58	39476.88	12071.80	42082.50	30010.70
16/09/2001	64730.65	67093.92	65573.26	59596.06	1520.66	7497.85	5977.19
17/09/2001	86636.28	87181.18	84629.20	84834.36	2551.98	2346.82	-205.16
18/09/2001	88050.97	89803.02	86230.68	87493.06	3572.34	2309.96	-1262.38
19/09/2001	87715.53	95524.31	90085.13	87927.09	5439.18	7597.22	2158.05
20/09/2001	90506.25	91888.97	87380.90	87253.76	4508.07	4635.21	127.14
21/09/2001	89111.41	89542.92	81573.49	75803.06	7969.42	13739.85	5770.43
Total	2601536.42	2660450.52	2471642.03	2257641.24	188808.50	402809.28	214000.79

Table 6.4: Daily savings results for September 2001 at Kopanang

October 2001							
Date	CBL cost	Model cost	Actual cost	Predicted cost	Actual savings	Predicted savings	Unrealised potential
22/09/01	73997.07	80317.04	80567.28	73019.54	-250.24	7297.50	7547.74
23/09/01	73997.07	67296.23	69141.42	67027.13	-1845.19	269.10	2114.29
24/09/01	73997.07	71789.62	70178.16	79695.75	1611.46	-7906.13	-9517.59
25/09/01	90590.62	84365.56	85704.77	82998.20	-1339.21	1367.36	2706.57
26/09/01	90245.49	90606.18	90894.08	91251.63	-287.89	-645.45	-357.56
27/09/01	93116.71	91697.67	89996.39	89925.15	1701.28	1772.53	71.25
28/09/01	91681.64	90824.29	83267.90	77144.92	7556.39	13679.37	6122.98
29/09/01	88380.20	89680.49	84941.19	78147.11	4739.30	11533.38	6794.08
30/09/01	66597.66	62102.33	55760.36	44124.51	6341.97	17977.81	11635.84
1/10/2001	89135.11	91295.19	90592.87	88347.24	702.32	2947.94	2245.63
2/10/2001	90590.62	95187.44	92294.04	89803.96	2893.40	5383.48	2490.08
3/10/2001	90245.49	95280.13	92983.54	92118.94	2296.59	3161.19	864.59
4/10/2001	93116.71	94610.53	91647.94	94143.63	2962.59	466.90	-2495.69
5/10/2001	91681.64	94459.85	89792.56	90897.99	4667.29	3561.86	-1105.43
6/10/2001	88380.20	89326.88	86330.00	83534.72	2996.88	5792.16	2795.28
7/10/2001	66597.66	65222.73	65281.89	62881.83	-59.16	2340.90	2400.06
8/10/2001	89135.11	94749.75	92943.31	88549.85	1806.44	6199.90	4393.46
9/10/2001	90590.62	93920.41	92124.73	91990.82	1795.68	1929.59	133.91
10/10/2001	90245.49	96062.98	93317.14	93440.01	2745.83	2622.96	-122.87
11/10/2001	93116.71	95696.50	93413.54	92823.45	2282.97	2873.06	590.09
12/10/2001	91681.64	93959.11	91188.86	90769.76	2770.25	3189.35	419.10
13/10/01	88380.20	90193.11	86684.90	86874.21	3508.21	3318.90	-189.31
14/10/01	66597.66	68591.08	66947.83	64193.15	1643.25	4397.93	2754.68
15/10/01	89135.11	94209.67	90081.62	90041.16	4128.05	4168.51	40.47
16/10/01	90590.62	93392.01	90510.14	92137.48	2881.86	1254.53	-1627.34
17/10/01	90245.49	94452.17	91343.13	92919.15	3109.04	1533.02	-1576.02
18/10/01	93116.71	95286.18	93521.83	92055.21	1764.35	3230.98	1466.62
19/10/01	91681.64	92738.95	91087.39	89320.39	1651.56	3418.57	1767.01
20/10/01	88380.20	94701.69	90273.19	85227.09	4428.51	9474.61	5046.10
21/10/01	66597.66	66863.24	66816.17	72546.74	47.06	-5683.50	-5730.56
22/10/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	2571845.83	2618879.00	2549628.16	2507950.71	69250.83	110928.29	41677.45

Table 6.5: Daily savings results for October 2001 at Kopanang

November 2001

Date	CBL cost	Model cost	Actual cost	Predicted cost	Actual savings	Predicted savings	Unrealised potential
22/10/01	89135.11	94302.57	92912.50	92257.67	1390.07	2044.89	654.82
23/10/01	90590.62	93893.00	92614.91	91864.59	1278.09	2028.40	750.32
24/10/01	90245.49	96956.24	94332.10	93694.02	2624.14	3262.22	638.08
25/09/01	93116.71	99218.70	95556.37	93547.78	3662.33	5670.92	2008.59
26/09/01	91681.64	96422.15	95035.16	90653.81	1386.99	5768.34	4381.35
27/09/01	88380.20	91262.78	89278.02	84709.68	1984.76	6553.09	4568.33
28/09/01	66597.66	69382.87	70555.92	64449.71	-1173.05	4933.17	6106.22
29/09/01	89135.11	95325.85	92204.73	91222.59	3121.12	4103.25	982.13
30/09/01	90590.62	93810.44	90662.08	92427.06	3148.36	1383.38	-1764.98
01/10/01	90245.49	95098.01	90604.90	92592.53	4493.11	2505.49	-1987.62
02/10/01	93116.71	93542.86	91471.90	91706.00	2070.96	1836.86	-234.10
03/10/01	91681.64	93488.55	90421.39	91720.11	3067.16	1768.44	-1298.72
04/10/01	88380.20	93304.72	90528.78	88343.63	2775.95	4961.09	2185.14
05/10/01	66597.66	67513.00	67386.37	64203.09	126.62	3309.90	3183.28
06/10/01	89135.11	90667.19	89091.16	89755.27	1576.04	911.93	-664.11
07/10/01	90590.62	94918.77	91590.84	94407.86	3327.93	510.91	-2817.02
08/10/01	90245.49	97324.57	92554.65	93576.69	4769.91	3747.87	-1022.04
09/10/01	93116.71	97311.11	92735.07	94433.18	4576.04	2877.93	-1698.11
10/10/01	91681.64	93500.80	89075.92	91203.81	4424.89	2296.99	-2127.90
11/10/01	88380.20	92755.15	87778.17	86536.00	4976.99	6219.15	1242.16
12/10/01	66597.66	69349.60	68000.74	63874.70	1348.86	5474.90	4126.04
13/10/01	89135.11	92138.40	90532.18	90479.01	1606.22	1659.39	53.16
14/10/01	90590.62	94787.25	91676.18	92002.00	3111.08	2785.26	-325.82
15/10/01	90245.49	95962.09	93236.42	94572.11	2725.67	1389.98	-1335.69
16/10/01	93116.71	94943.28	93144.15	91948.41	1799.13	2994.86	1195.73
17/10/01	91681.64	95724.99	92085.94	92644.56	3639.05	3080.43	-558.62
18/10/01	88380.20	91390.19	88232.01	87777.00	3158.18	3613.19	455.01
19/10/01	66597.66	68402.10	66806.99	65969.23	1595.11	2432.87	837.76
20/10/01	89135.11	94067.27	90850.10	90799.87	3217.16	3267.40	50.24
21/10/01	90590.62	93717.19	92139.15	92299.94	1578.04	1417.25	-160.79
Total	2528124.85	2636764.49	2560955.64	2543371.99	77386.90	94809.76	17422.86

Table 6.6: Daily savings results for November 2001 at Kopanang

Graphical representations of the average weekday profiles are shown in *Figure 6.19*, *Figure 6.20* and *Figure 6.21*. It can be seen that not all the required load was shifted during the peak price periods of the day especially between 18:00 and 19:00. This is largely due to the refrigeration plant and BAC's.

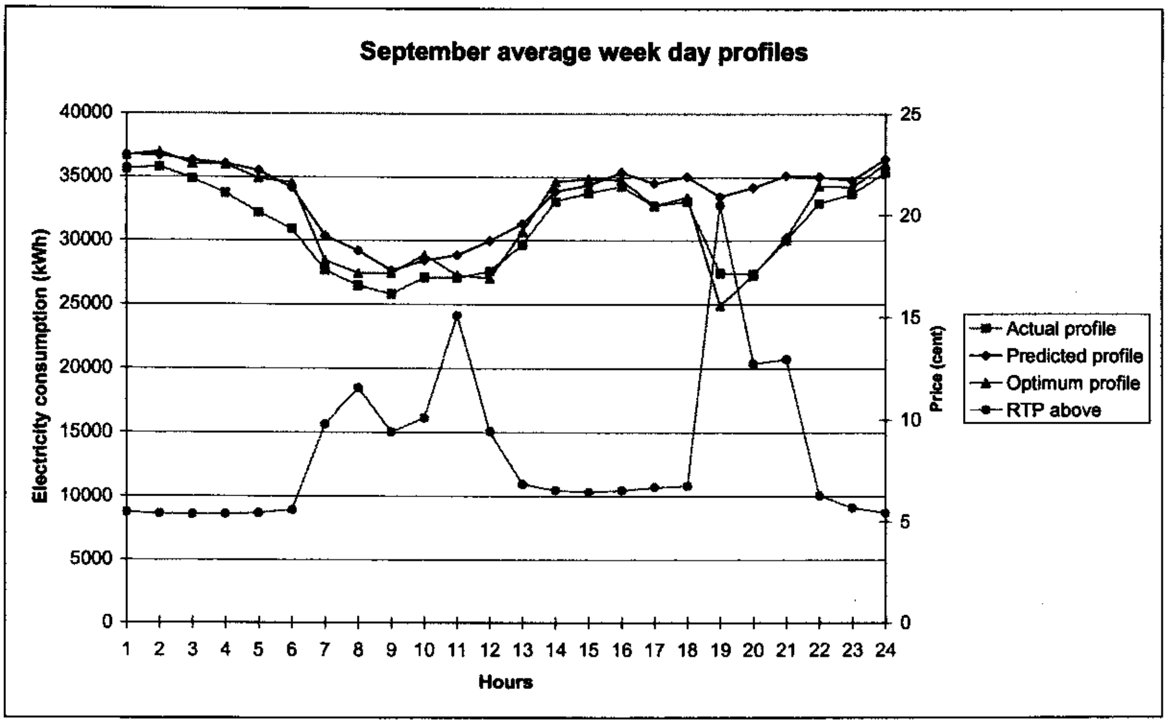


Figure 6.19: Average week day demand profiles September 2001 at Kopanang

The biggest unrealised potential during October occurred between 18:00 and 20:00. This was still due to problems controlling the refrigeration plants as well as not pumping enough water in the early morning hours causing one pump to be turned on during this time.

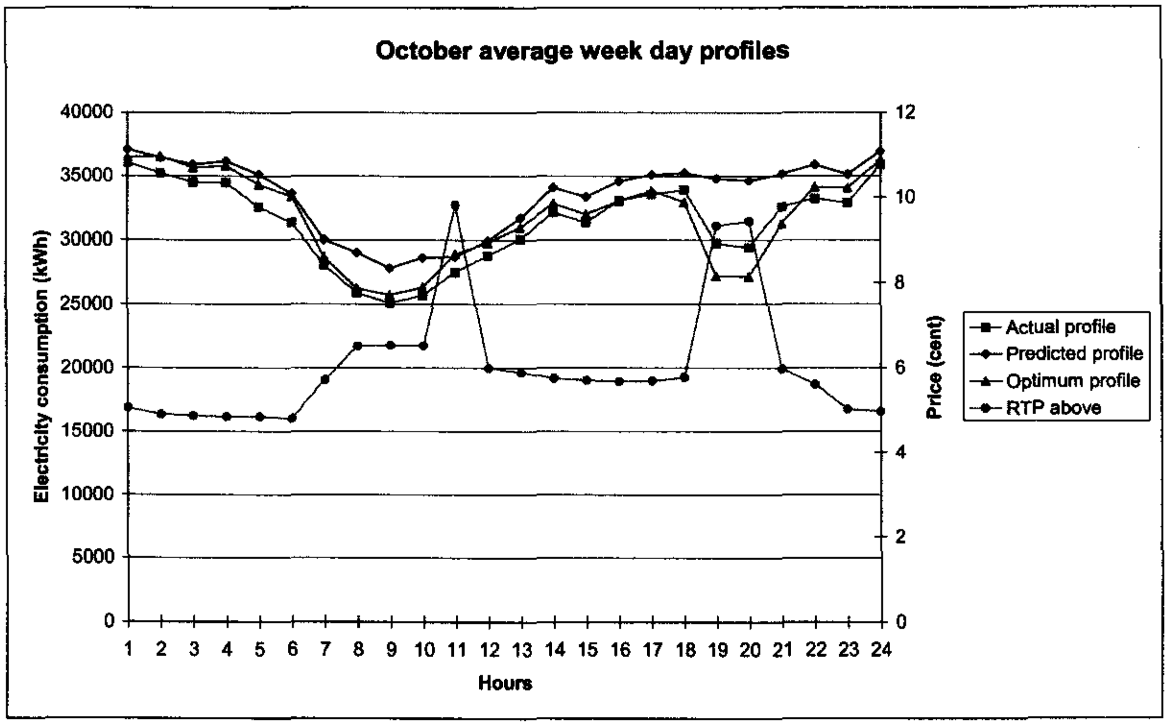


Figure 6.20: Average week day demand profiles October 2001 at Kopanang

During November the response during the morning peak period was exceptional. The response during the early morning peak hours still needs some attention as this causes forced deviations during the evening peak period. The unrealised potential is not that great due to the flatter price tariff as we go into the summer months.

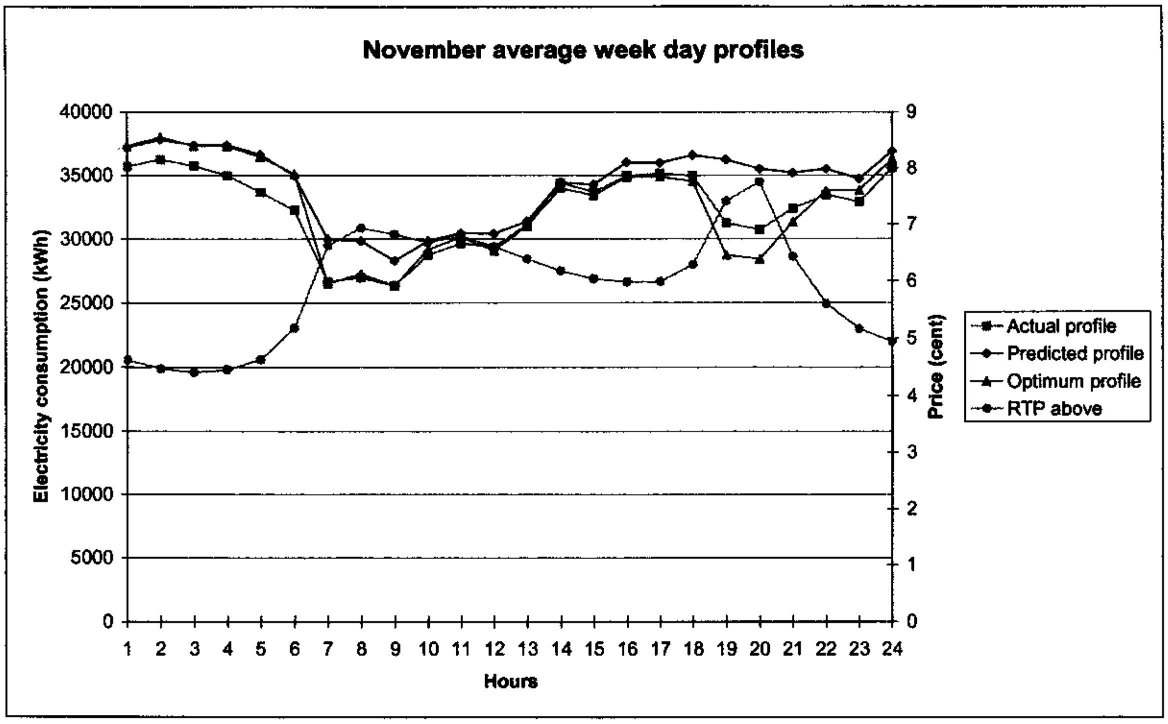


Figure 6.21: Average week day demand profiles November 2001 at Kopanang

6.5 Conclusion

6.5.1 Summary

Meetings with the three mines' management were held after the completion of the preliminary study. In these meetings the proposed strategies and saving potential were discussed. The implementation of these strategies for a trial period of three months was also discussed. Amandelbult felt that the risk was too great to be one of the first mines to implement the proposed strategies.

Target had the same basic feeling but proposed that we rather run the optimisation concurrently with the current operating system and then compare electricity costs on a monthly basis for three months. This is however still a theoretical comparison and not an actual implementation.

Kopanang was very impressed with the available savings and decided to implement the strategies on a manual control basis for three months after which the success of the strategies will be discussed and a final decision on automatic control implementation of the strategies will be made.

The implementation consists basically of a daily service providing the mine operators with an hourly operating schedule. The infrastructure requirements were minimal for the implementation. It consisted of only two phone lines as well as a modem. On the software side a small program was added to the current SCADA system to display the operating schedule and any deviations from it. This program also stored the required condition data for the calibrations and reports.

This data was used to calculate the actual savings as well as to monitor the control response to the operating schedules supplied daily.

A load prediction model was required to simulate the electricity demand according to the previous operating strategies as a function of the RTP price and climate conditions. This model was within 1% of the total measured electricity cost for the year 2000.

The predicted, measured and optimised cost was compared for each of the months to calculate the actual saving achieved during the trial period as seen in *Table 6.7*.

	Actual saving	**Unrealised saving**	**Total possible saving**
Sep-01	188808.5	214000.79	402809.29
Oct-01	69250.83	41677.45	110928.28
Nov-01	77386.8	17422.86	94809.66
	335446.13	273101.1	608547.23

Table 6.7: Summarised measured savings

All these findings were summarised in one report for every month that was presented to the mine's representatives at the end of each month.

6.5.2 Recommendations

After this phase of the project an implementation strategy must be setup to assist in future DSM projects on mines (chapter 7). Lastly the national impact of the implementation of DSM strategies on mine underground services must be assessed (chapter 8).

CHAPTER 7.

MINE DSM IMPLEMENTATION STRATEGY

The experience gained in the implementation is summarised in this chapter. A proposed implementation procedure is also discussed.

7 MINE DSM IMPLEMENTATION STRATEGY

7.1 Electricity management

Electricity management is an integrated process of managing different aspects contributing to electricity consumption. This may include load shifting as a tool for achieving more effective management. Electricity management takes the following points into consideration:

- Effective electricity use;
- Optimal electricity consumption;
- Maintenance and maintenance management;
- Demand side management;
- Operational and administrative management;
- New technologies;
- Safety;
- New legislation and regulatory activities.

From an organisational point of view, to be effective as an electricity management component within a business or mine, the component must be given the same emphasis as the management of any other cost/profit centre. In this regard, the functions of top management are as follows [17]:

- Establish the electricity cost/profit centre, in this case the VCP systems;
- Assign management responsibility for the program;
- Hire or assign an electricity manager. This step may also include an electricity consultant;
- Allocate resources;
- Ensure that the electricity management program is clearly communicated to all departments to provide necessary support for achieving effective results;
- Monitor the cost-effectiveness of the program;
- Clearly set the program goals;
- Encourage ownership of the program at the lowest possible level in the organisation;
- Set up an ongoing reporting and analysis procedure to monitor the electricity management program.

It is the task of electricity management to minimise the cost of electricity while ensuring satisfactory operating conditions. This means that the cost/profit centre has to be as electricity effective and efficient as possible. Electricity management can either save electricity through various methods or save money by managing electricity effectively. The ideal is if electricity and money could be saved. This will profit the company (Mine) financially and the environment because of the lower demand for electricity that will cause less burning of coal and reduced CO_2 emissions.

An effective electricity management program requires that the manager acts according to changes and cost signals and be held accountable for those actions. If it is not possible to add a full-time, first-line manager to the staff, an existing employee, preferably with a technical background, should be considered for either a full- or part-time position. This person must be trained to organise an electricity management program. Electricity management should not be an alternate or collateral duty of an employee who is already fully occupied.

The success of an electricity management program depends on the interests and motivation of the people implementing it [18]. Participation and communication are key points. Employees can be motivated to support an electricity management program through awareness of the following:

- Amount of electricity they use;
- Cost of electricity;
- Critical role of electricity in the continued viability of their jobs;
- Meaning of electricity saving in their operations;
- Relationship between production rate and electricity consumption;
- Benefits of participation, such as better working conditions and improved profitability.

Simulation and optimisation tools, in the hands of specialised consulting engineers, can greatly assist management to determine the best course of action with changing inputs. The VCP can be managed on a daily basis for the best possible electricity consumption, given certain boundaries like tariff, climate and production schedules. Demand Side Management (DSM) can be incorporated in the management strategy without endangering lives or incurring a loss of production.

With optimisation and simulation any constraint can be simulated and the best possible result obtained for electricity conservation. Software can form the basis of an electricity management program and can be integral in the whole electricity management process. Its can be used by specialised electricity consultants to provide the mine with a service to help achieve the goal of an electricity efficient and environmental friendly mine.

With the advent of modern technology, electricity management doesn't have to be an on-site exercise. More and more institutions are moving towards remote electricity management systems (REMS). In REMS the management team or electricity consultant can control the activity of the system remotely via computers and modems. This allows the team or consultant the ability to provide a more dynamic service and the capability to take on more projects.

7.2 Electricity efficiency

When looking to save electricity in a system, one has to look at the electricity efficiency of a system. This means, looking at a system and determining whether the system is using its electricity resources effectively. Many systems supply more than what is needed. In practice it is typical during the design stage to specify equipment larger than needed to provide for extreme conditions. This provides a certain safety factor in the system. A chiller may have double the cooling capacity than what is required for the average day operations.

Most of the times the system isn't used to full capacity, causing equipment to run at lower efficiencies. Or too much electricity is wasted on equipment and services that offer little to no tangible effect on the system. Electricity efficiency, as part of a DSM program, aims to decrease the total amount of electricity used (Area under load curve, measured in kWh), while still maintaining the integrity of the service the system has to provide.

In the mining industry there are specific demands on the VCP systems. A certain amount of cold water must be supplied to the underground operations. This means a set amount of electricity is needed to cool the water down. The amount of water is non-negotiable, which means little can be done to decrease the amount of electricity used to cool the water.

A few options can be implemented to improve efficiency like:

- Ensuring the thermal losses and leakages in the system are kept to a minimum;
- Using the lower ambient temperatures during the cooler times of the day to assist the cooling process. This helps to make the cooling towers and bulk-air coolers more effective;
- Installing newer and more electricity efficient equipment (High capital costs);
- Optimised scheduling of equipment to ensure that the minimum electricity is used to perform the same task at the right time of the day.

In the mining sector little effect can be achieved through scheduling and other low capital cost efforts. This means little electricity savings can be achieved without some major changes to the system through buying new equipment. A far bigger potential lies in the load management or load shifting options that the mines possess due to thermal storage.

7.3 Load shifting

In most industries, including mining, the electrical load profile consists of a static or base load and a dynamic or controllable load part. Little can be done about the base load for it usually includes basic and fundamental electricity usage from key areas in the industry like production. It takes a big effort at great cost to change this load profile, although wastage is often included in this load, such as leaking pipes or pumps and fans operating unnecessarily.

The controllable parts of the load profile are systems that can be turned off without directly affecting production and other key areas. Complete controls over these controllable systems are available to operators within limits. Some systems can be switched off for only a certain period of time.

Load shifting refers to the ability to shift part or the entire controllable load in an industry or mine. The reason for shifting load is to move a load from a more expensive electricity rate period to a period of cheaper rates. Because of the drive towards more cost-reflective tariffs, this will become a more important consideration that mines will have to take.

It is important to note that load shifting is not a saving in the amount of electricity used but only a shift from an expensive rate period to a less expensive period. Because of this shift a higher demand will be experienced at another time and may cause a higher peak demand. One has to make sure that this higher demand doesn't cost more than the saving achieved through load shifting.

The potential for load shifting is dependent on the capacity of the system to store thermal or electrical load in some form during low rate periods and releasing it during the high rate periods. These storage systems can be thermal water storage or electrical capacitors. The ability to produce the needed services before and after the low tariff period is another important constraint that has to be considered.

Before the low rate period the system will, for instance, have to warm up more water to ensure the availability of warm water during the high rate period. This in turn causes the higher electricity demand in the low rate period that the system will have to be capable of delivering. If the equipment cannot deliver the extra capacity, then load shifting is not possible. Many mines operate to their full capacity and do not have the ability, due to equipment and storage constraints, to deliver extra capacity during low cost periods.

This aspect of load shifting was investigated in a couple of mines, including both a gold and a platinum mine [19][20]. Only the potential was determined in these mines. The financial possibilities were discussed in [21]. The potential of electricity savings due to the implementation of DSM strategies on the underground cooling systems is also discussed in this report.

7.4 Implementation procedure

Once the potential of electricity conservation in a mine has been determined and the potential outweighs the risks for the mine and electricity consultants, the new electricity management system can be implemented. It is important that all the controlling activities and processes, needed for successful electricity management, are put into place. Make sure that there is a person responsible on site for the program that can be held accountable for problems and that can advise on changes in the system.

There are basically six stages in implementing an electricity management program [17]:

1. Develop a thorough understanding of how the systems work and the electricity is used;

2. Conduct a planned, comprehensive walkthrough audit to identify all potential opportunities for electricity savings;
3. Determine and clearly specify the electricity and cost savings analysis methods to be used. All participating parties must agree on the method of calculating the savings to prevent future problems when payment or performance evaluations are made [22];
4. Identify, analyse, acquire, allocate and prioritise the resources necessary to implement electricity conservation opportunities (ECO's). This step is designed to ensure that the best people are available for the project and that the implementation doesn't interfere with production or safety;
5. Determine the financing responsibilities of the implementation and specify responsibilities and ownership of the implementation and equipment. DSM programs run by utilities, like ESKOM, can potentially be used to help finance the capital costs of an electricity management program;
6. Implement the ECO in a rational order. This is usually a series of independent activities that can take place over a period of time, depending on the scope of the implementation. If a mine doesn't have a monitoring system on their VCP system, this has to be installed. Then a central control centre has to be established;
7. Monitor and maintain electricity conservation measures taken. Systems, equipment, production and goals may change over time. This step is needed to maintain and update the electricity management system to ensure optimal savings throughout the project life. Monitoring and control can be done with monitoring system (like SCADA) and can also be done remotely.

A typical implementation activity procedure, with REMS included, can be seen in *Table 7.1*. REMS stand for Remote Electricity Management System with REMS.exe the user interface and software on the SCADA system. SCADA is a monitoring system that incorporates different measurements, like electricity, temperatures, flows, dam levels, etc. and it has the ability to control equipment.

Establish modem access	1 day (on site)
Develop interface and algorithms	1 week
Link REMS interface to SCADA feedback	1 week (on site)
Implement control hardware	1 week
Link SCADA to REMS control signals	1 week (on site)
Test phase	1 month
Sign service agreement	Before end of test month
Continue with service	3 month notice

Table 7.1: Implementation schedule for mine

Figure 7.1 shows the flow of information in the implemented mine. The information is sent from the remote computer to the mine where the schedule is interpreted by the SCADA system. Signals can then be sent to the equipment and its operating status (on or off) can then be changed.

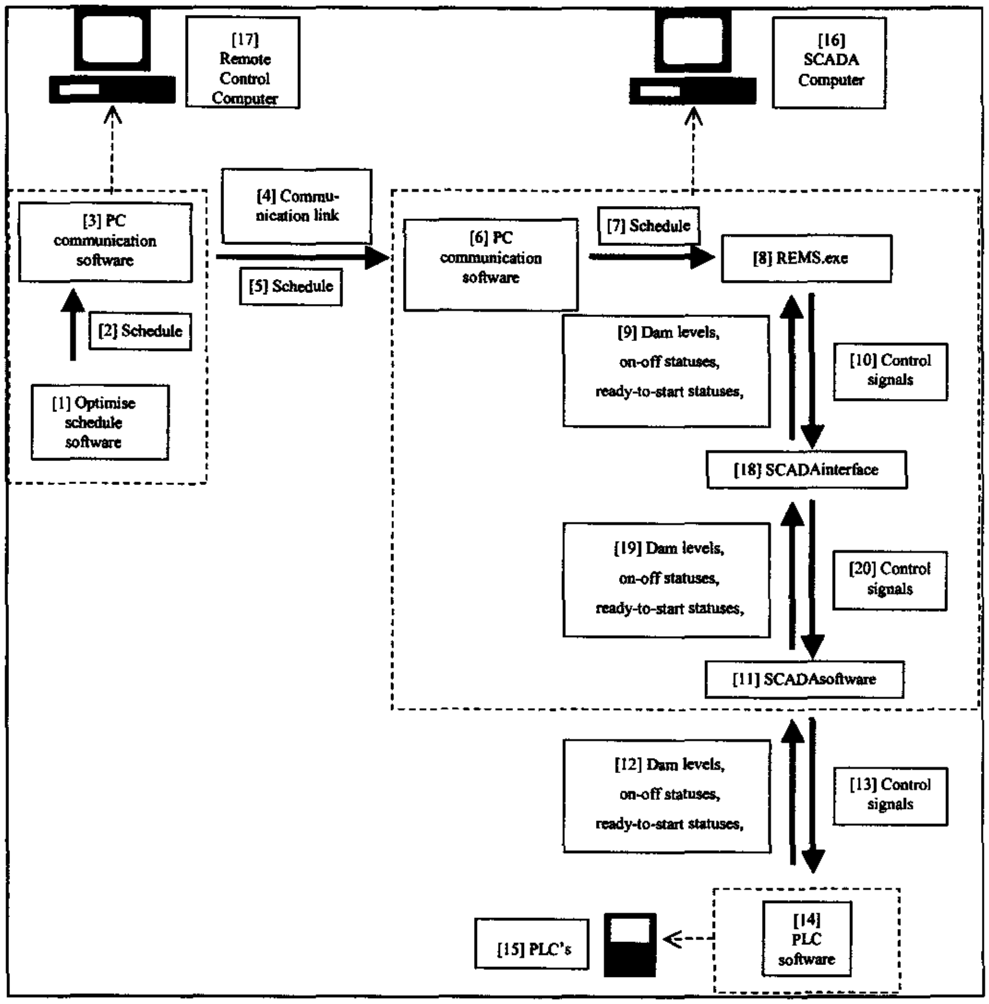


Figure 7.1: Schematic diagram of information flow of REMS

A test phase is an important and good method of determining savings before the actual business and savings contract is signed. The method of saving can be tested and proven for all parties involved. The continued monitoring and maintaining of system can include further testing phases to ensure that savings still occur and that the system is being operated correctly.

The U.S. Department of Electricity has invested a lot of money, time and human resources to establish a Measurement and Verification protocol [23]. Though this may be different for South Africa and the mining industry, some of the measures and procedures can be of great value when trying to standardise Measurement and Verification protocols to establish the savings obtained in an electricity management program.

7.5 Identified problems and experience gained

In all the case studies some form of monetary savings was possible in the mines but not all the mines were interested in implementing the new systems. The following is a list of some of the problems experienced in dealing with mines:

- *Information:* By far the biggest problem when dealing with mines is the gathering of information. It is not that the people are overly reluctant to give the information; it is more that finding the person to get the information from is a problem. And more often than not it takes a long time and a lot of effort to obtain the information;
- *Conservative attitudes:* In many of the mines where a rather substantial saving is possible, they are too conservative to take the risk. The risk factor can be determined by the mine, but still they are resistant. This risk has to do with the risk of loss in production and risk to safety due to possible breakdowns in the ventilation and cooling system. In many cases this is purely because of resistance to change;
- *Incentive:* Even though the savings potential is quite high, for the mine the amount of money saved is just not substantial enough compared to their other expenses and turn-over. If their electricity bill became a more substantive part of their expenses, then they would probably be more open for this type of electricity management;
- *Mining hierarchy:* All mines have some sort of hierarchy. The best place to

start selling electricity management is at the top. If one doesn't start high enough the project usually comes to an end in the lower ranks of the hierarchy. This is mainly due to the fact that the lower order managers or engineers don't always see the advantages of such a service and only see the technical and social problems. Top management has the long-term vision and they are the people that have to sign the cheque in the end.

Despite some problems that were experienced, many people were excited about the whole concept. Possibly, with incentives from ESKOM's DSM project, more mines will be willing to open their doors and their minds to electricity management.

7.6 Conclusion

7.6.1 Summary

In a country where there are definite and substantial peak demands on the electricity grid and electricity tariffs are moving towards being more cost reflective, one of the best ways for companies to minimise their electricity costs is through proper electricity management. Proper EM also gives the company or mine the opportunity to contribute positively to the country's physical environment and possible reduce carbon emissions.

Three case studies are mentioned in this chapter. Two are gold mines and the other is a platinum mine. These mines have the combined potential of shifting some 54MW during a typical week day in summer and 61MW in winter with the proper electricity management applied to them. Well-defined methods and implementation strategies are essential to achieve the full potential in these mines, along with management maintenance to ensure a continuous and sustainable monetary saving.

Progressing from determining the potential and actually implementing it is not always that simple. Some mines are resistant to the idea of electricity management by outside companies. Where the system was implemented great success was achieved. The positive effect of electricity management can be clearly seen in the savings and the risk-free applications of the schedules are evident. An added bonus is that the mines now have tighter control over their electricity expenses.

7.6.2 Recommendations

A few things still have to change in the country, like more cost-reflective electricity prices, before the opportunities offered by electricity management can be fully explored. Government policy and new ESKOM DSM strategies can greatly improve the situation and give incentives for both mining companies and electricity consultants.

This methodology needs to be put into practice to ensure that the potential impact discussed in chapter 8 can be achieved for the benefit of ESKOM and their customers.

CHAPTER 8.

POTENTIAL FINANCIAL AND ELECTRICAL IMPACT ON SOUTH AFRICA

In this chapter the findings of this study are extrapolated to calculate the national financial, economical and environmental impact on South Africa. This chapter summarises the essence of this thesis.

8 POTENTIAL FINANCIAL AND ELECTRICAL IMPACT ON SOUTH AFRICA

8.1 Financial impact on mines

8.1.1 Background

In the previous chapters the development of the simulation models, the verification thereof and the implementation of the electricity management system were discussed. The question now is what impact and advantages proper electricity management can have on the entire mining community in South Africa. What is the quantitative gain that the mining community will experience through electricity management?

The DSM potential was identified in a variety of mines. When looking at the three mines studied in this project, two gold mines and one platinum mine, they have a combined potential of shifting some 54MW during a typical week day in summer and 61MW in winter. This, if managed correctly, has the financial potential of saving these mines up to R 6.1million per year. But this is not the full picture.

There are a few questions that a mine will ask before implementing a DSM program with electricity management. The most important elements that will influence the decision of a mine to implement DSM strategies with load shifting are as follows:

1. Cost of implementation;
2. Additional cost in maintenance;
3. Potential savings;
4. Pay-back on capital expenditure, taking maintenance into account;
5. Current and future electricity pricing structures;
6. Risks involved for the safety of the staff and possible losses in production;
7. Acceptance of the staff of the new approach to plant operations.

8.1.2 Kopanang

Table 8.1 shows a quick cash-flow analysis of Kopanang, based on current cash flows where interest and inflation were ignored. The cash flow is done over a period of five years. This was for managing the load in such a way to best suit the tariffs available. The cash flow, showing the capital, operating and maintenance costs are for the additional costs caused by the saving.

Capital Cost	-50000	0	0	0	0
Operating cost	-40000	-40000	-40000	-40000	-40000
Maintenance and Spare parts	-100000	-100000	-100000	-100000	-100000
Saving in Electricity	1470000	1470000	1470000	1470000	1470000
Net Cash Flow	**1280000**	**1330000**	**1330000**	**1330000**	**1330000**

Table 8.1: Cash-flow analysis of Kopanang

Not all the mines have the same level of savings potential and they don't necessarily have a well installed measuring and monitoring system.

8.1.3 Target

Table 8.2 shows Target's cash-flow analysis where there is a lot of additional control and measuring infrastructure required for some of the proposed strategies. The introduction of variable speed drives will also have a considerable impact on the current maintenance costs of Target.

Capital Cost	-1500000	0	0	0	0
Operating cost	-50000	-50000	-50000	-50000	-50000
Maintenance and Spare parts	-250000	-250000	-250000	-250000	-250000
Saving in Electricity	2550000	2550000	2550000	2550000	2550000
Net Cash Flow	**750000**	**2250000**	**2250000**	**2250000**	**2250000**

Table 8.2: Cash-flow analysis of Target

8.1.4 Amandelbult

Amandelbult is one of the mines where the savings potential is not huge and a substantial amount of infrastructure is required to effectively implement the proposed strategies.

Capital Cost	-1000000	0	0	0	0
Operating cost	-50000	-50000	-50000	-50000	-50000
Maintenance and Spare parts	-100000	-100000	-100000	-100000	-100000
Saving in Electricity	1500000	1500000	1500000	1500000	1500000
Net Cash Flow	**350000**	**1350000**	**1350000**	**1350000**	**1350000**

Table 8.3: Cash-flow analysis of Amandelbult

The cash-flow analysis in *Table 8.3* still shows an acceptable net cash-flow even when considering the additional capital and inferred costs.

8.2 Electrical impact on South Africa

8.2.1 Background

From the three mines mentioned in the previous section it is clear that there is great potential for Demand Side Management. This is important for the country's DSM programs and the whole electricity supply picture. If all the mines in South Africa were capable of delivering such potential, then the whole country could gain from it financially, environmentally and in the supply side of electricity.

The country's total electricity sales for 1999 were 172.56 TWh (Without the sales in respect of Department of Water Affairs and Forestry (DWAF)) [25]. This figure rose to 181.511TWh in 2001 (With sales to DWAF) [26]. Of this figure the mining sector contributed 18.4 % or some 31.92 TWh at an average load of 3.64 GW. This constituted electricity sales of R 4.26 billion for 2001. This is an increase of 5.1% from 2000 and the average price went up 3.4% to 13.35 c/kWh in 2001 from 2000.

8.2.2 Calculation

Taking the potential determined in the case study mines and incorporating other mining electricity use and VCP data, a national load shift potential can be determined. It was found that gold mining constitutes 18% of the industrial electricity consumption [27] or two-thirds of the mining sectors electricity consumption. The rest of the mining industry consumes 9% of the mining electricity consumption.

The following assumptions were made for the determination of the national potential:

- That the average load shift potential found in the case studies can be used as a benchmark for the national potential;
- That the potential for load shifting in the gold mining industry is 36.32% of the demand (Based on case studies);
- The potential for load shifting in the platinum mining industry is 41.67% of the demand (Based on case studies);
- Platinum mining constitute 50% of the rest of the mining industry's electricity consumption without gold mining. This means that platinum consumes 4.5% of the industry's electricity;
- That only half the mines, gold and platinum, will be capable of shifting the equivalent load as the case study mines. This is assumed on the basis that

the case study mines are deeper than most mines and consume a larger than average amount of electricity. The average VCP consumption of mines is 25%. In the case study mines this figure was above 40%;

- That the national average demand, based on the latest national electricity consumption in the mining industry, can be used as a basis for calculating the load shift potential.

The load shift potential can be calculated as follow:

$$LS = ANMD * \left(\frac{2}{3} * 0.5 * CSGP + \frac{1}{3} * 0.5 * 0.5 * CSPP \right) \quad \text{(2)}$$

LS: Load Shift (GW);

ANMD: Average National Mining Demand (GW);

CSGP: Case Study Gold Potential (%);

CSPP: Case Study Platinum Potential (%).

8.2.3 Results

A measured potential of the case study mines were extrapolated with a model based on data from a previous study. The extrapolated load shift potential was found to be 500 MW [2]. With (2) the revised potential is found to be 658.23 MW. Two different models were used and the results are considerably more for this case study due to the inclusion of DSM on the VCP systems in this study and only SSM strategies in [2]. For the sake of simplification the load shift potential will be taken as 650 MW.

This potential is a virtual power station that can be used during peak demand periods. This is also approximately the figure that ESKOM has in mind for their industrial and commercial DSM program by 2020 (535 MW), and this is only in the mining sector [28]. Much more can be achieved in the entire industrial and commercial sector.

But this is only for the current situation. It is obvious that there is great national electricity potential with the use of electricity management. It is of interest to look at the impact that this may have on the future electricity situation. ESKOM is currently analysing alternative scenarios for the next 25 years and what is needed to maintain the integrity of electricity supply end use and customer satisfaction.

It is expected that the peak demand will be more than the peak supply by 2007 if nothing is done to change the situation [29]. The current load capacity of the system is 39.81 GW. The aim of ESKOM and the whole DSM drive is to push this break point (end of capacity) to 2015 [29].

The projected peak demands can be seen in *Figure 8.1* [28]. This shows a drastic forecasted increase in the peak demands by 2015. The expected average peak demand will be about 44.50 GW by 2015, compared to its current average peak in winter of about 26 GW. The increase is about 18 GW over the next 14 years (A 70% increase in average demand). This will mean that ESKOM will have to increase its average supply capacity by at least 4,69GW or 11.9% to meet the average peak demands in winter. The maximum peak demand can be as much as 18% higher than the average demand. This means that ESKOM will have to be able to supply at least 52.5 GW (32% more than current capacity)

It is clear that ESKOM with its DSM program will not be able to outbalance the total peak demand increase. ESKOM is aiming at deferring some 3.67 GW by means of a variety of DSM programs, which will still mean a deficit of some 14 GW. *Table 8.4* shows a projection of how ESKOM proposes to implement its DSM programs for different penetration scenarios [28]. With proper electricity management some 650 MW (3.6 % of the forecasted increase of 18 GW) can be moved in the mining sector alone.

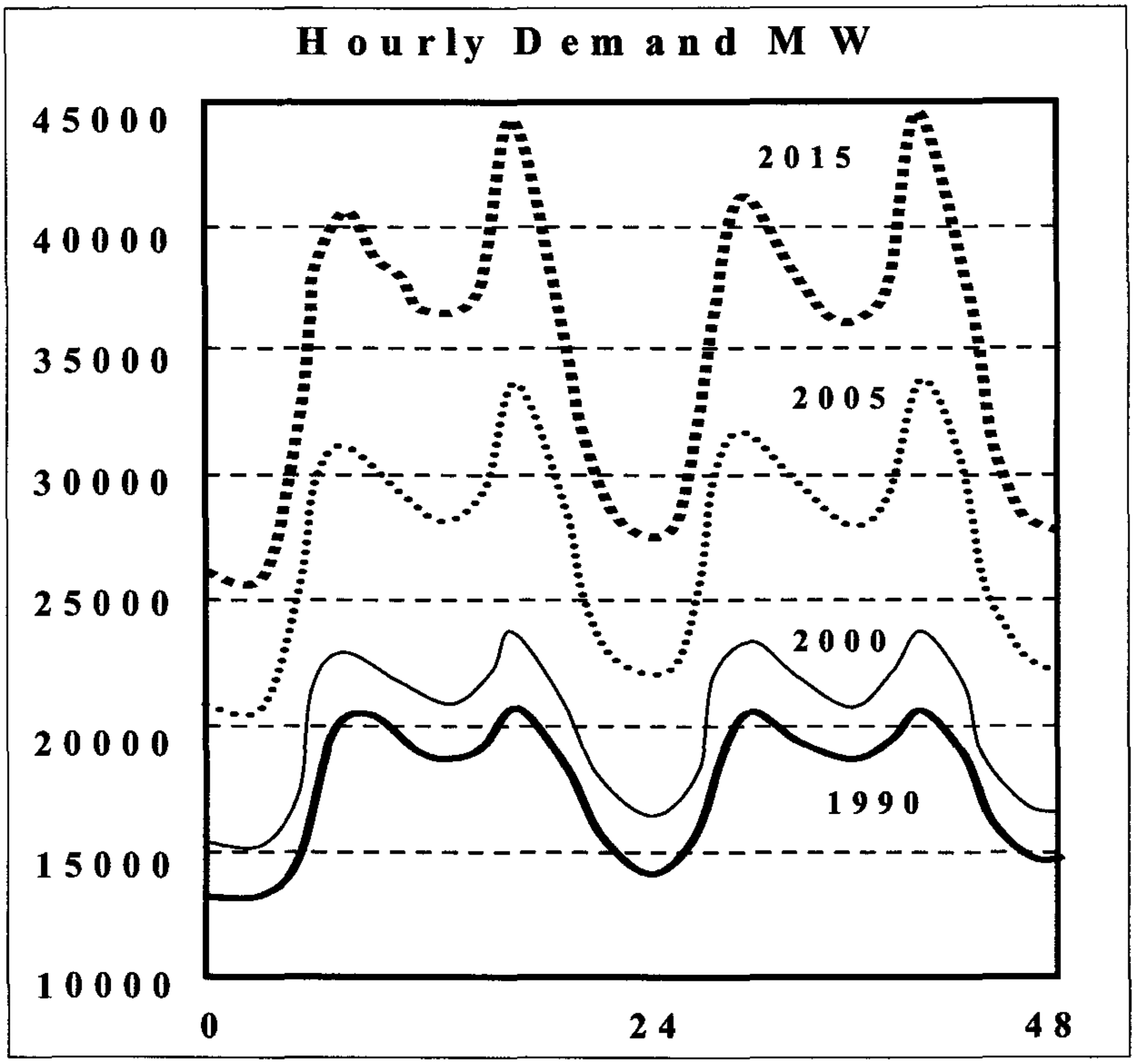


Figure 8.1: Typical average 48-hour winter demand forecast

	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
ICEE (MW)	567	878	889	1270	890	1270
REE (MW)	171	514	537	930	537	930
ICLM (MW)	355	444	428	535	510	535
RLM (MW)	222	735	443	936	669	936
Total (MW)	**1315**	**2571**	**2297**	**3671**	**2607**	**3671**

Table 8.4: ESKOM's projected DSM penetration scenarios

***ICEE*:**	Industrial and commercial electricity efficiency (35% of DSM program by 2020 at high penetration);
***REE*:**	Residential electricity efficiency (25%);
ICLM:	Industrial and commercial load management (15%);
***RLM*:**	Residential load management (25%).

With the associated price increases to be expected with these high demands, this potential can have a major financial impact on the South African economy.

8.3 Financial impact for South Africa

8.3.1 Background

This potential of a 650 MW load shift has different implications for different stakeholders. Obviously it has substantial financial implications and advantages for the mining sector and individual companies. From the three case studies done the savings (R 6.1-million) amounted to R 111,000 per MW. If this figure is used as a benchmark for the national mining industry (An estimated 650 MW shift), the potential financial saving, with present tariffs, amounts to R72.1 million per year for the mining sector. This is a 1.7% saving in the electricity sales from ESKOM to the mining sector and 0.3% of the whole country's sales. This means R 72.1 million per year that can be taxed, improved profitability for the mines and extra dividends for shareholders. And this will have secondary benefits for the whole population as the money filters back into the economy.

8.3.2 Potential future implications

This is for the current tariffs provided by ESKOM to the mines. ESKOM's medium and long term pricing plan includes an increase corresponding to the CPI (Consumer Price Index) plus 2% per annum for the next five years, and thereafter by CPI plus

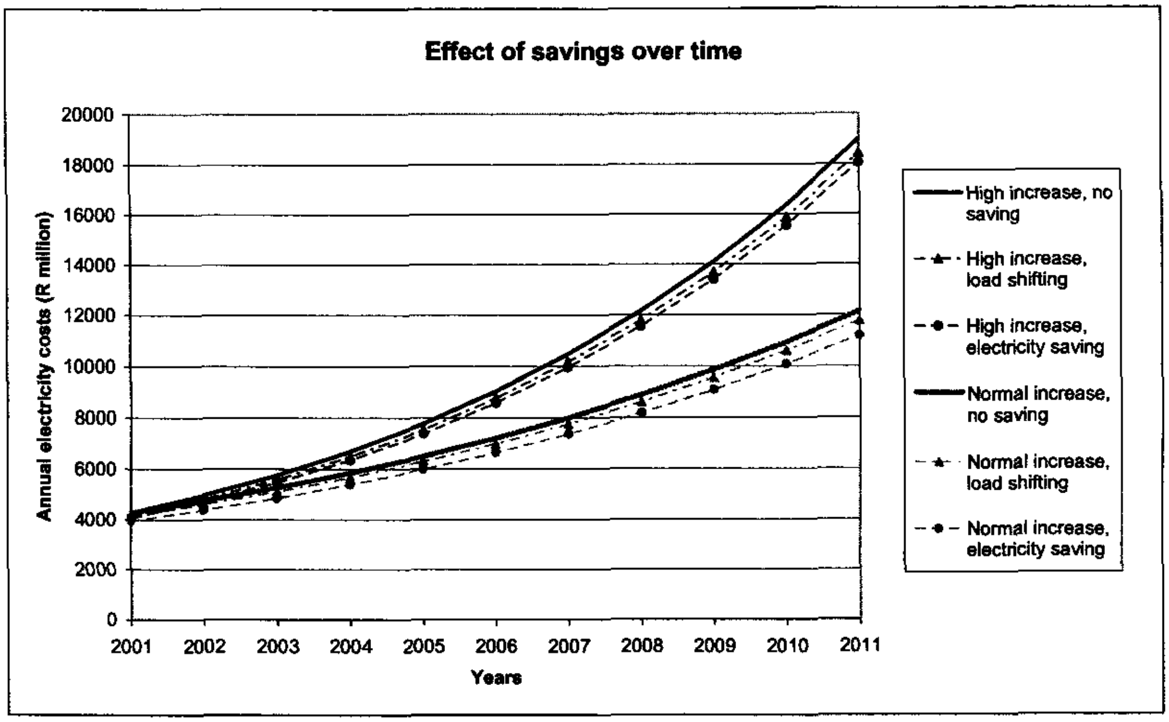


Figure 8.2: Electricity costs for mining sector, expressed in Rand-of-the-day: Without DSM savings vs. with DSM savings

The cost of building a power station with a 650 MW capacity will cost ESKOM, or any other utility in South Africa, in the order of R5000 million. A number of these power stations are needed to supply the projected additional peak demand of about 18 GW by 2025. Comparing the cost of a new power station to the loss in revenue, there can be no real question that such a loss (0.3 % in revenue) is worthwhile for ESKOM.

8.4 Environmental impact

8.4.1 Background

Another cost that is not really talked about too much is the environmental cost associated with electricity generation. In developed countries there are environmental taxes and costs to internalise the external costs of pollution and overusing resources in accordance to the Kyoto Protocol [31] [32]. For now, those costs are not applicable for developing countries, like South Africa (signed in 2002) that have to comply by 2012, but it will become a real cost that will also increase the cost of supply [34] [33].

Currently South African companies can request voluntary environmental and sustainability audits by auditing companies. Bigger companies that are listed on the stock exchange, or those wanting to be listed have to report on their non-financial matters, like environmental, social, ethical and safety issues, in their annual shareholder reports [35].

An international protocol or guideline is available and used for reporting on sustainable environmental matters namely the Sustainability Reporting Guidelines [36]. There is also a protocol aimed specifically at reporting electricity consumption, namely the Electricity Consumption Protocol [37]. This is only used to make annual reports more attractive to investors and is not something that can be used to force companies to adhere to specific costs, taxes and penalties.

In South Africa, KPMG, in conjunction with the University of Pretoria, does a yearly survey on the environmental and social reporting done by the Financial Mail's Top 100 Industrial companies, public companies and the top 48 JSE-listed mining companies. The results are published in the Survey of Environmental and Social Reporting in South Africa [38].

Some guidelines and legislation are available on the matter of environmental matters like the National Environment Management Act, the National Water Act and the Environmental Conservation Act [39] [39] *No.107 of 1998, National Environment Management Act*, Republic of South Africa Government Gazette, Vol. 401, No. 19519, Cape Town, 1998.

[40] [41]. Of these the National Environmental Management Act is the most important. It is a guideline for development that has to be socially, environmentally and economically sustainable. All these legislations only contain some governance guidelines but they do indicate that government is moving towards making companies and public sector institutions more environmentally accountable.

Utilities, like ESKOM, and all other users of electricity will have to internalise the external costs of pollution and gas emissions and this will be reflected in the price of electricity. Most of the external costs cannot be quantified precisely but have environmental and social costs attached to it. The environmental implications of using 1 kW of power are as follow [42]:

- 1.26 liters of water used;
- 0.5 kg coal burnt;
- 139.78 g ash produced;
- 0.31 g ash emitted;

- 7,91 g SO_2 emissions;
- 3,61 g NO_x emissions;
- 0.89 kg CO_2 emissions.

8.4.2 Potential future impact

Load shifting in itself does not offer opportunities to improve the environmental impact mines have. The environmental impact is directly related to the amount of electricity used and not the ability the shift load from one period to another, while the amount of electricity used remains the same.

Extrapolating the findings of the three case studies an electricity savings potential of about 5% exists in the mining sector. This computes to an electricity saving of 1.6 GW per year. The effect this has on the environment is summarised in *Table 8.5*.

Savings on:		
Water	2011	ML
Coal	798000	ton
Ash production	223089	ton
Ash emitted	495	ton
SO2 emissions	12624	ton
NOx emissions	5762	ton
CO2 emissions	1420	ton

Table 8.5: Environmental impact of the potential yearly electricity savings

8.5 Conclusion

8.5.1 Summary

An ideal opportunity exists in the mining sector to do electricity management. Considering the current tariffs available to mines, a potential of R72.1 million can be saved per year due to the ability of mines to shift 650 MW load per day as well as save up to 5% on the electricity consumption. Over time, with increasing electricity tariffs, this saving can grow to about R327 million by 2010, assuming a 15% real increase rate in electricity costs.

For the mining industry this offers great promise if used. For a supply utility like ESKOM this means loss in revenue. But ESKOM has other and much bigger questions to answer. They face an increasing peak demand that is expected to exceed the current supply capacity by 2007. This means that they must either build new power stations or create virtual power stations through load management.

The mining industry, with the help of electricity management companies and simulation tools, can provide ESKOM with one such a virtual power station of 650 MW for peak demand periods. This can save the country (for in the end the country's people will pay for it) the expense of about R5000 million for building a new power station to supply an equivalent amount of peak demand capacity.

It also helps to reduce the environmental and social costs associated with electricity consumption. A saving of 798000 ton of coal burnt and 1420 ton CO_2 emissions can be achieved through electricity savings annually.

8.5.2 Recommendations

Now that the national impact has been calculated and discussed all these findings must be used to motivate the implementation of these strategies throughout the mining sector.

CHAPTER 9.

CONCLUSION

This chapter summarises the chief findings of the thesis. Recommendations for future work are also made.

9 CONCLUSION

9.1 Summary

Three suitable mines were identified for this study using the following criteria.

- The systems and sub systems under investigation should be representative of systems found on the majority of mines. This is imperative to ensure that the results can be extrapolated to give a true reflection of the potential impact for the mining sector in South Africa
- The mine must have the potential for DSM and load shifting on underground services. These include underground pumping ventilation and cooling. These systems must have spare capacity to enable the implementation of DSM and load shifting strategies.
- The mine must be willing to implement the proposed strategies for a trial period if the predicted savings and proposed strategies warrant it.
- Be keen on the performance of the studies themselves. This pre-requisite will ensure that the study is done in the shortest possible time as input from the mine is vital during the case study.

The mines are Kopanang, Target (both gold mines), and Amandelbult (a platinum mine). At Kopanang a cost saving of R1.47 Million per year is possible according to the optimisation and simulation models. The cost savings at Amandelbult amounts to almost R62 500 on NIGHTSAVE, just over a R1 Million on MEGAFLEX. An additional R500 000 can be saved using RTP. The new DSM and load shifting strategies at Target can deliver a cost saving of almost R1.5 million on NIGHTSAVE. This figure is substantially increased on MEGAFLEX to R2.55 Million. A further increase in the cost savings can be achieved by using two-part RTP with the CBL base on the optimum MEGAFLEX profile. This further saving amounts to another R500 000.

These results were presented to the three mines to get the approval of management to implement the proposed strategies on one of the mines for a trial period of three months.

Kopanang decided to implement the strategies on a manual control basis for three months after which the success of the strategies will be discussed and a final decision on automatic control implementation of the strategies will be made.

In this three month period a total saving of approximately R335 500 was achieved. This figure correlates very well with the theoretical studies prediction of R 367 500.

An ideal opportunity exists in the mining sector to do electricity management. Considering the current tariffs available to mines, a potential of R72.1 million can be saved per year due to the ability of mines to shift 650 MW load per day as well as save up to 5% on the electricity consumption. Over time, with increasing electricity tariffs, this saving can grow to about R327 million by 2010, assuming a 15% real increase rate in electricity costs.

For the mining industry this offers great promise if used. For a supply utility like ESKOM this means loss in revenue. But ESKOM has other and much bigger questions to answer. They face an increasing peak demand that is expected to exceed the current supply capacity by 2007. This means that they must either build new power stations or create virtual power stations through load management.

The mining industry, with the help of electricity management companies and simulation tools, can provide ESKOM with one such a virtual power station of 650 MW for peak demand periods. This can save the country, for in the end the country's people will pay for it, the expense of about R5000 million for building a new power station to supply an equivalent amount of peak demand capacity.

It also helps to reduce the environmental and social costs associated with electricity consumption. A saving of 798000 ton of coal burnt and 1420 ton CO_2 emissions can be achieved through electricity savings annually.

9.2 Recommendations

Now that the national impact has been calculated and discussed all these findings must be used to motivate the implementation of these strategies throughout the mining sector. A similar project can be undertaken to look at possible DSM strategies in the industrial sector.

This might proof to be more difficult as the electricity intensive systems are mostly all linked to the final production. This as discussed previously out weighs the possible cost savings that can be achieved in the mind of management.

ESKOM and the NER will have to rethink their strategy. Through DSM and load shifting actions alone the pending electricity crisis will not be averted. ESKOM's strategy should be to postpone the building of new power stations at any cost lower than the cost of a new power station. Clearly it is not really worth all the effort needed by the mining industry to save only R72 million per year considering the risks. The new tariff structure should be one where electricity is sold below cost during times when supply outweighs the demand, yet well above cost during times of high demand. A tariff structure like this if implemented smartly will not cost ESKOM anything more yet will postpone the building of new power stations. This tariff structure will also provide huge incentive for DSM.

Another problem that must be addressed to achieve the DSM targets set for 2007 is the time that it takes to complete the study as well as the implementation time. Software can easily be created to help in the speeding up of the case study itself as the process and steps followed as well as models used are very generic at least in the gold and platinum mining sector.

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APPENDIX A

OPTIMISED AND PREVIOUS LOAD COMPARISON AT KOPANANG

In this appendix the detail results of the load comparison between the optimised load and the previous years load at Kopanang is given.

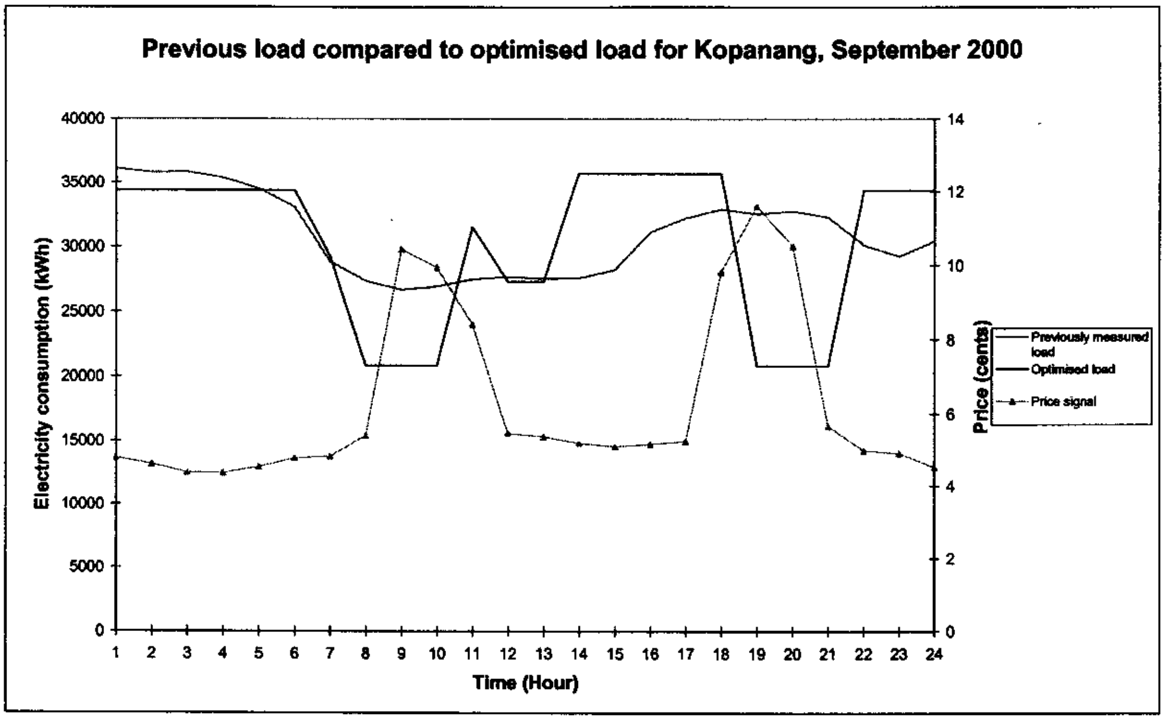

Figure A.2: Typical Saturday, Kopanang, September 2000

On a typical Saturday load can be shifted from both the morning and evening peak electricity usage periods. In total 46MW can be shifted on such a typical day seen in *Figure A.2.* On the refrigeration side a 9% electricity saving can be achieved through optimisation and delivering only the underground cooling demand.

A total of 37MW of load is shifted from the peak price periods to the cheaper late afternoon period as shown in *Figure A.3.* On the refrigeration side electricity saving of 8% is achieved.

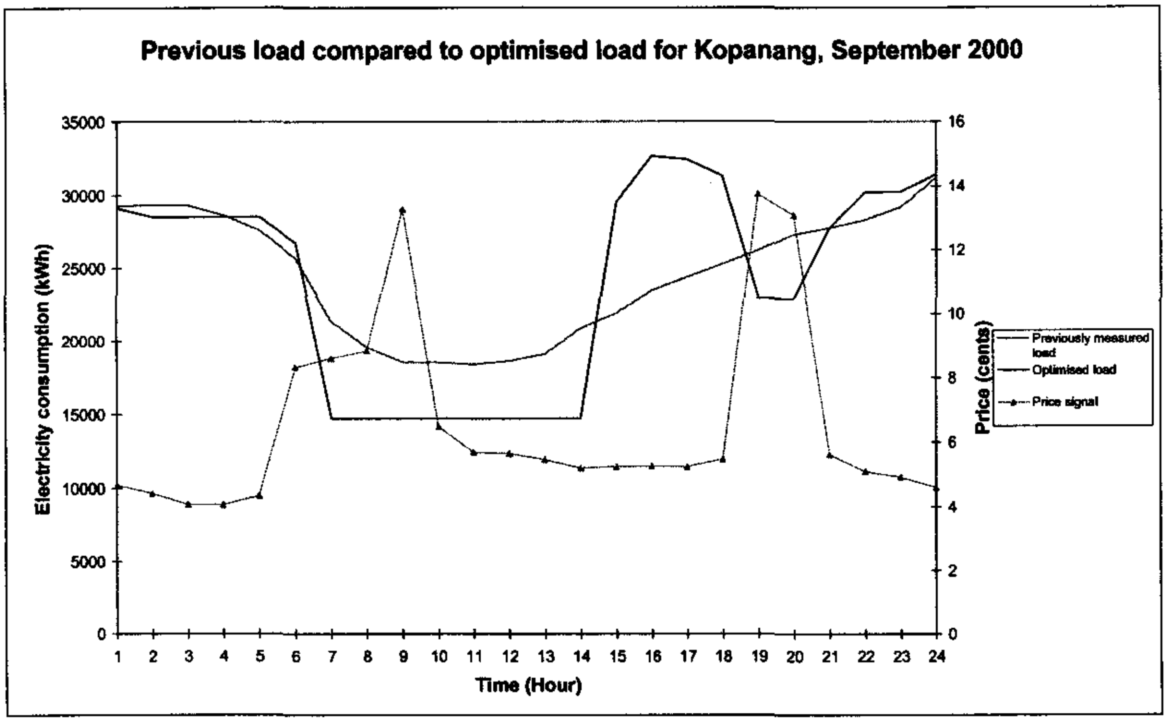

Figure A.3: Typical Sunday, Kopanang, September 2000

A.2 October, 2000

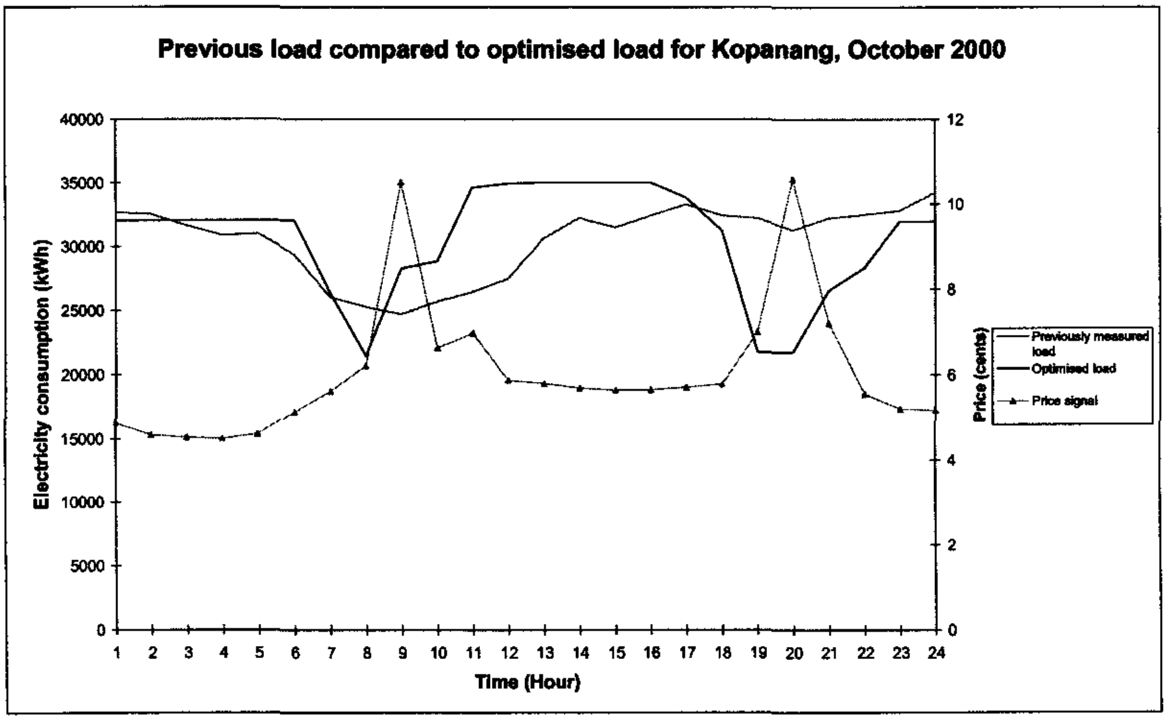

Figure A.4: Typical weekday, Kopanang, October 2000

Figure A.4 shows that a large amount of load can be shifted to the middle of the day from the peak evening period. In total 42MW electricity can be shifted on a typical weekday. 2.5% more electricity was used on the refrigeration system. After examination of the measured conditions during the month it became clear that this made sense because the operating limits as set for the optimisation were not maintained during this month.

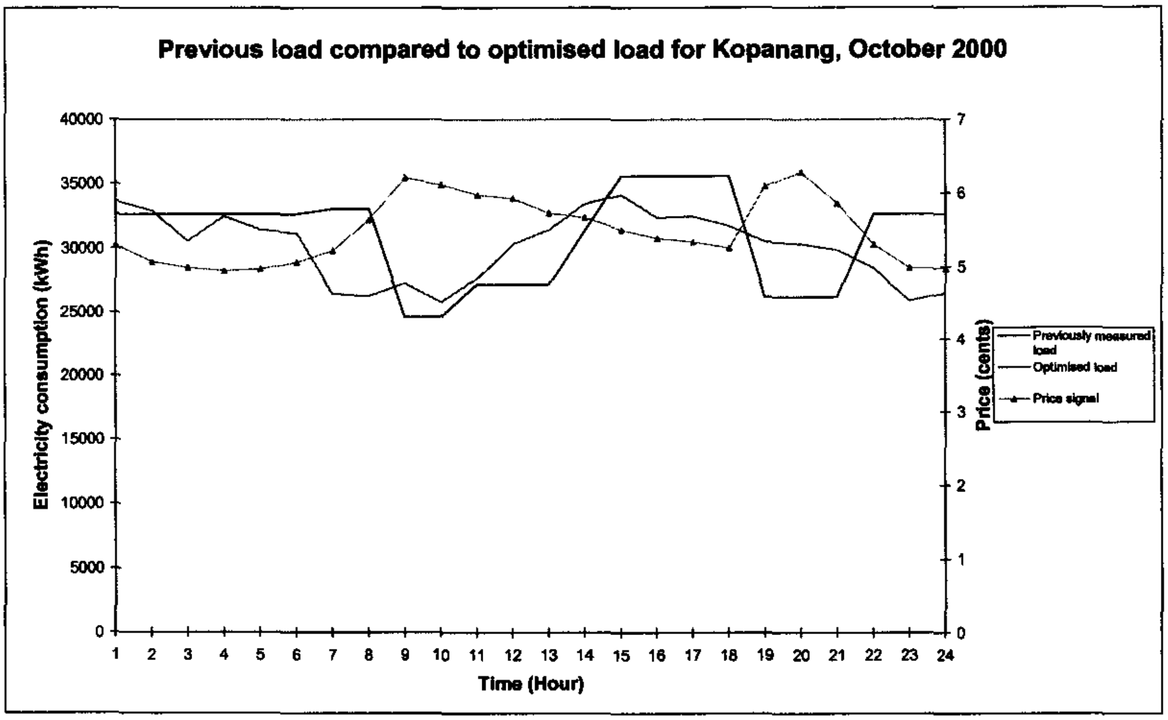

Figure A.5: Typical Saturday, Kopanang, October 2000

On a typical Saturday load can be shifted from both the evening peak electricity usage period. In total 46MW can be shifted on such a typical day seen in *Figure A.5*. On the refrigeration side 13% more electricity was used. This can be explained by the unusual high cooling demand in this month over Saturdays.

A total of 33MW of load is shifted from the peak price periods to the cheaper late afternoon period as shown in *Figure A.6*. On the refrigeration side an electricity saving of 30% is achieved this is largely due to the unusual low demand for cooling on Sundays. This is explained by the fact that the mine experimented with a new shift schedule where Saturday was a full working day and on Sunday there were no shifts until 22:00.

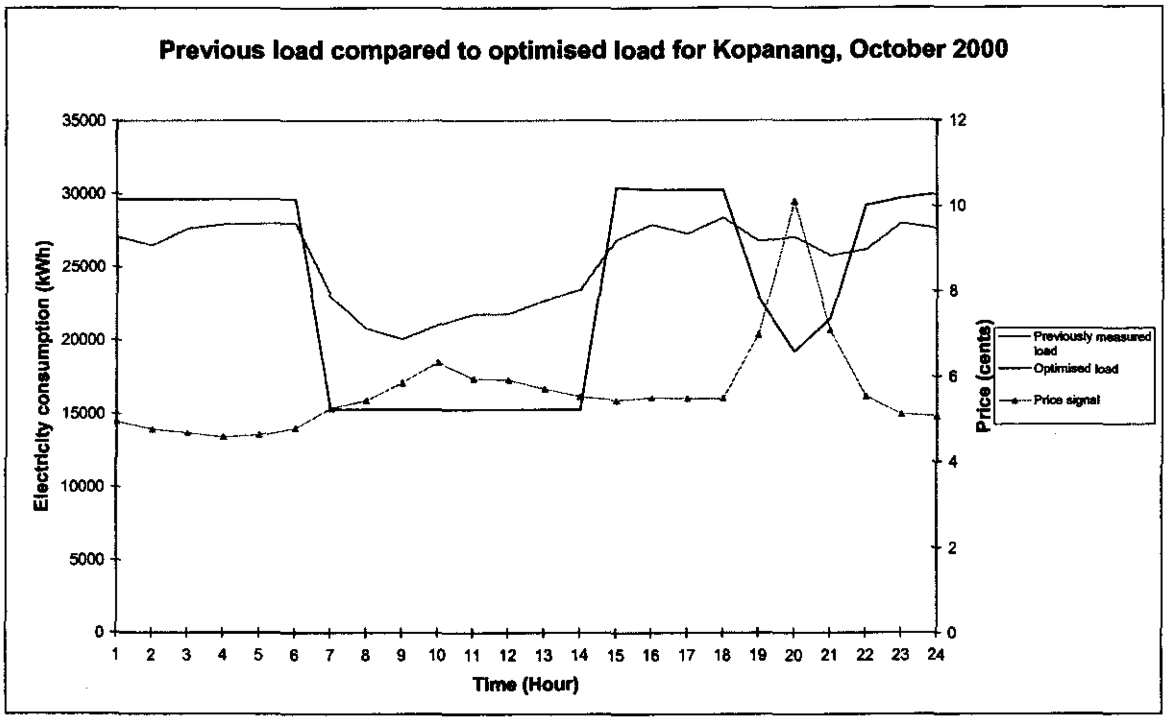

Figure A.6: Typical Sunday, Kopanang, October 2000

A.3 November, 2000

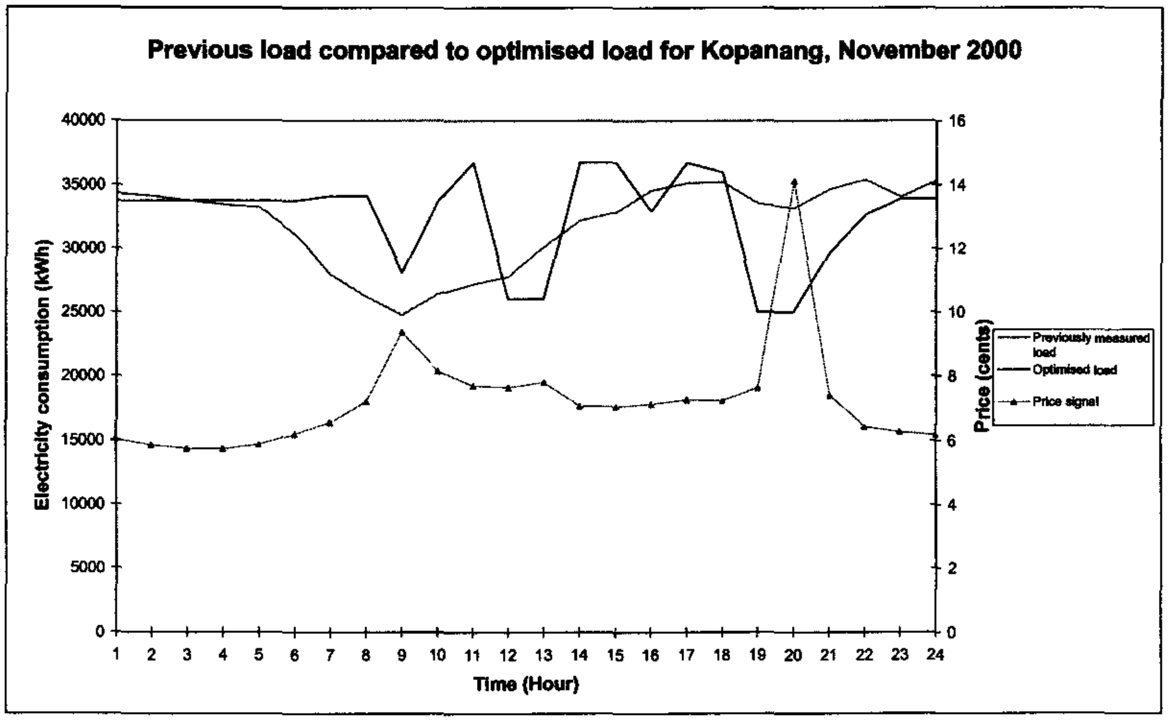

Figure A.7: Typical weekday, Kopanang, November 2000

Figure A.7 shows that a large amount of load can be shifted to the middle of the day from the peak evening period. In total 48MW electricity can be shifted on a typical weekday. 9% more electricity was used on the refrigeration system. After examination of the measured conditions during the month it became clear that this made sense because the operating limits as set for the optimisation were not maintained during this month.

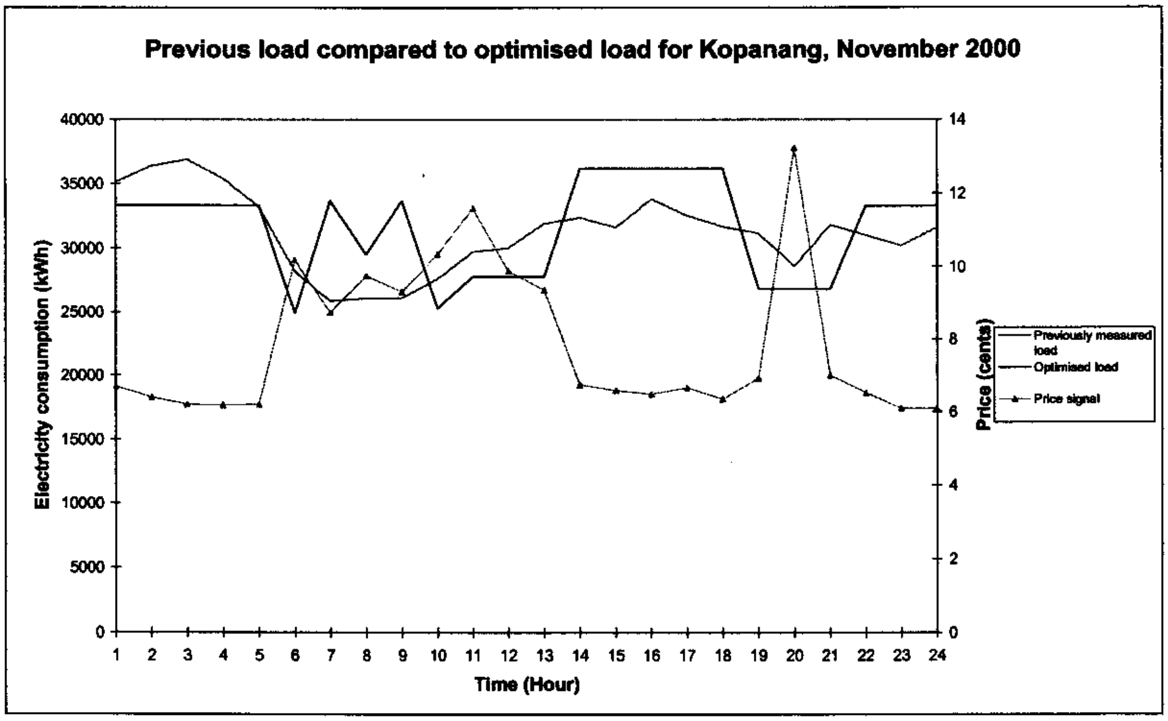
Previous load compared to optimised load for Kopanang, November 2000

Figure A.8: Typical Saturday, Kopanang, November 2000

On a typical Saturday load can be shifted from the evening peak electricity usage period. In total 44MW can be shifted on such a typical day as seen in *Figure A.8*. On the refrigeration side 6% more electricity was used. This can be explained by the unusual high cooling demand in this month over Saturdays.

A total of 19MW of load is shifted from the peak price periods to the cheaper late afternoon period as shown in *Figure A.9*. On the refrigeration side an electricity saving of 45% is achieved this is largely due to the unusual low demand for cooling on Sundays. This is explained by the fact that the mine experimented with a new shift schedule where Saturday was a full working day and on Sunday there were no shifts until 22:00.

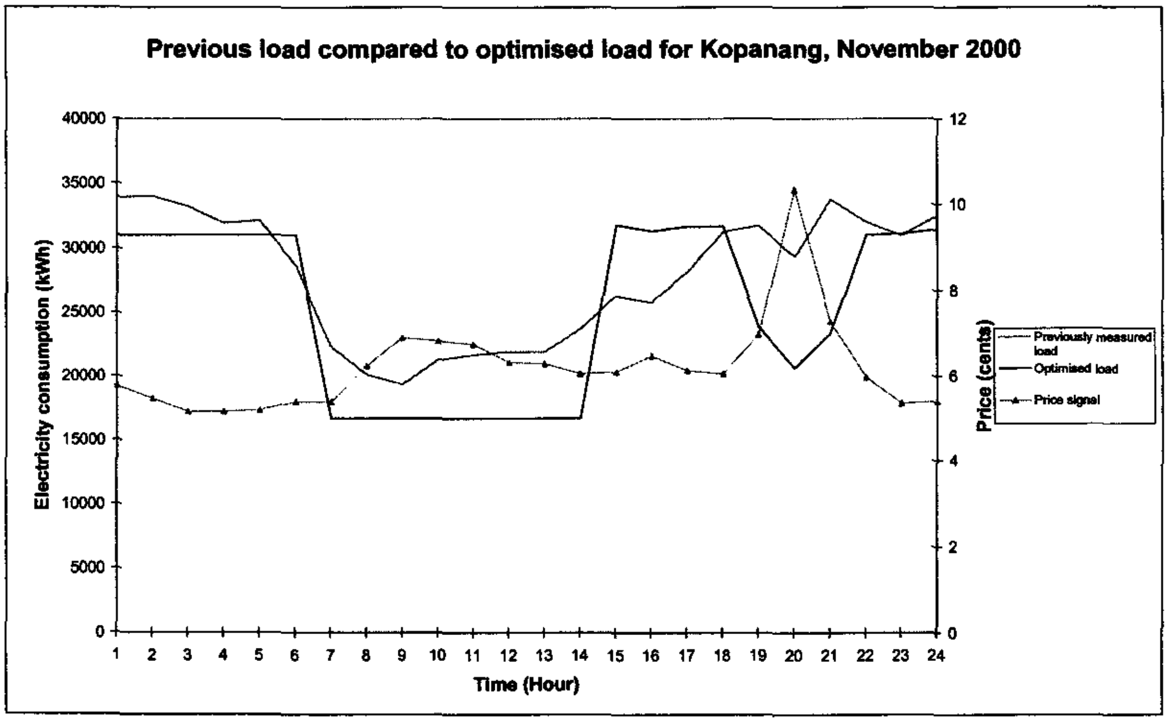

Figure A.9: Typical Sunday, Kopanang, November 2000

A.4 December, 2000

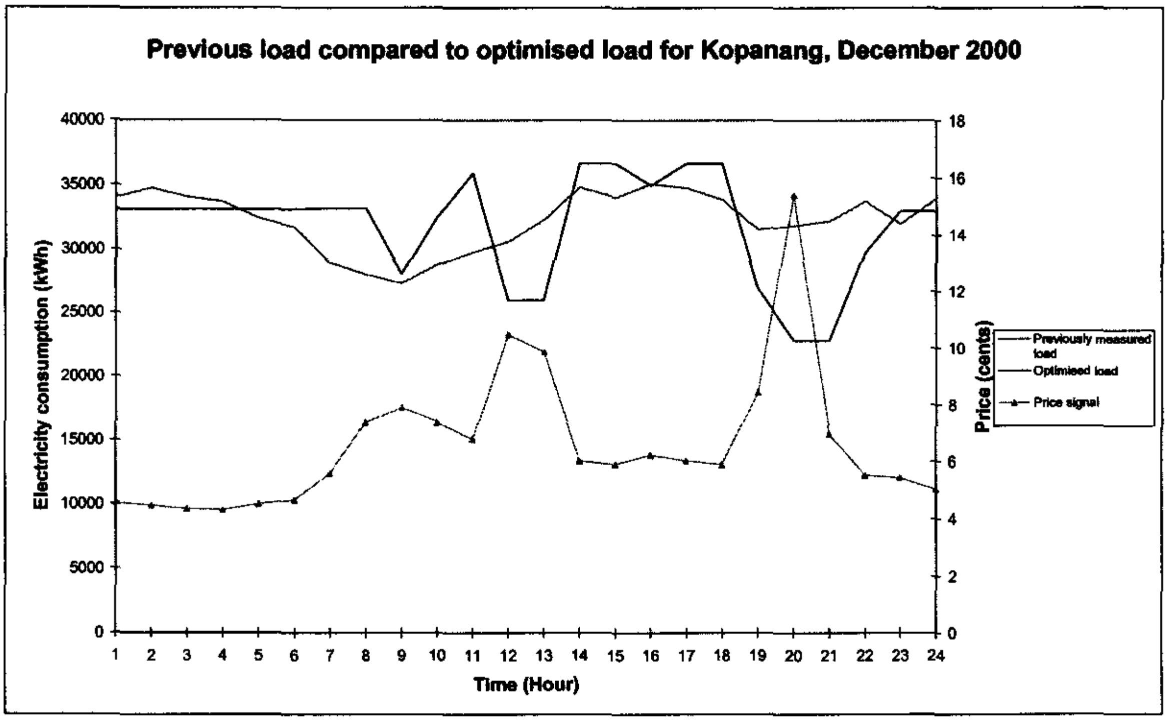

Figure A.10: Typical weekday, Kopanang, December 2000

Figure A.10 shows that a large amount of load can be shifted to the afternoon from the unusual peak mid day period. In total 33MW electricity can be shifted on a typical weekday. A 6% electricity saving can be achieved in this month due to the cooling load reduction due to fewer shifts in the festive season.

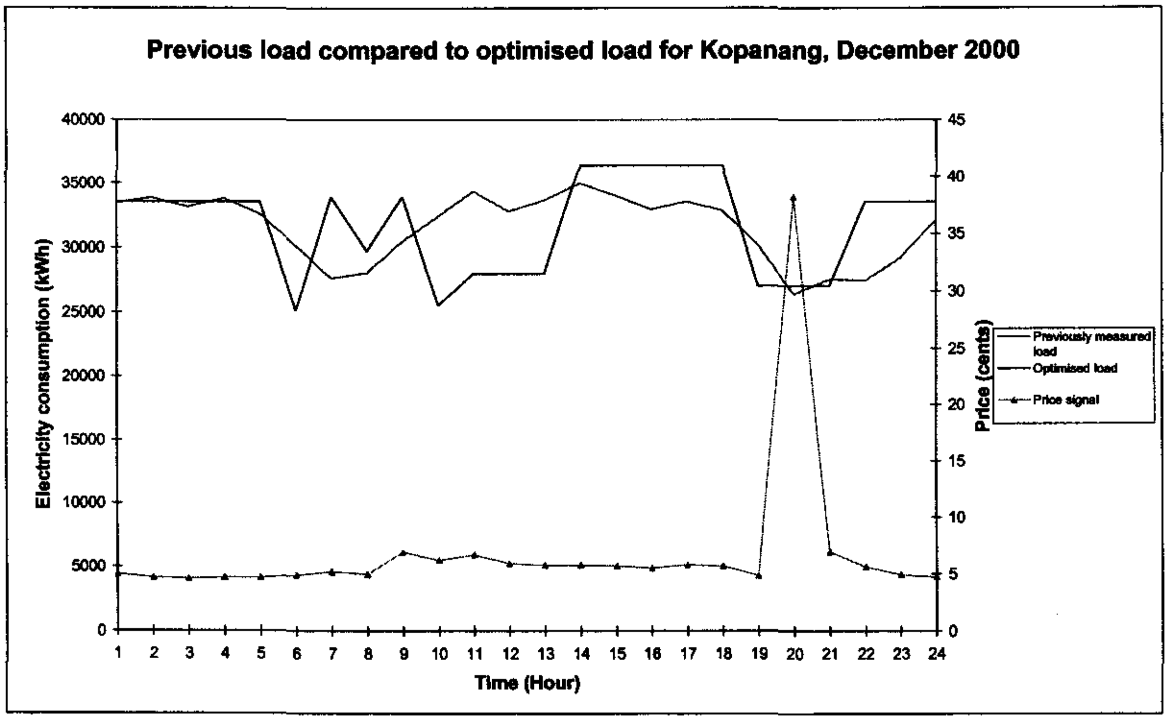

Figure A.11: Typical Saturday, Kopanang, December 2000

On a typical Saturday load can only be shifted from the mid day period due to the pumping demand. In total 39MW can be shifted on such a typical day seen in *Figure A.11*. On the refrigeration side 4% more electricity was used. This can be explained by the unusual high cooling demand in this month over Saturdays.

A total of 45MW of load is shifted from the peak price periods to the cheaper late afternoon period as shown in *Figure A.12*. On the refrigeration side an electricity saving of 41% is achieved this is largely due to the unusual low demand for cooling on Sundays.

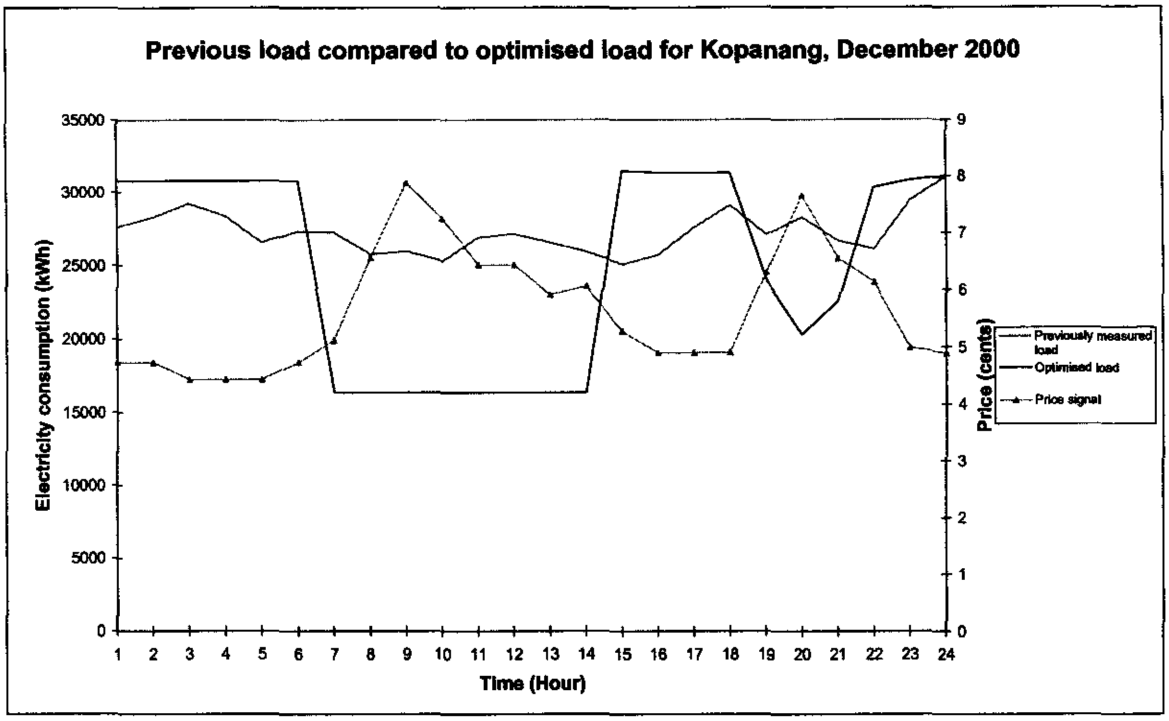

Figure A.12: Typical Sunday, Kopanang, December 2000

A.5 January, 2001

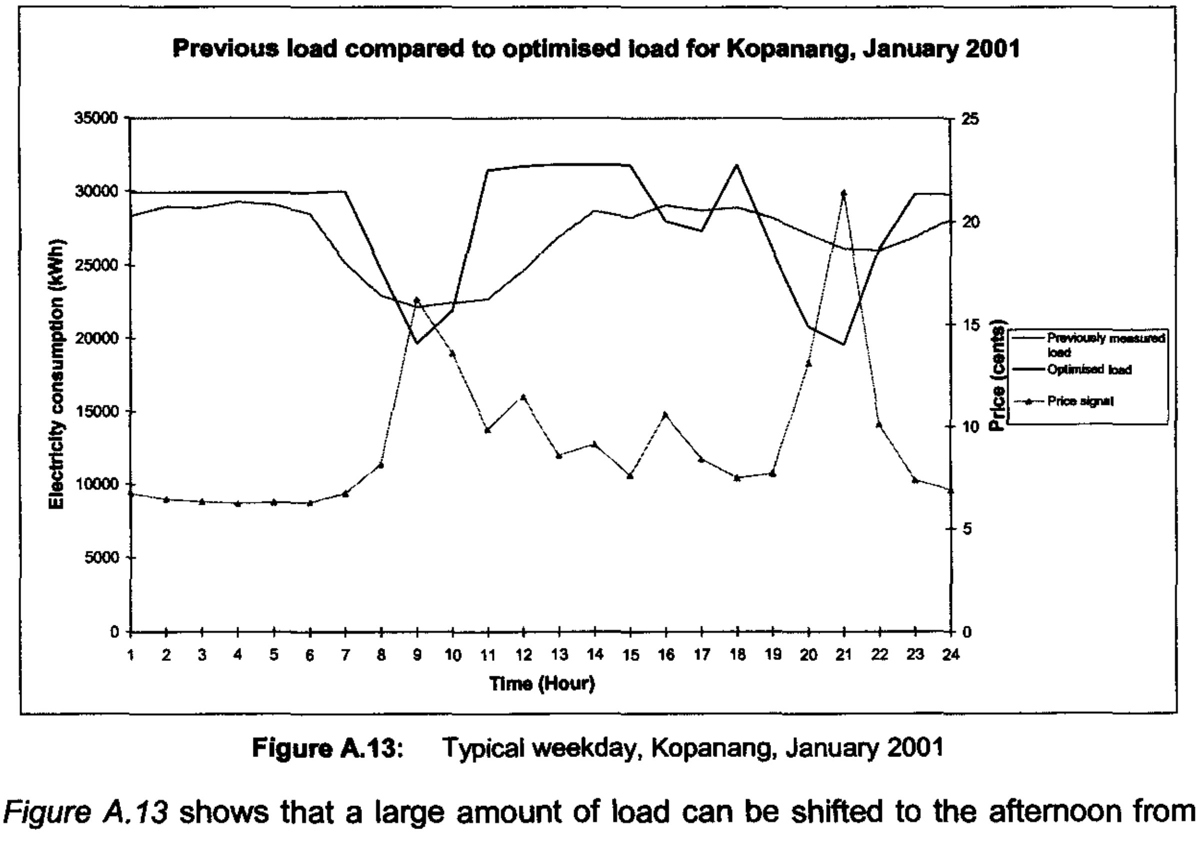

Figure A.13: Typical weekday, Kopanang, January 2001

Figure A.13 shows that a large amount of load can be shifted to the afternoon from the unusual peak mid day period. In total 46MW electricity can be shifted on a typical weekday. To meet the refrigeration demand 21% more electricity is used. This is mainly due to the increased shift load after the festive season and January being very warm, an average maximum temperature of 31.5°C.

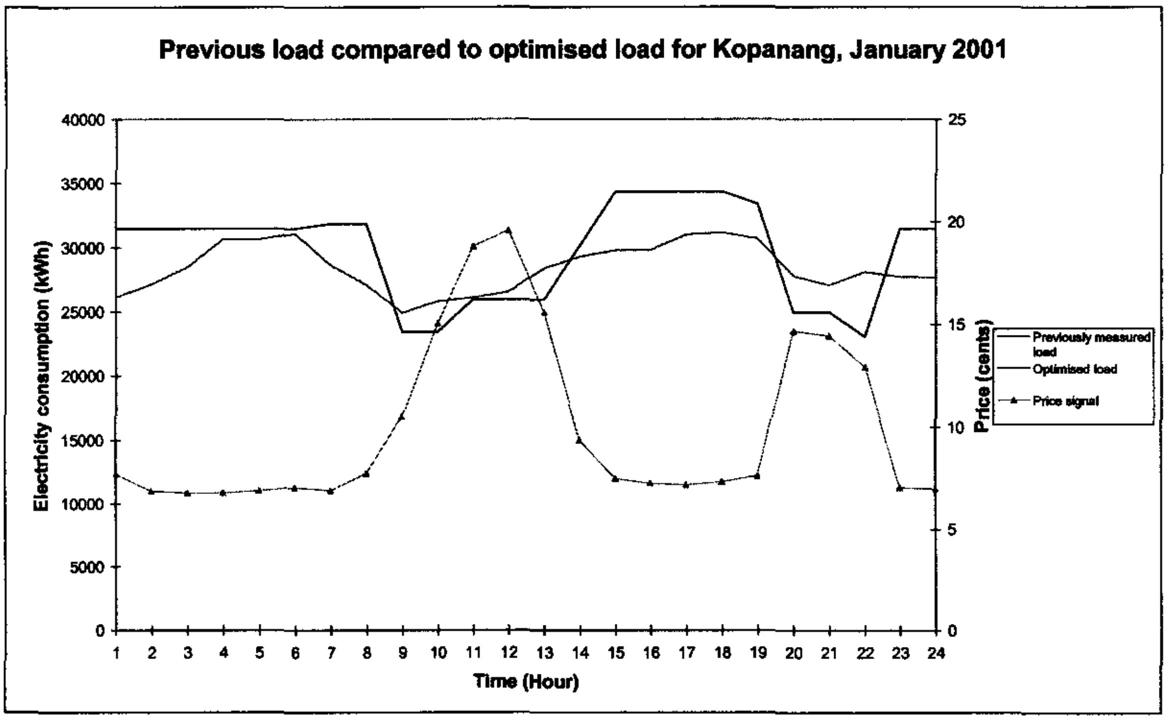

Figure A.14: Typical Saturday, Kopanang, January 2001

On a typical Saturday load can be shifted from both the afternoon and evening high demand periods. In total 47MW can be shifted on such a typical day seen in *Figure A.14*. On the refrigeration side 24% more electricity was used. This can be explained by the unusual high cooling demand in this month over Saturdays as well as the high minimum and maximum temperatures.

A total of 53MW of load is shifted from the peak price periods to the cheaper late afternoon period as shown in *Figure A.15*. On the refrigeration side an electricity saving of only 2% is achieved on a typical Sunday.

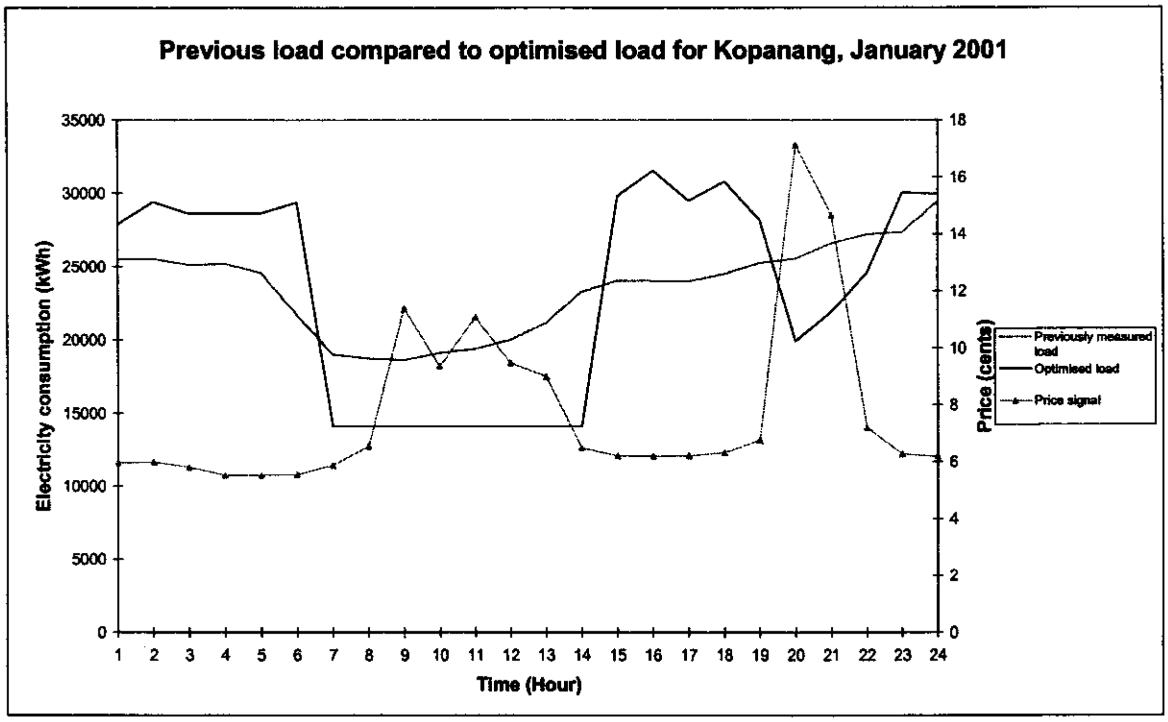

Figure A.15: Typical Sunday, Kopanang, January 2001

A.6 February, 2001

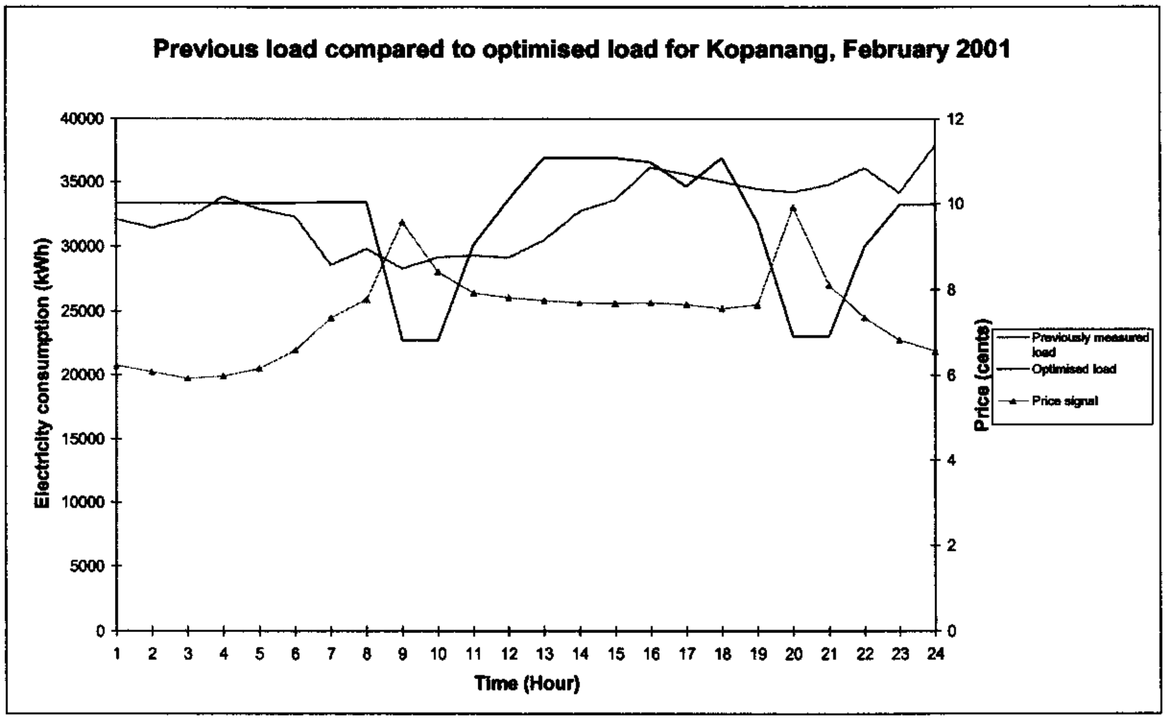

Figure A.16: Typical weekday, Kopanang, February 2001

Figure A.16 shows that a large amount of load can be shifted to the afternoon. In total 36MW electricity can be shifted on a typical weekday. Due to the lower temperatures and demand a 9% electricity saving can be achieved.

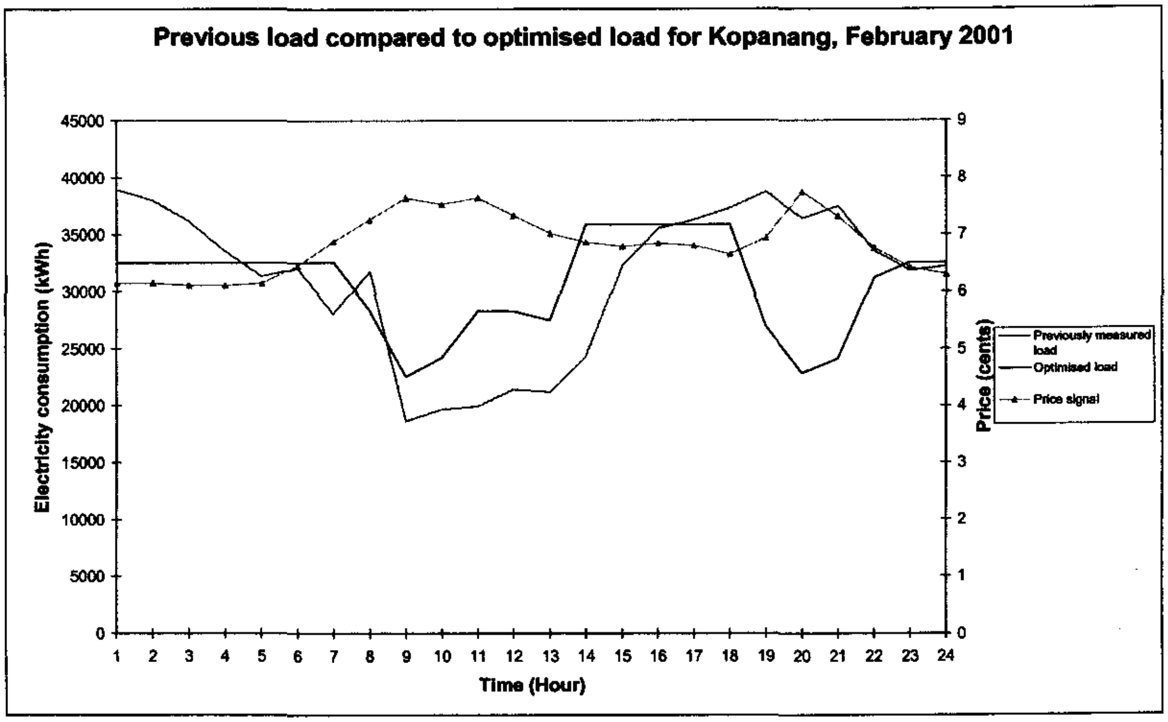

Figure A.17: Typical Saturday, Kopanang, February 2001

On a typical Saturday load can be shifted from both the afternoon and evening high demand periods. In total 53MW can be shifted on such a typical day seen in *Figure A.17*. On the refrigeration side 6% less electricity was used.

A total of 48MW of load is shifted from the peak price periods to the cheaper late afternoon period as shown in *Figure A.18*. On the refrigeration side an electricity saving of 12% is achieved.

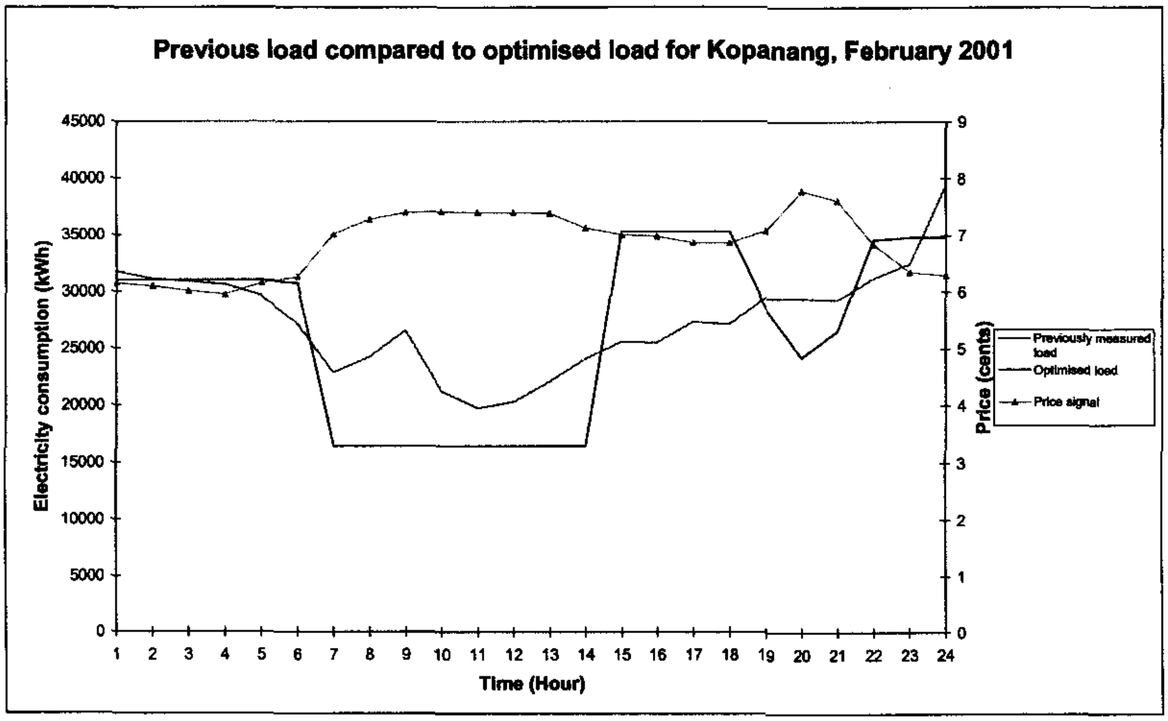

Figure A.18: Typical Sunday, Kopanang, February 2001

A.7 March, 2001

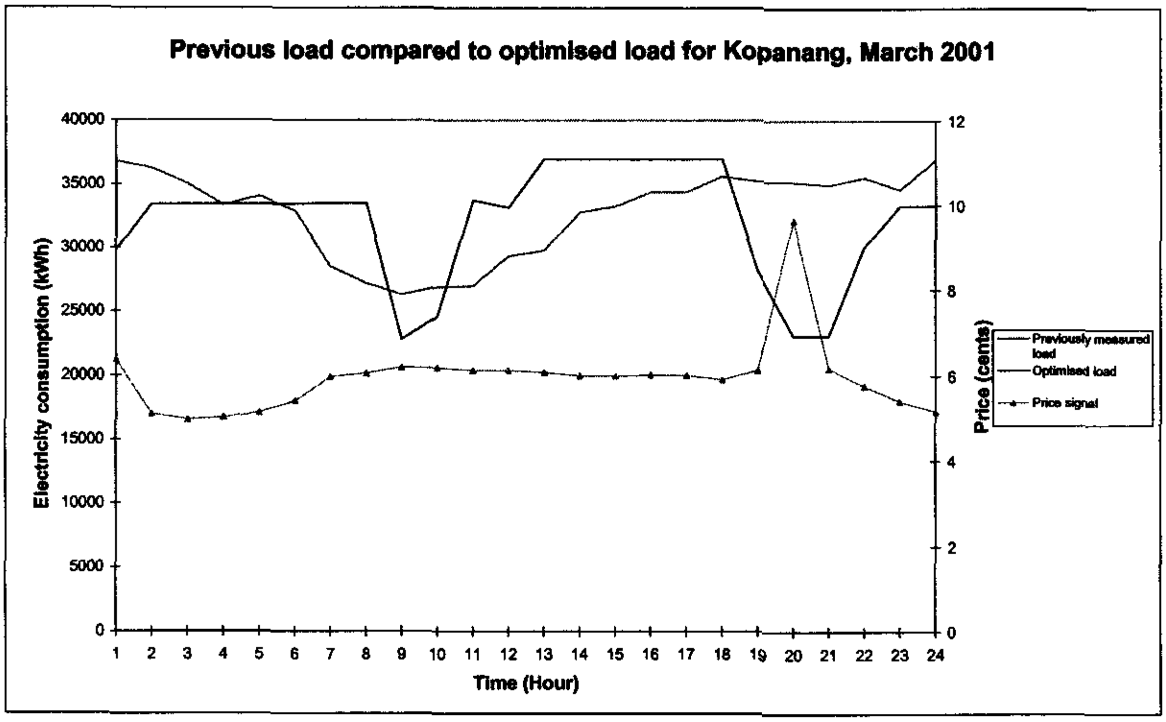

Figure A.19: Typical weekday, Kopanang, March 2001

Figure A.19 shows that a large amount of load can be shifted from the afternoon peak period. In total 45MW electricity can be shifted on a typical weekday. Due to the lower temperatures and demand a 9% electricity saving can be achieved.

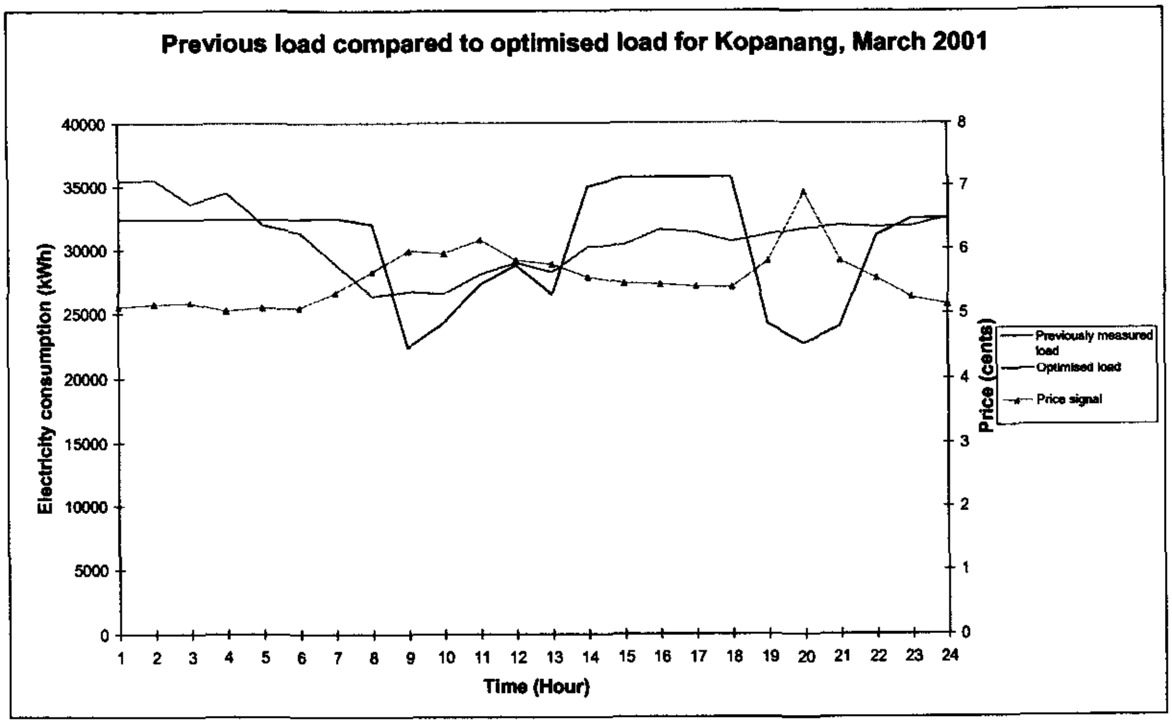

Figure A.20: Typical Saturday, Kopanang, March 2001

On a typical Saturday load can be shifted from both the afternoon and evening high demand periods. In total 35MW can be shifted on such a typical day seen in *Figure A.20*. On the refrigeration side 5% less electricity was used.

A total of 25MW of load is shifted from the peak price periods to the cheaper late afternoon period as shown in *Figure A.21*. On the refrigeration side an electricity saving of 50% is achieved due to the cooler climate temperatures.

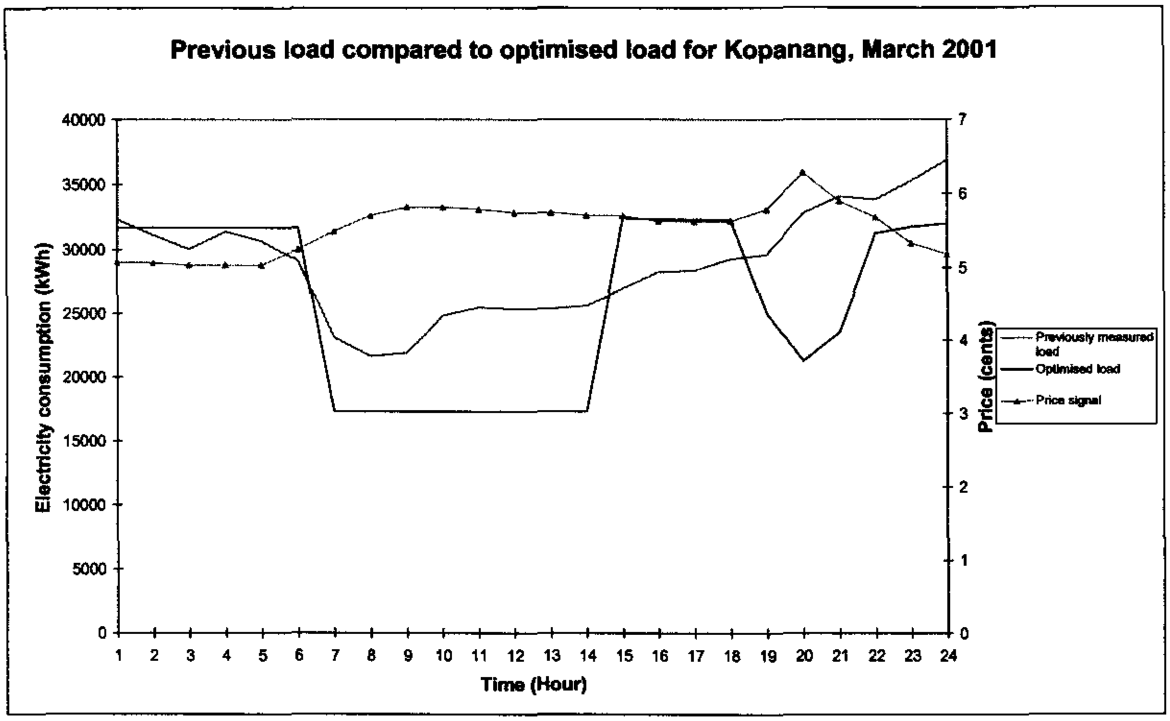

Figure A.21: Typical Sunday, Kopanang, March 2001

A.8 April, 2001

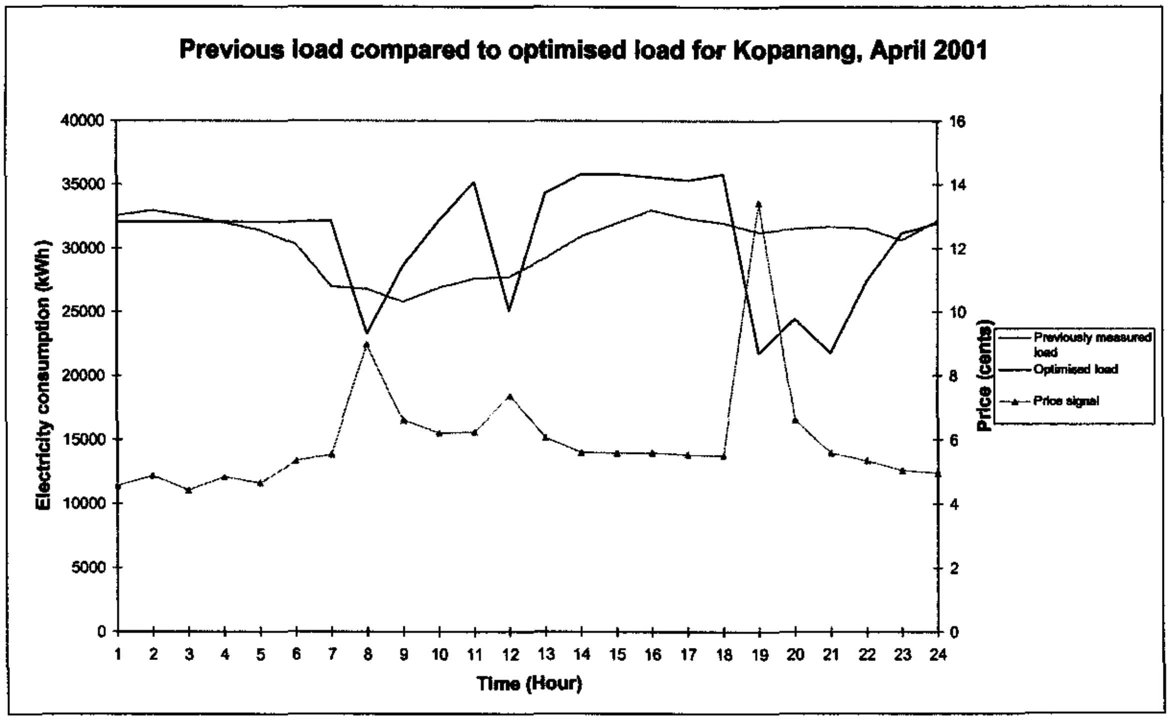

Figure A.22: Typical weekday, Kopanang, April 2001

Figure A.22 shows that a large amount of load can be shifted from the afternoon peak period. In total 47MW electricity can be shifted on a typical weekday. Due to the lower temperatures and demand a 9% electricity saving can be achieved.

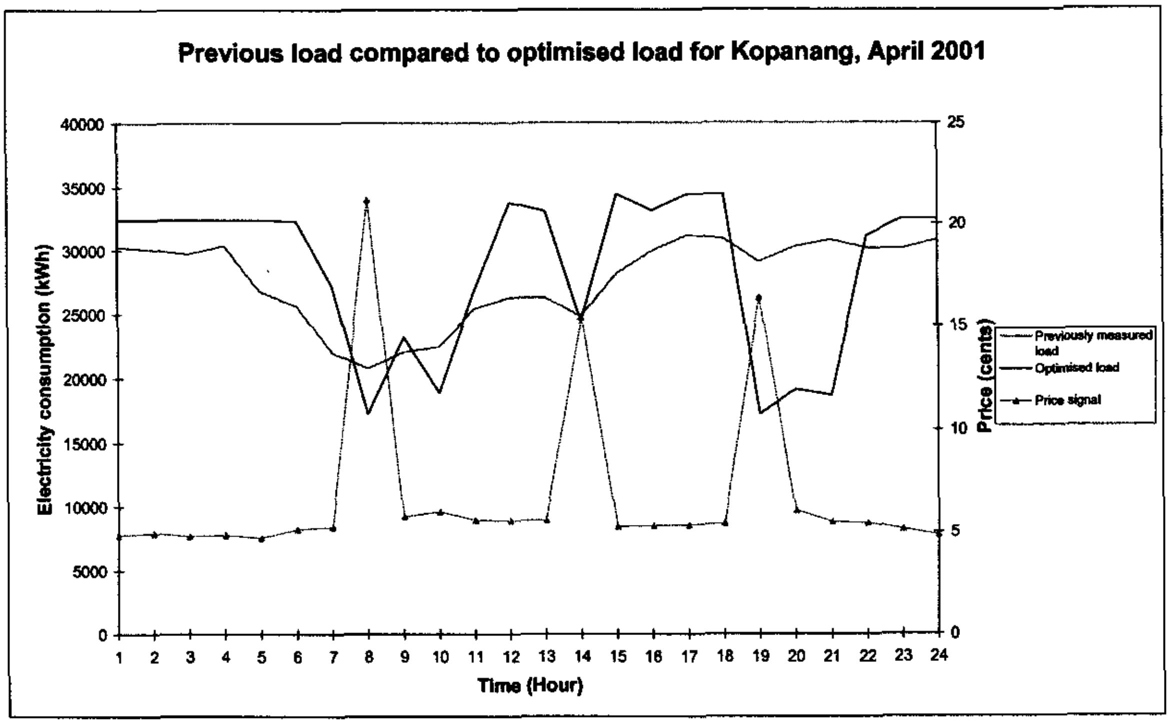

Figure A.23: Typical Saturday, Kopanang, April 2001

On a typical Saturday load can be shifted from both the afternoon and evening high demand periods. In total 63MW can be shifted on such a typical day seen in *Figure A.23*. On the refrigeration side 5% less electricity was used.

A total of 26MW of load is shifted from the peak price periods to the cheaper late afternoon period as shown in *Figure A.24*. On the refrigeration side an electricity saving of 51% is achieved due to the cooler climate temperatures.

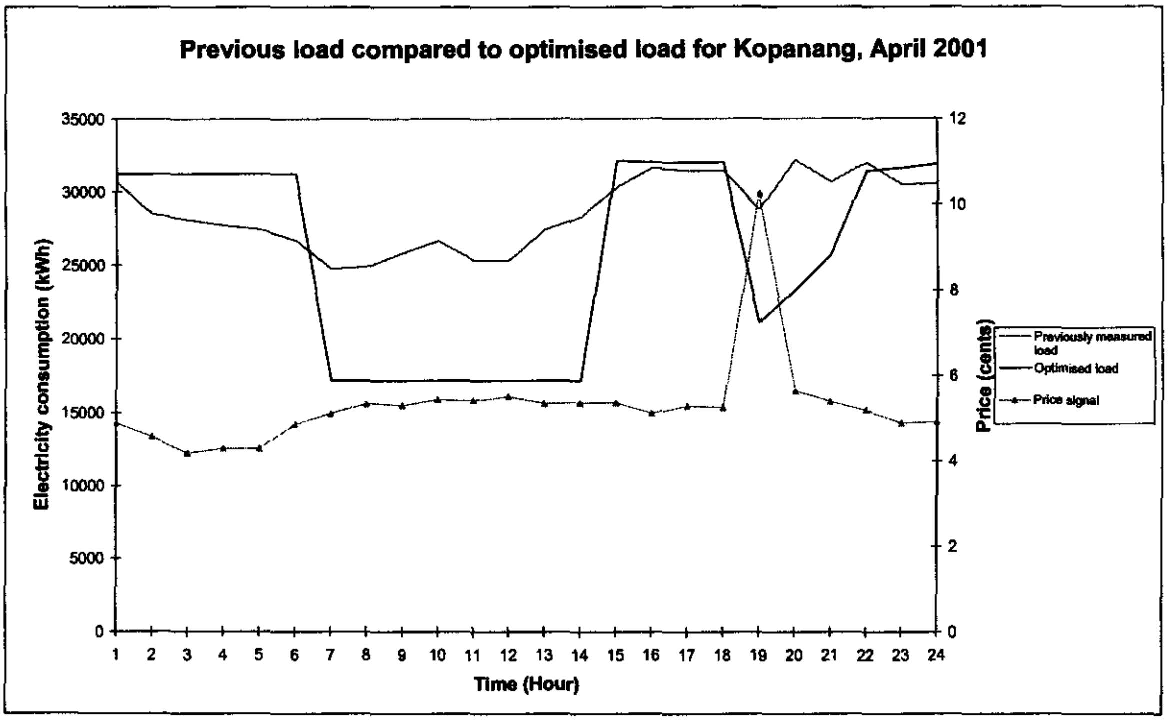

Figure A.24: Typical Sunday, Kopanang, April 2001

A.9 May, 2001

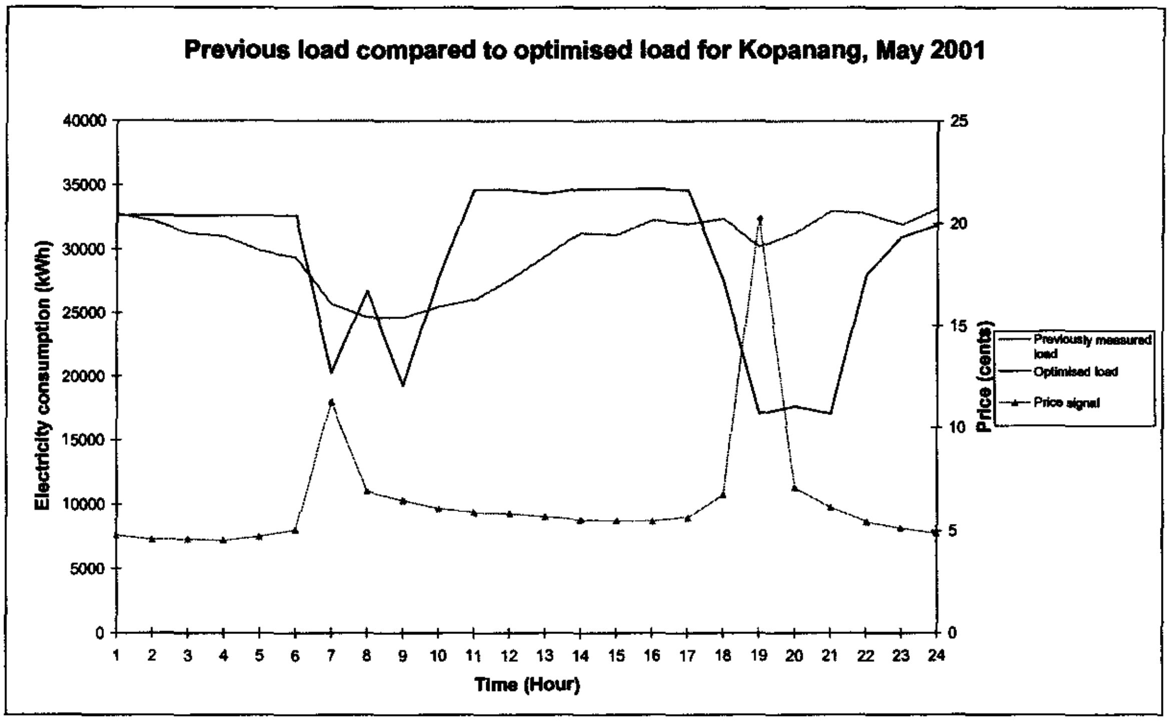

Figure A.25: Typical weekday, Kopanang, May 2001

Figure A.25 shows that a large amount of load can be shifted from the afternoon peak period. In total 47MW electricity can be shifted on a typical weekday. Due to the lower temperatures and demand a 13% electricity saving can be achieved.

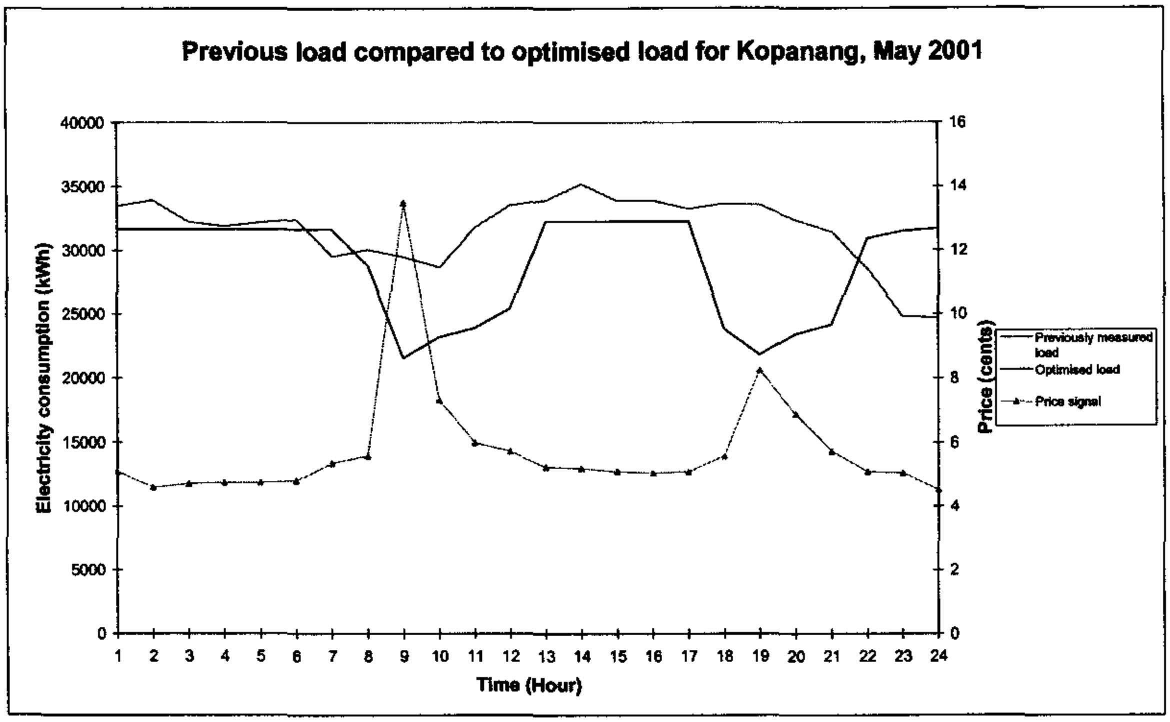

Figure A.26: Typical Saturday, Kopanang, May 2001

On a typical Saturday load can be shifted from both the afternoon and evening high demand periods. In total 19MW can be shifted on such a typical day seen in *Figure A.26*. On the refrigeration side 43% less electricity was used.

A total of 28MW of load is shifted from the peak price periods to the cheaper late afternoon period as shown in *Figure A.27*. On the refrigeration side an electricity saving of 39% is achieved due to the cooler climate temperatures.

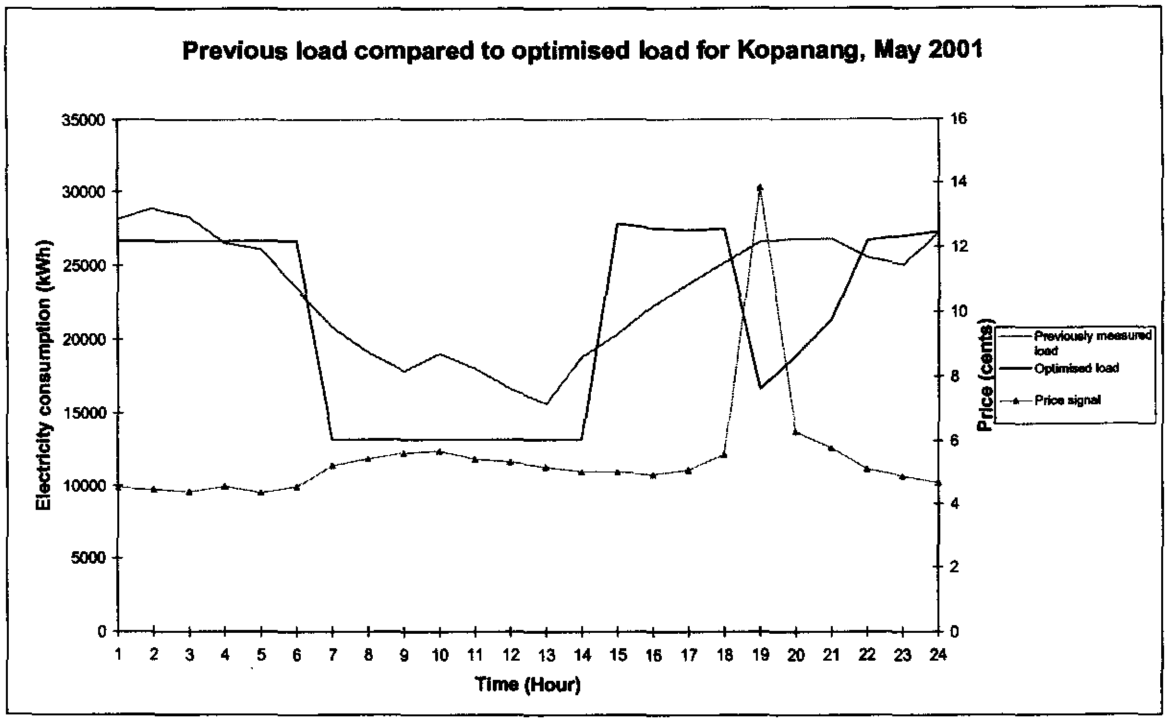

Figure A.27: Typical Sunday, Kopanang, May 2001

A.10 June, 2001

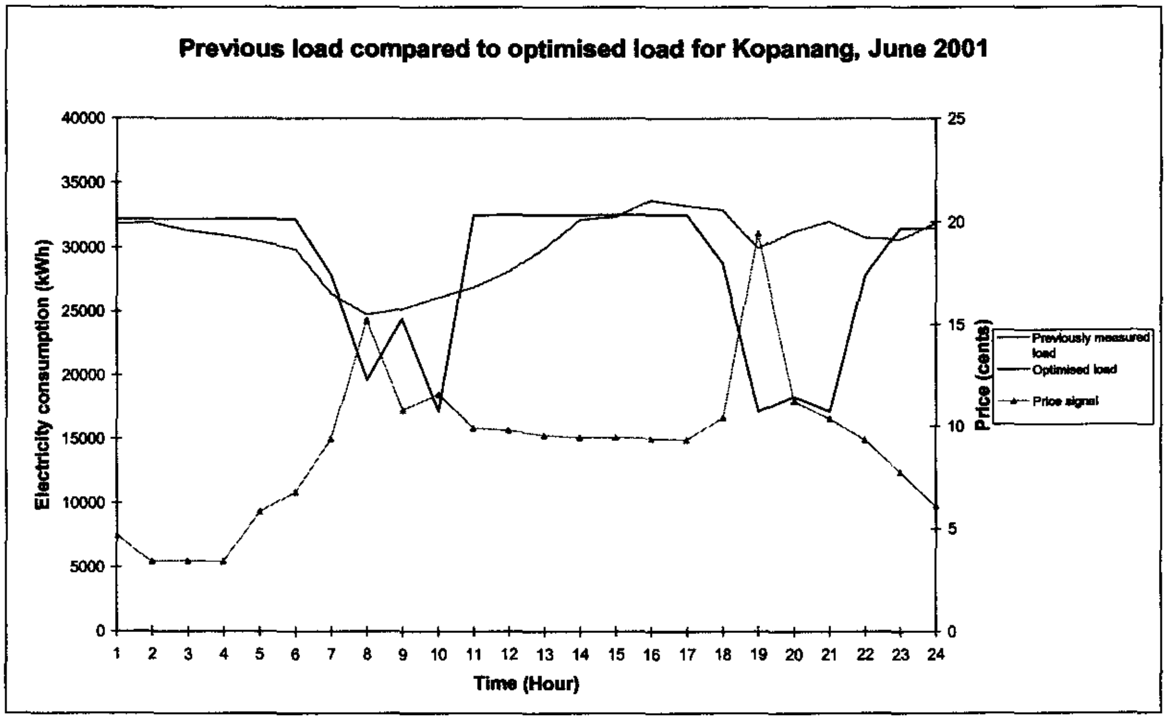

Figure A.28: Typical weekday, Kopanang, June 2001

Figure A.28 shows that load can be shifted from the afternoon peak period. In total 24MW electricity can be shifted on a typical weekday. Due to the lower temperatures and demand a 29% electricity saving can be achieved on the refrigeration systems.

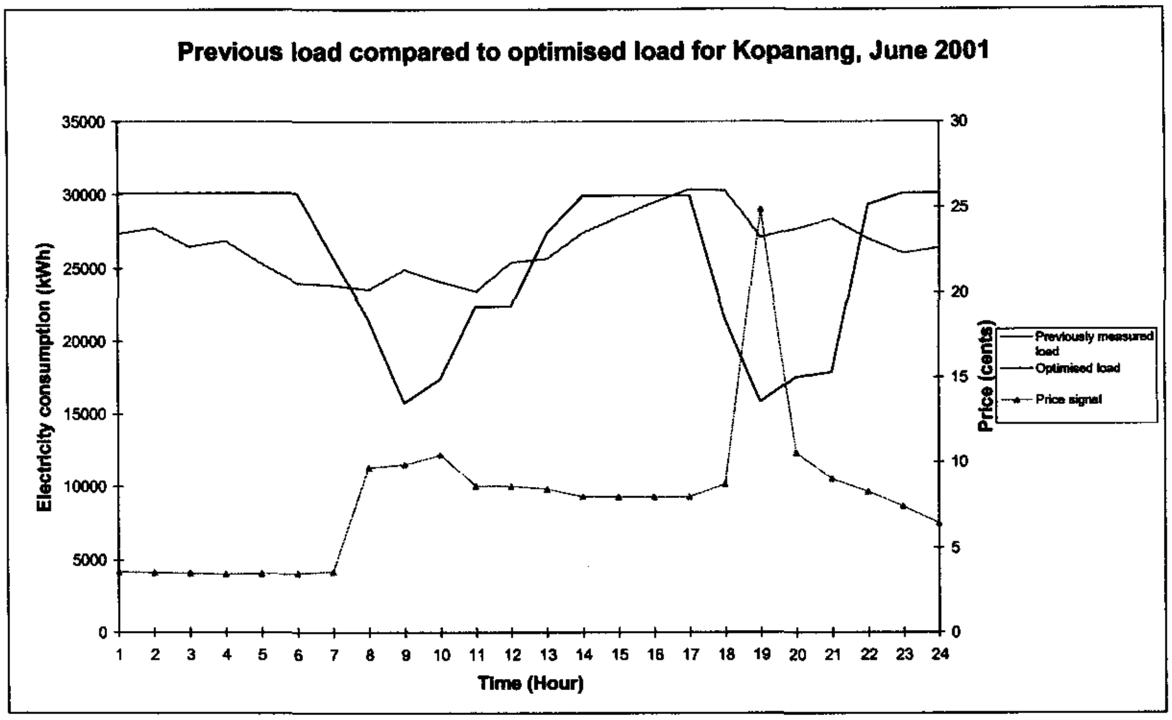

Figure A.29: Typical Saturday, Kopanang, June 2001

On a typical Saturday load can be shifted from both the afternoon and evening high demand periods. In total 43MW can be shifted on such a typical day seen in *Figure A.29.* On the refrigeration side 16% of the refrigeration electricity can be saved.

A total of 24MW of load is shifted from the peak price periods to the cheaper early morning period to take advantage of the unusual price signal as shown in *Figure A.30.* On the refrigeration side an electricity saving of 55% is achieved due to the cooler climate temperatures and very low demand.

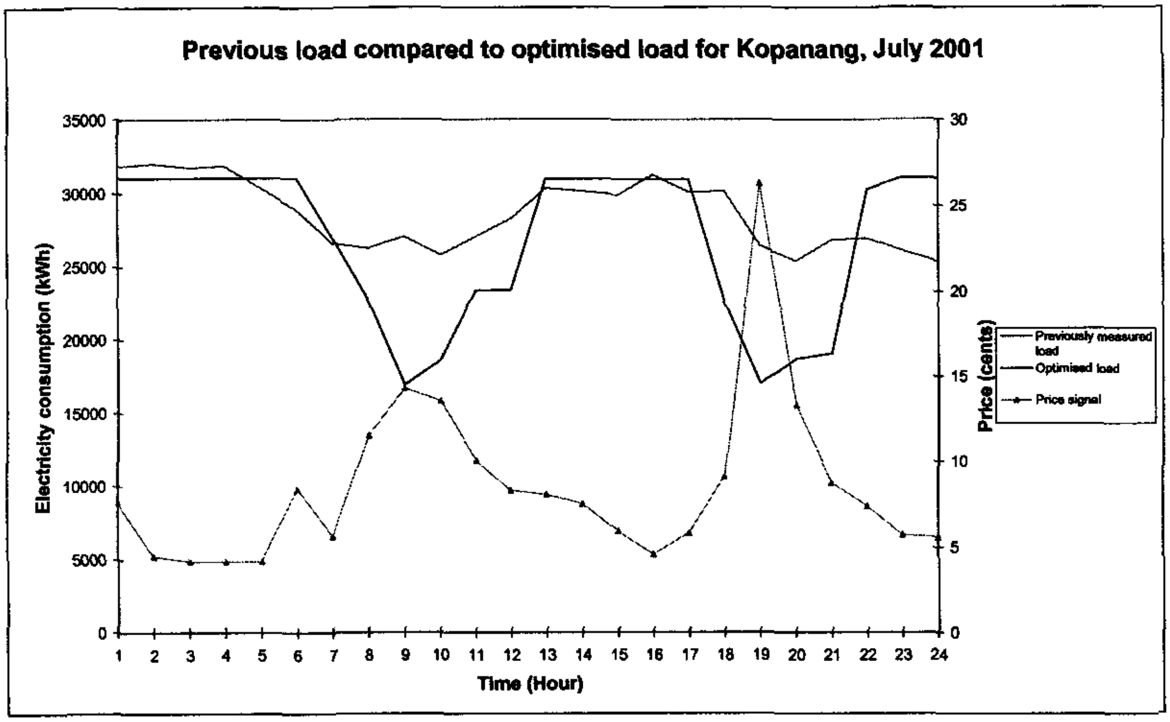

Figure A.32: Typical Saturday, Kopanang, July 2001

On a typical Saturday load can be shifted from both the afternoon and evening high demand periods. In total 22MW can be shifted on such a typical day seen in *Figure A.32*. On the refrigeration side 32% of the refrigeration electricity can be saved.

A total of 19MW of load is shifted from the peak price periods to the cheaper early morning period as shown in *Figure A.33*. On the refrigeration side an electricity saving of 50% is achieved due to the cooler climate temperatures and very low demand.

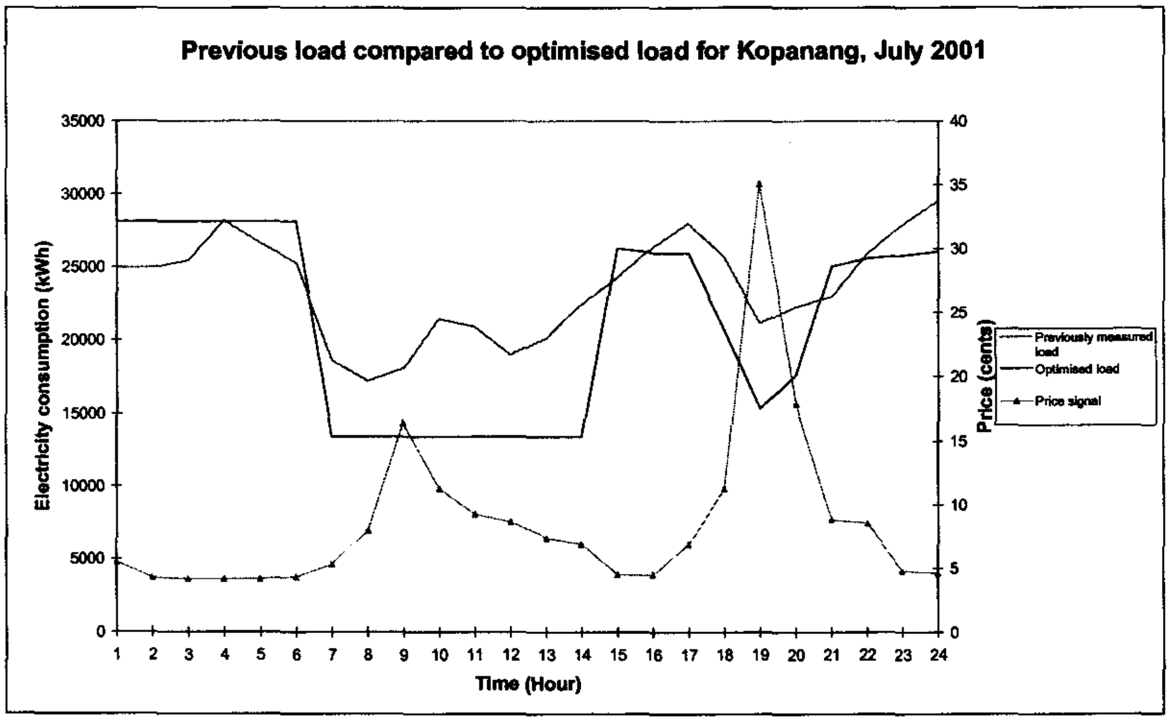

Figure A.33: Typical Sunday, Kopanang, July 2001

A.12 August, 2001

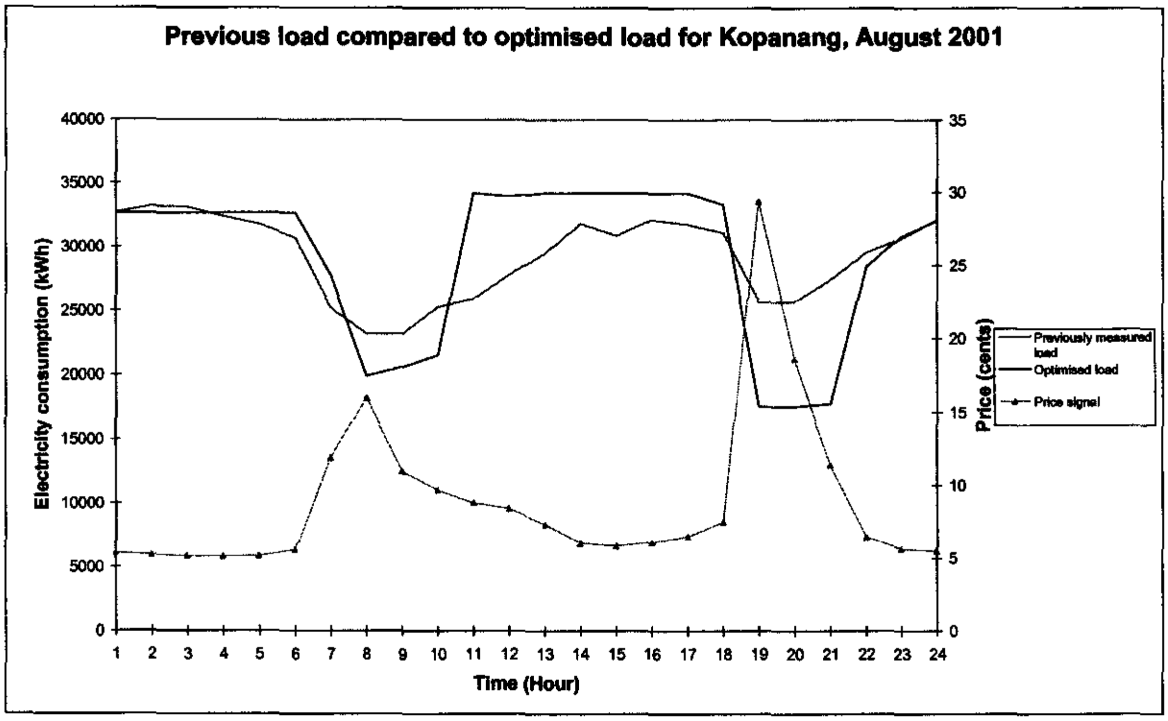

Figure A.34: Typical weekday, Kopanang, August 2001

Figure A.34 shows that load can be shifted from the morning and afternoon peak periods. In total 38MW electricity can be shifted on a typical weekday. Due to the increase in temperatures and demand no electricity saving can be achieved on the refrigeration systems.

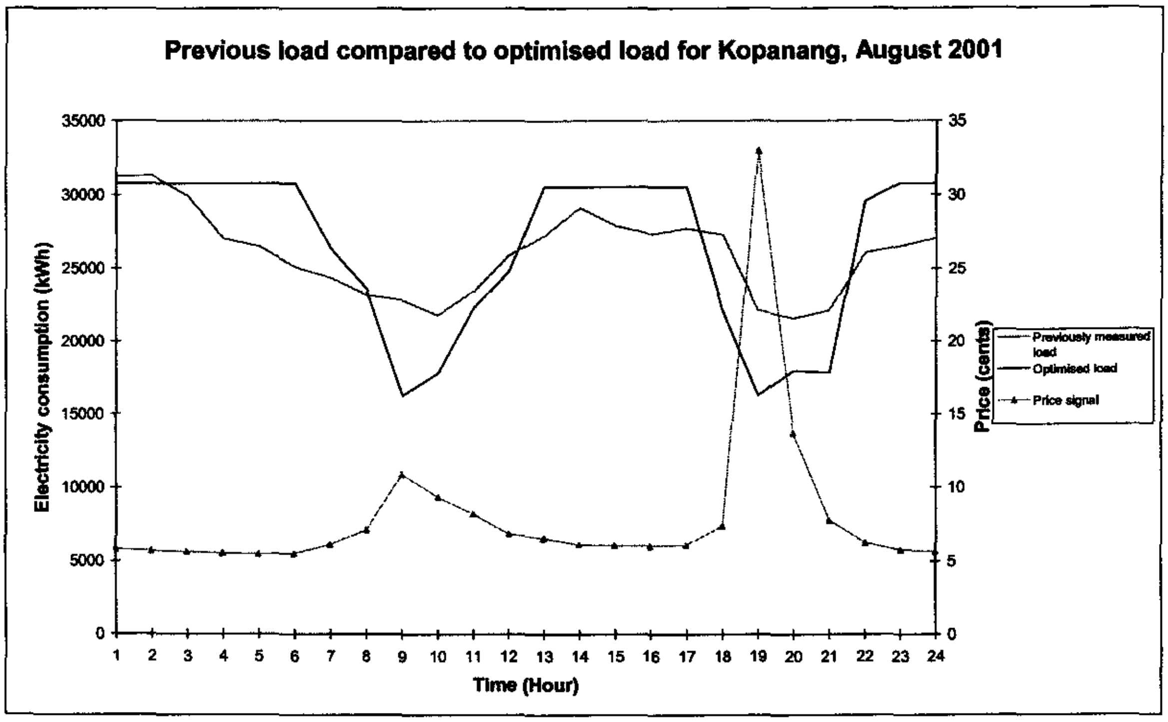

Figure A.35: Typical Saturday, Kopanang, Augustus 2001

On a typical Saturday load can be shifted from both the afternoon and evening high demand periods. In total 42MW can be shifted on such a typical day seen in *Figure A.35.* On the refrigeration side 7% more electricity is required to maintain the desired operating conditions due to the increase in temperatures.

A total of 24MW of load is shifted from the peak price periods to the cheaper early morning period as shown in *Figure A.36.* On the refrigeration side an electricity saving of 49% is achieved due to the cooler climate temperatures and very low demand.

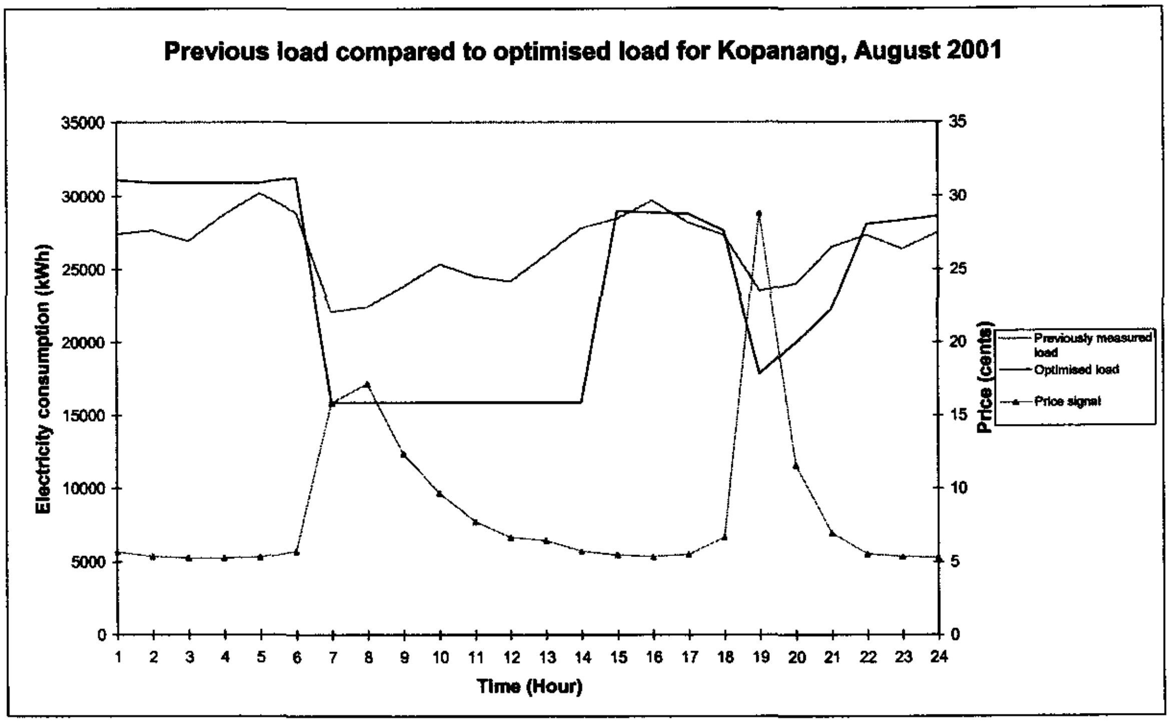

Figure A.36: Typical Sunday, Kopanang, August 2001

APPENDIX B

OPTIMISED AND PREVIOUS LOAD COMPARISON AT AMANDELBULT

In this appendix the detail results of the load comparison between the optimised load and the previous years load at Amnadelbult is given.

B OPTIMISED AND PREVIOUS LOAD COMPARISON AT AMANDELBULT

B.1 January, 2001

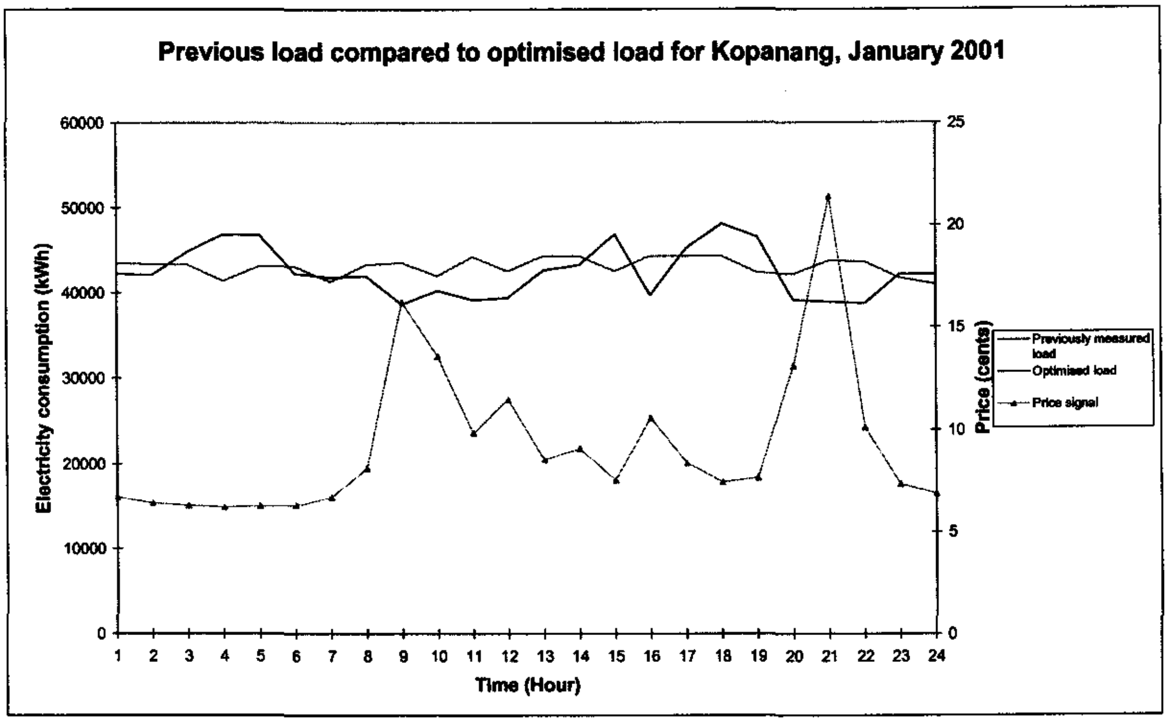

Figure B.1: Typical weekday, Amandelbult, January 2001

During a typical weekday a total of 26.5MW can be shifted from the morning and afternoon peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure B.1*.

On the refrigeration side an average electricity saving of 46% of the refrigeration electricity consumption is achievable. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

B.2 February, 2001

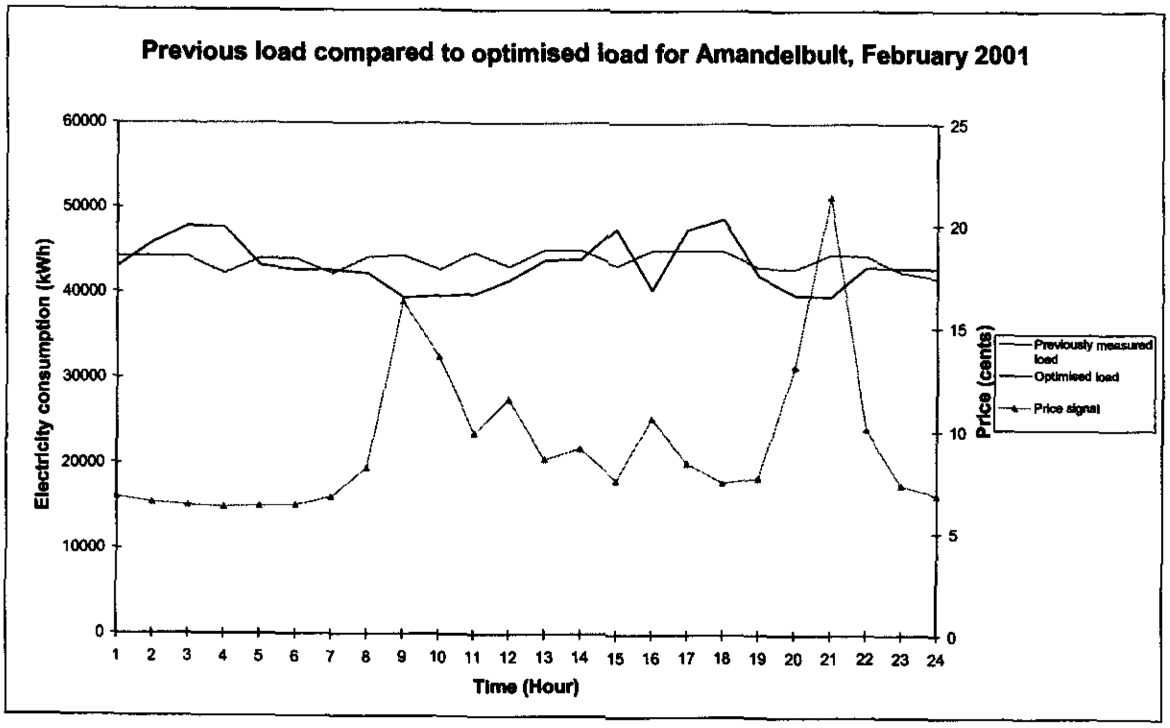

Figure B.2: Typical weekday, Amandelbult, February 2001

During a typical weekday a total of 23.9MW can be shifted from the morning, afternoon and evening peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure B.2*.

On the refrigeration side an average electricity saving of 43.8% of the refrigeration electricity consumption is achievable. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

B.3 March, 2001

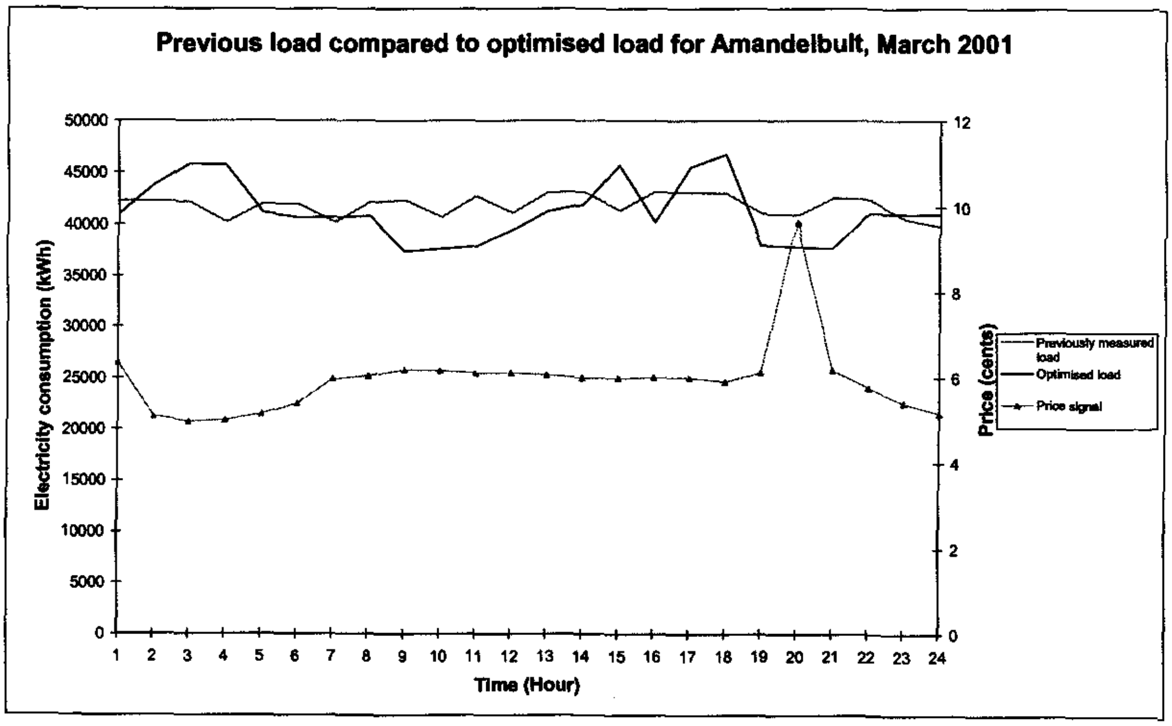

Figure B.3: Typical weekday, Amandelbult, March 2001

During a typical weekday a total of 23.7MW can be shifted from the morning and evening peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure B.3.*

On the refrigeration side an average electricity saving of 49.5% *of the refrigeration* electricity consumption is achievable. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

B.4 April, 2001

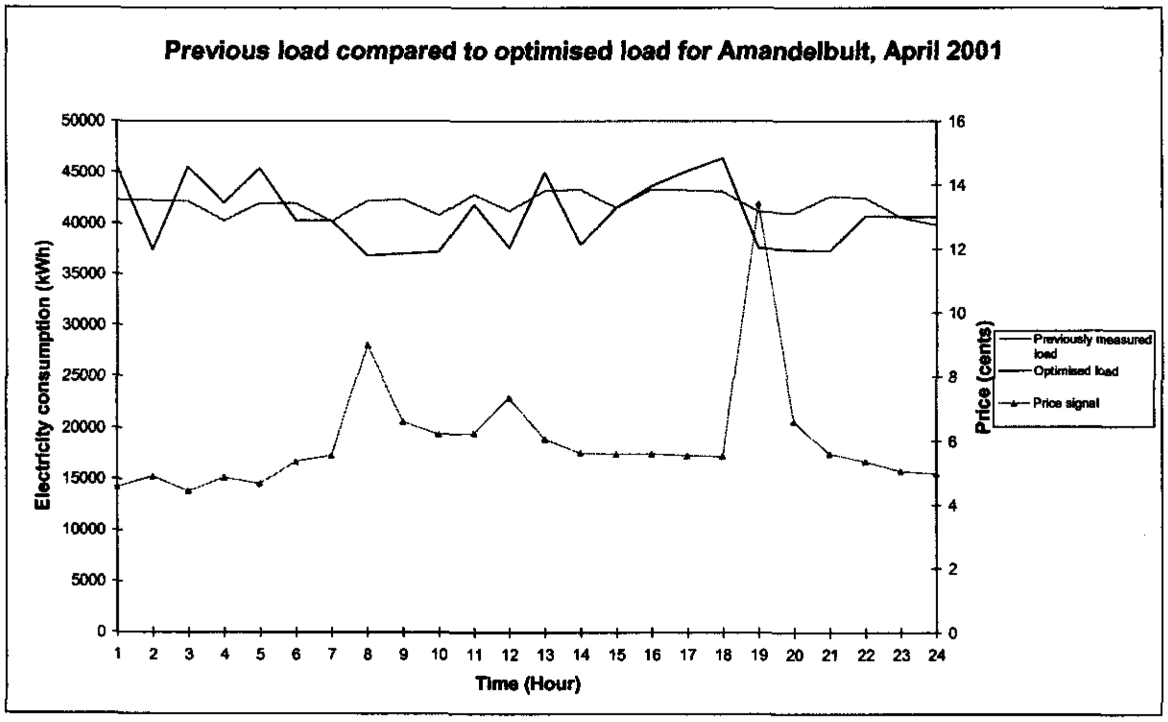

Figure B.4: Typical weekday, Amandelbult, April 2001

During a typical weekday a total of 20MW can be shifted from the morning and evening peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure B.4*.

On the refrigeration side an average electricity saving of 89% of the refrigeration electricity consumption is achievable due to the cooler than usual climate in April 2001. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

B.5 May, 2001

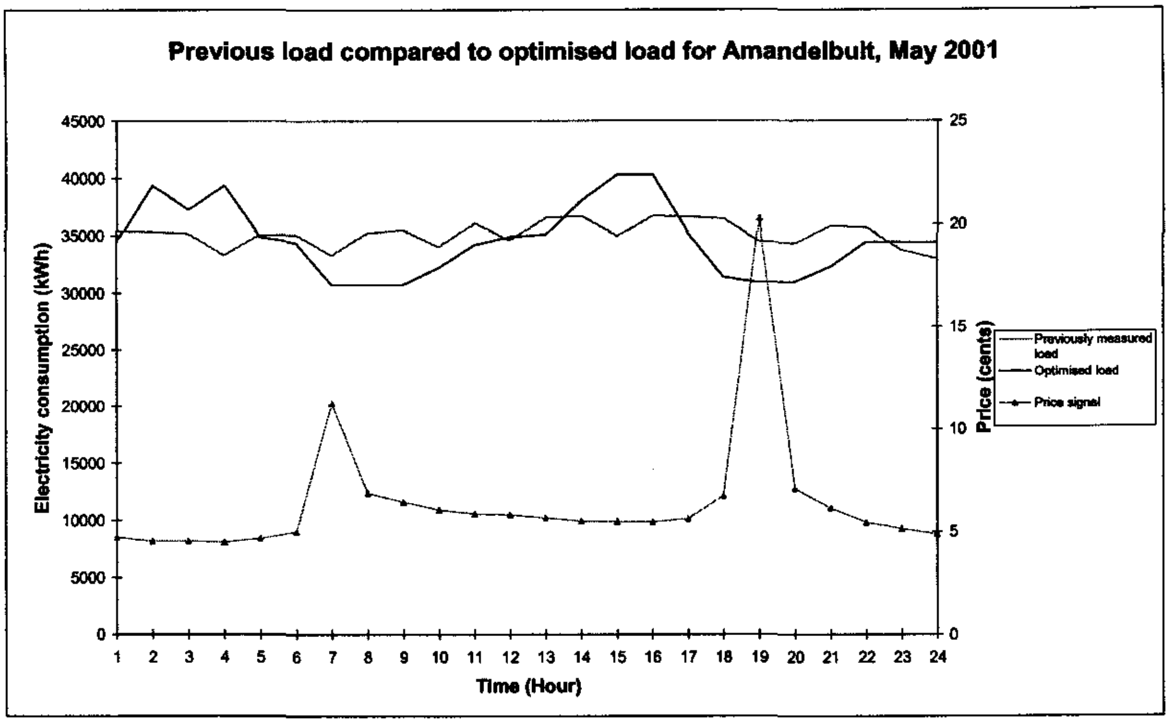

Figure B.5: Typical weekday, Amandelbult, May 2001

During a typical weekday a total of 25MW can be shifted from the morning and evening peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure B.5.*

On the refrigeration side an average electricity saving of 50% of the refrigeration electricity consumption is achievable. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

B.6 June, 2001

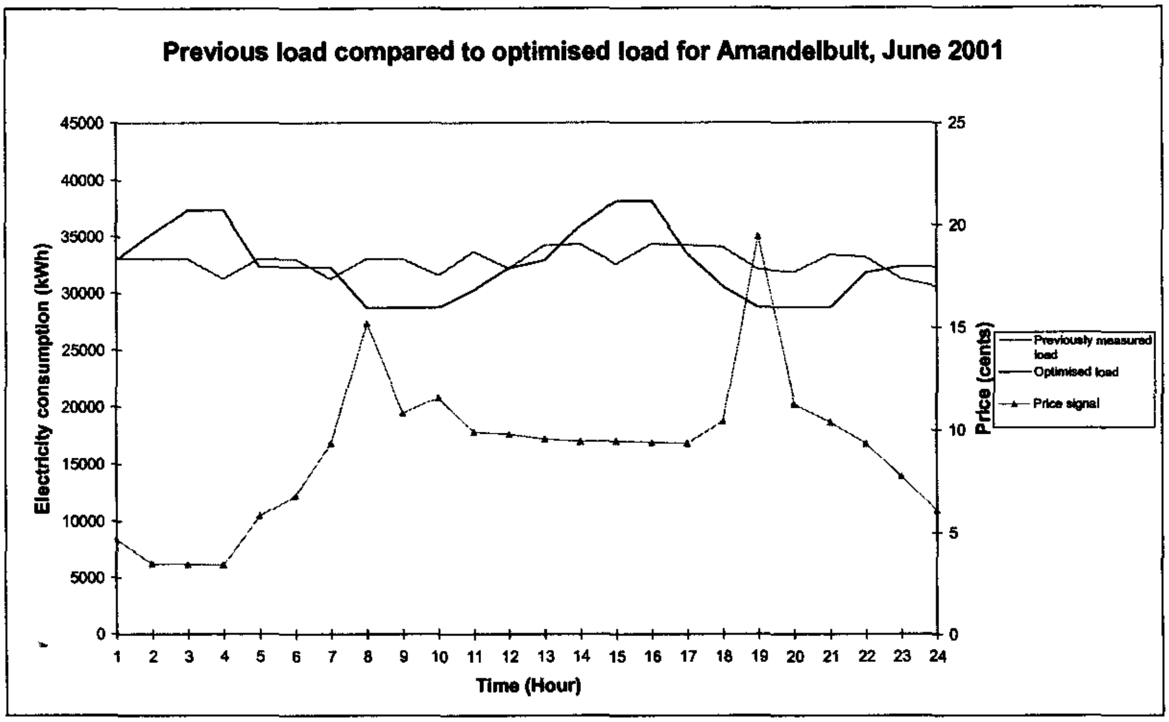

Figure B.6: Typical weekday, Amandelbult, June 2001

During a typical weekday a total of 27.7MW can be shifted from the morning and evening peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure B.6.*

On the refrigeration side an average electricity saving of 33% of the refrigeration electricity consumption is achievable. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

B.7 July, 2001

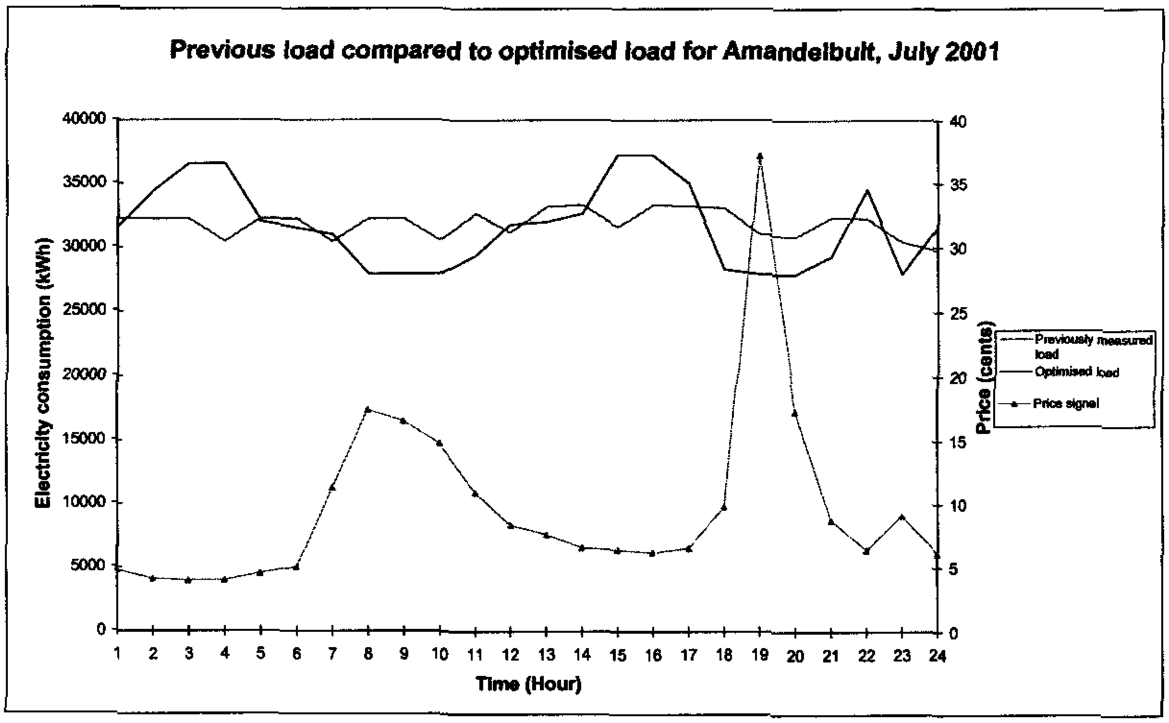

Figure B.7: Typical weekday, Amandelbult, July 2001

During a typical weekday a total of 29.5MW can be shifted from the morning and evening peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure B.7.*

On the refrigeration side an average electricity saving of 23.3% of the refrigeration electricity consumption is achievable. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

B.8 August, 2001

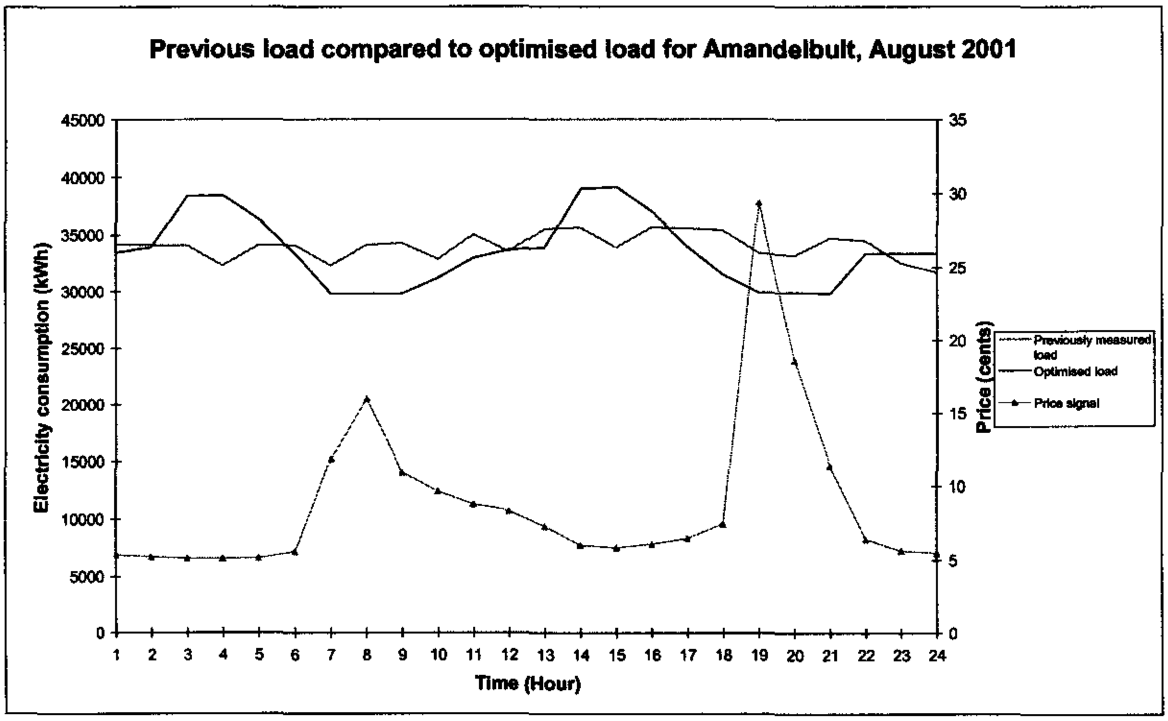

Figure B.8: Typical weekday, Amandelbult, August 2001

During a typical weekday a total of 25.5MW can be shifted from the morning and evening peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure B.8*.

On the refrigeration side an average electricity saving of 48% of the refrigeration electricity consumption is achievable. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

B.9 September, 2001

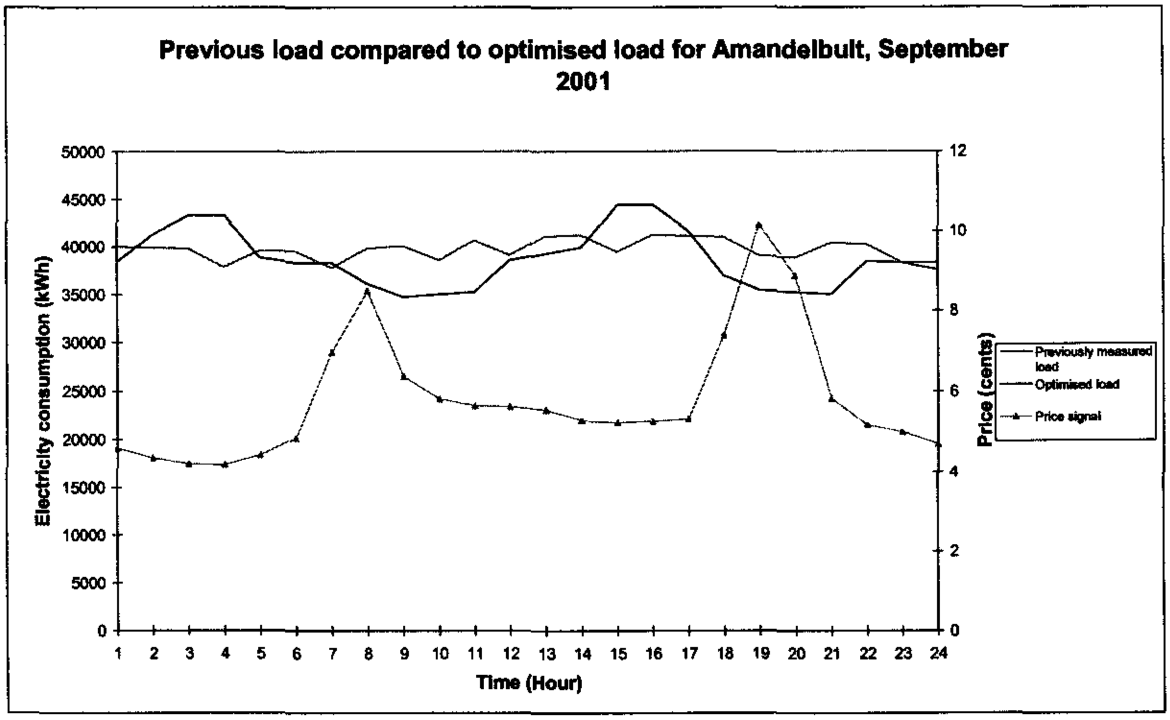

Figure B.9: Typical weekday, Amandelbult, September 2001

During a typical weekday a total of 21MW can be shifted from the morning and evening peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure B.9.*

On the refrigeration side an average electricity saving of 86% of the refrigeration electricity consumption is achievable due to the cooler climate conditions in September than the other summer months. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

B.10 October, 2001

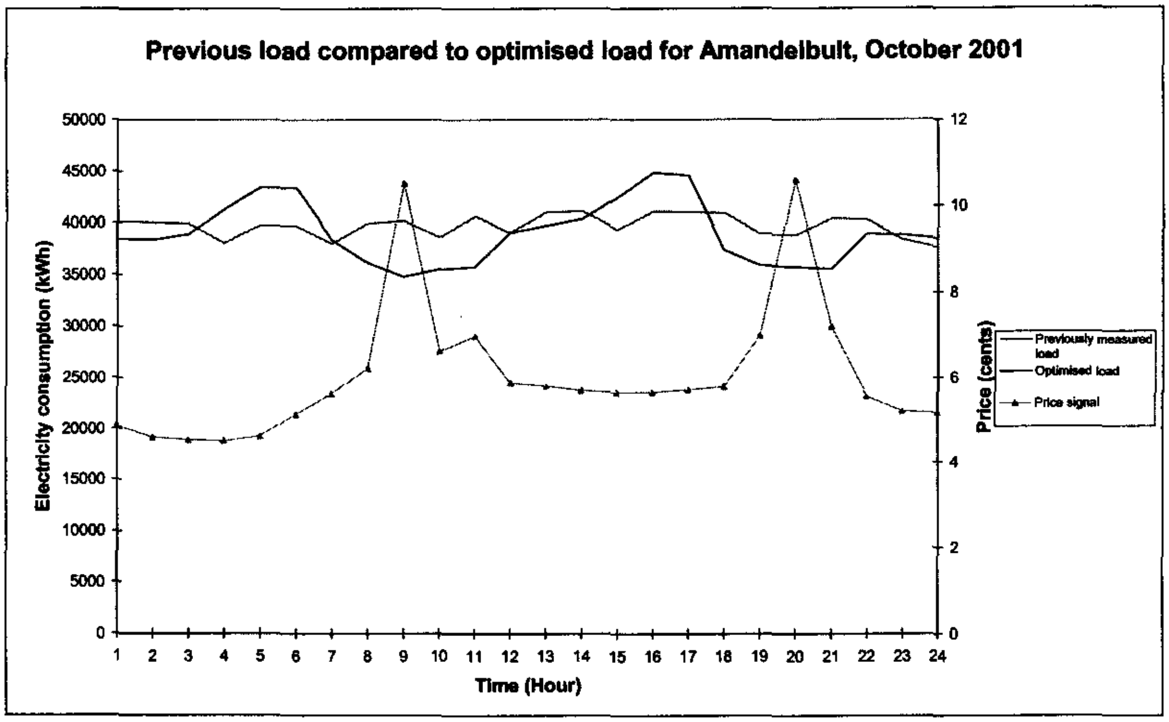

Figure B.10: Typical weekday, Amandelbult, October 2001

During a typical weekday a total of 23MW can be shifted from the morning and evening peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure B.10*.

On the refrigeration side an average electricity saving of 62% of the refrigeration electricity consumption is achievable due to the cooler climate conditions in September than the other summer months. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

B.11 November, 2001

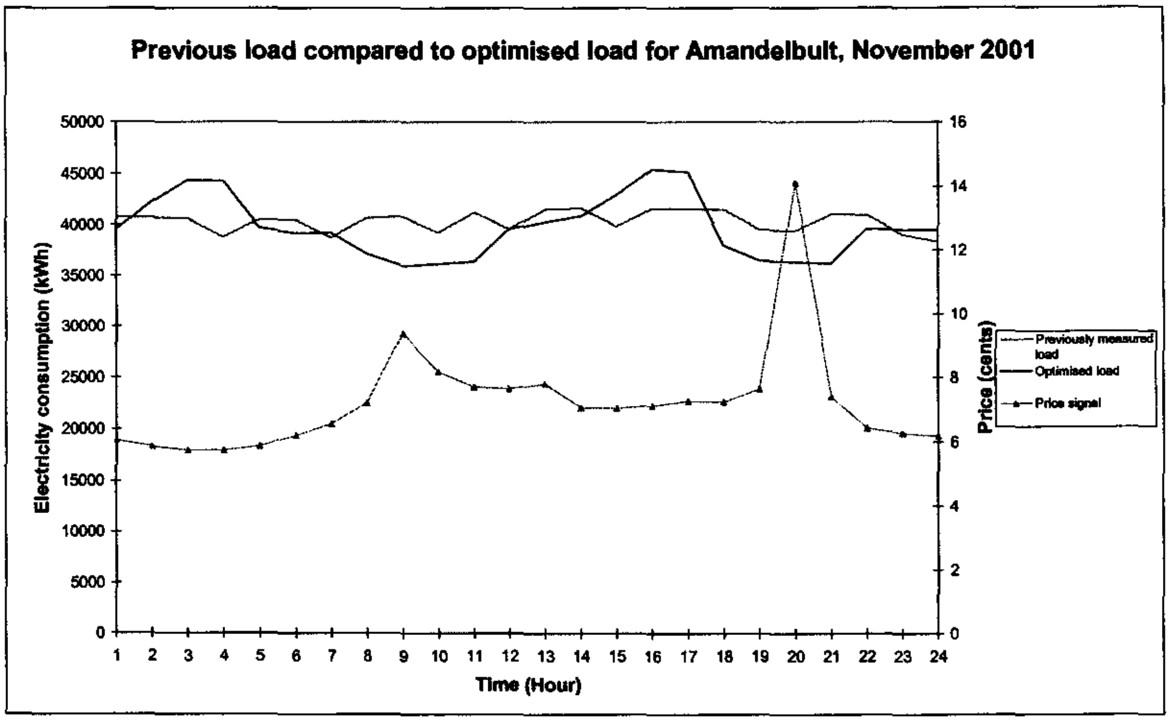

Figure B.11: Typical weekday, Amandelbult, November 2001

During a typical weekday a total of 23.7MW can be shifted from the morning and evening peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure B.11*.

On the refrigeration side an average electricity saving of 52.5% of the refrigeration electricity consumption is achievable. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.

B.12 December, 2001

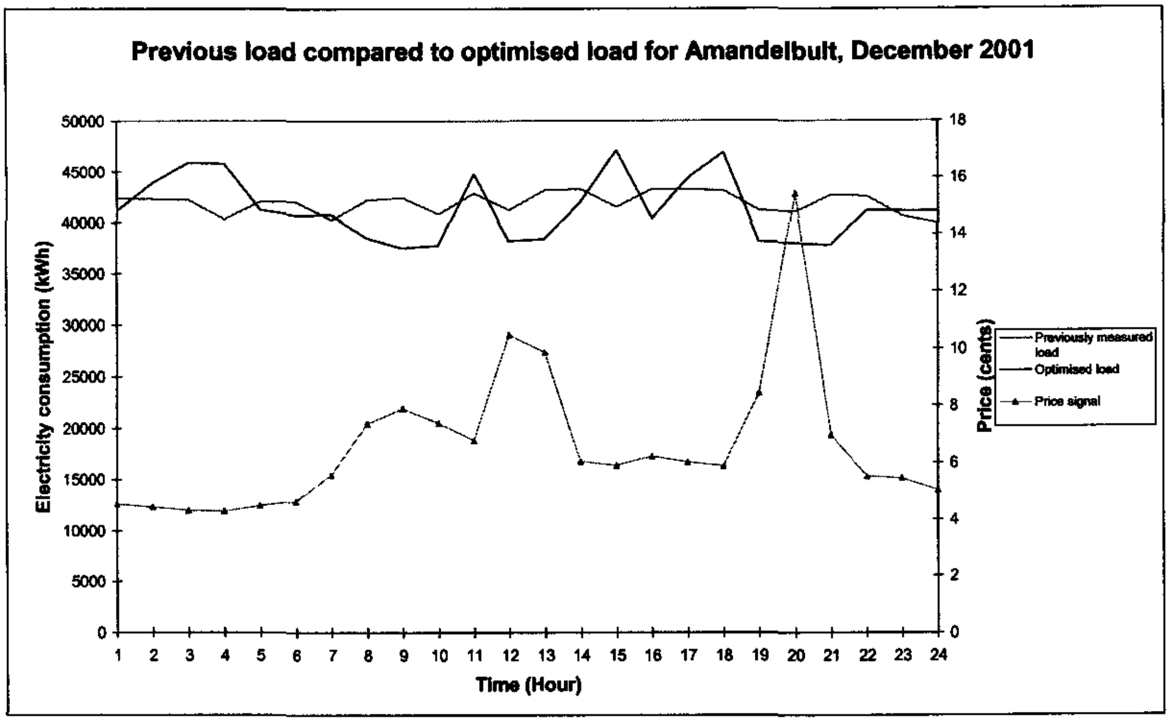

Figure B.12: Typical weekday, Amandelbult, December 2001

During a typical weekday a total of 25.7MW can be shifted from the morning and evening peak price periods. The most of the load is shifted to the early morning and early evening low demand periods as shown in *Figure B.12*.

On the refrigeration side an average electricity saving of 49% of the refrigeration electricity consumption is achievable. This is done by changing the control strategy from supplying a constant chilled water temperature to one that only supplies enough chilled water to keep the underground temperature within acceptable limits.