

**A METHODOLOGY TO IDENTIFY,  
QUANTIFY AND VERIFY THE COST  
BENEFITS OF ENERGY AND PROCESS  
IMPROVEMENTS ON A FERRO-METAL  
PRODUCTION PLANT**

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Cobus Martins

## **Abstract**

**Title:** A methodology to identify, quantify and verify the cost benefits of energy and process improvement opportunities in a Ferro-metal production plant.

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**School:** Mechanical and Materials Engineering.

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South Africa has an energy intensive economy with a high dependency on local mining and base metal industries. Furnace plants, which form part of the metal industry, are energy intensive as a result of the actual melting processes which require a great amount of energy. The high electricity and energy usage translates into high operating costs for these plants which in turn reduces the profitability of the plants.

South Africa's ferrochrome industry supplies about 60% of the world's ferrochrome demand and holds around 80% of the world's chrome reserves. This makes South Africa one of the key ferrochrome producers in the world. There is however a need to reduce the cost of production of these plants to ensure competitiveness and profitability within the world market.

This dissertation starts by providing an introduction to the problem and then defining the objective and scope of the study. The need for a methodology to identify, quantify and verify energy and process improvement opportunities in Ferro-metal production plants is highlighted. This need exists because there is a lack of adequate methods for an integrated approach. Three main barriers to energy projects were identified in this study, namely: institutional, technological and financial barriers. The opportunities for energy management and process improvements are investigated, including opportunities to overcome the barriers identified in the study.

A methodology, which is developed to incorporate both increased production and energy efficiency scenarios, is then provided. The methodology is firstly aimed at identifying possible opportunities and then quantifying them in terms of financial benefits for the plant. This is necessary to establish whether it will be worth while to explore the opportunities further. Benchmarking is also included in the methodology as this helps to track the performance of the plant over time.

A process was developed to enable accurate measurement and verification of energy related projects in order to evaluate the effectiveness or success of implemented projects. This process is necessary to enhance the credibility of energy related projects by providing an accurate and transparent evaluation of the project's performance. This in turn provides the stakeholders with invaluable information regarding their investments in energy projects.

The developed methodology was applied to a case study of a Ferro-metal production plant in order to evaluate the methodology. The case study revealed that the methodology can successfully identify and quantify potential opportunities. The no-cost and low-cost opportunities identified, showed a maximum possible annual saving of up to R925,500 depending on the specific options implemented. Load control opportunities in peak periods revealed an estimated annual cost saving of up to R3,767,400 per year. A possible estimated annual energy consumption saving worth R22,629,900 was identified by a Cusum analysis. This analysis was also used to examine the benefit of a production gain instead of energy efficiency which showed a possible increase in production of 60,300 tonnes per year.

The measurement and verification process was then used to determine the impact that an upgrade of a furnace, aimed at increasing production, had on the actual performance of the furnace. The verification process showed an increase in production worth over R3million and an energy saving of over R1million as a direct result of the upgrade. The process showed that the upgrade did indeed achieve a production gain and therefore the upgrade is considered to be a success.



## Uittreksel

- Titel: 'n Metodologie vir die identifisering, kwantifisering en verifiëring van die finansiële voordele van energie en proses verbeterings in 'n Ferro-metaal produserende aanleg.
- Outeur: G.J. (Cobus) Martins.
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Suid-Afrika het 'n energie intensiewe ekonomie wat 'n hoë afhanklikheid van plaaslike myn en basis metaal industrieë het. Smeltings aanlegte, wat deel vorm van die metaal industrie, is energie intensief as gevolg van die smeltings prosesse wat groot hoeveelhede energie benodig. Die hoë elektrisiteit en energie gebruik veroorsaak hoë operasionele kostes vir die aanlegte wat lei tot 'n verlaagde winsgewendheid van die aanlegte.

Suid-Afrika se ferrochroom industrie voorsien 60% van die wêreld se ferrochroom aanvraag en beskik oor sowat 80% van die wêreld se chroom reserwes. Dit bring mee dat Suid-Afrika een van die sleutel ferrochroom produseerders in die wêreld is, maar daar bestaan 'n behoefte om produksiekostes te verlaag om kompetering en winsgewendheid in die wêreldmark te verseker.

Dié skripsie begin deur 'n inleiding tot die probleem daar te stel en dan die doelwit sowel as die omvang van die studie te definieer. Die behoefte aan 'n metodologie vir die identifisering, kwantifisering en verifiëring van energie en proses verbeterings geleenthede in Ferro-metaal produserende aanlegte word daarna ondersoek. Hierdie behoefte bestaan as gevolg van 'n tekort aan voldoende metodes vir 'n geïntegreerde benadering tot energie. Drie hoof struikelblokke vir energie projekte is binne die studie geïdentifiseer, naamlik: institusionele, tegnologiese en finansiële struikelblokke. Die geleenthede vir energie bestuur en proses verbeterings is ondersoek en sluit geleenthede in om die geïdentifiseerde struikelblokke te oorkom.

'n Metodologie, wat ontwerp is om beide verhoogte produksie sowel as energie effektiwiteit in ag te neem, word verskaf. Die metodologie is eerstens daarop gemik om moontlike geleenthede te identifiseer en daarna die geleenthede te kwantifiseer in terme van finansiële voordele vir die aanleg. Laasgenoemde is nodig om te bepaal of 'n verdere ondersoek van die geleenthede die moeite werd sal wees. 'n Hoogtemerk word ingesluit by die metodologie omdat dit help om die verrigting van die aanleg oor tyd te volg.

'n Proses is ontwikkel vir die akkurate meting en verifiëring van energie projekte om te help met die evaluering van die effektiwiteit van geïmplimenteerde projekte. Die proses is nodig om die kredietwaardigheid van energie projekte te verbeter deur 'n akkurate en deursigtige evaluering van die projek se verrigting te gee.

Die ontwikkelde metodologie is toegepas op 'n gevallestudie van 'n Ferro-metaal produserende aanleg om die metodologie te evalueer. Die gevallestudie het getoon dat die metodologie potensiële geleenthede suksesvol kan identifiseer en kwantifiseer. Die geen-koste en lae-koste geleenthede wat geïdentifiseer is, wys 'n maksimum potensiële jaarlikse besparing van tot R925,500 afhangende van die spesifieke opsies wat geïmplimenteer word. Beheer geleenthede in spitsstye het 'n potensiële benaderde jaarlikse koste besparing van tot R3,767,400. 'n Moontlike jaarlikse koste besparing van R22,629,900 is geïdentifiseer deur 'n Cusum analise te gebruik. Hierdie analise is gebruik om die voordeel van verhoogde produksie teenoor energie effektiwiteit te ondersoek. Die analise wys 'n moontlike verhoging in produksie van 60,300 ton per jaar.

Die meting en verifiëring proses is toegepas op 'n oond opgradering, wat daarop gemik is om die produksie van die oond te verhoog, en sodoende vas te stel wat die impak van die opgradering was. Die verifikasie proses het getoon dat die opgradering 'n toename in produksie van meer as R3 miljoen en 'n energie besparing van meer as R1 miljoen tot gevolg het. Die proses het getoon dat die opgradering wel 'n verhoogde produksie tot gevolg het en dus as 'n sukses toegekryf kan word.

## **Contributions of this study**

This study contributed the following:

- ❑ A conference presentation presented at the Industrial and Commercial Use of Energy (ICUE) conference, May 2004 entitled: *Performance and Energy Optimisation for a South African ferrochrome producing plant*, W.L.R. den Heijer, prof. L.J. Grobler and G.J. Martins.
- ❑ Methodologies to identify, quantify, and verify cost benefits of energy and process improvements.
- ❑ Energy and Process improvement opportunities identified and quantified for the ferrochrome plant under consideration.
- ❑ A scoping study report for the plant investigated.
- ❑ A feasibility study performed for the plant.

## Nomenclature

<i>Btu</i>	<i>British Thermal Unit</i>
<i>BOF</i>	<i>Basic Oxygen Furnace</i>
<i>CDM</i>	<i>Clean Development Mechanism</i>
<i>CERs</i>	<i>Certified Emission Reductions</i>
<i>CIP</i>	<i>Continuous Improvement Programme</i>
<i>CO<sub>2</sub></i>	<i>Carbon Dioxide</i>
<i>CUSUM</i>	<i>Cumulative Sum</i>
<i>DOE</i>	<i>Designated Operational Entity</i>
<i>DSM</i>	<i>Demand Side Management</i>
<i>DSS</i>	<i>Decision support System</i>
<i>EAF</i>	<i>Electric Arc Furnace</i>
<i>EE</i>	<i>Energy Efficiency</i>
<i>EMS</i>	<i>Energy Management System</i>
<i>FeSi</i>	<i>Ferrosilicon</i>
<i>GHG</i>	<i>Greenhouse Gasses</i>
<i>ICEE</i>	<i>Industrial Commercial Energy Efficiency</i>
<i>IEP</i>	<i>Integrated Electricity Planning</i>
<i>IPMVP</i>	<i>International Performance Measurement and Verification Protocol</i>
<i>IRR</i>	<i>Internal Rate of Return</i>
<i>kJ</i>	<i>Kilo Joules</i>
<i>KPI</i>	<i>Key Performance Indicator</i>
<i>kVA</i>	<i>Kilovolt Ampere</i>
<i>kvarh</i>	<i>Kilovar-hour</i>
<i>kW</i>	<i>Kilo Watt</i>
<i>kWh</i>	<i>Kilo Watt hour</i>
<i>MtCO<sub>2</sub>e</i>	<i>Mega Tonnes Carbon Dioxide Equivalent</i>
<i>M&amp;V</i>	<i>Measurement and Verification</i>
<i>MW</i>	<i>Mega Watt</i>
<i>MWh</i>	<i>Mega Watt hour</i>
<i>NER</i>	<i>National Electricity Regulator</i>
<i>NIM</i>	<i>National Institute for Metallurgy</i>
<i>NPV</i>	<i>Net Present Value</i>
<i>PB</i>	<i>Payback</i>
<i>R</i>	<i>Rand</i>
<i>SCADA</i>	<i>Supervisory Control and Data acquisition</i>
<i>SO<sub>2</sub></i>	<i>Sulphur Dioxide</i>
<i>SSM</i>	<i>Supply Side Management</i>
<i>tCO<sub>2</sub>e</i>	<i>Tonnes Carbon Dioxide equivalent</i>
<i>TOU</i>	<i>Time of Use</i>
<i>UNFCCC</i>	<i>United Nations Framework Convention on Climate Change</i>
<i>US</i>	<i>United States</i>
<i>VSD</i>	<i>Variable Speed Drive</i>

## TABLE OF CONTENTS

<b>ACKNOWLEDGEMENTS</b> .....	<b>I</b>
<b>ABSTRACT</b> .....	<b>II</b>
<b>UITTREKSEL</b> .....	<b>IV</b>
<b>CONTRIBUTIONS OF THIS STUDY</b> .....	<b>VI</b>
<b>NOMENCLATURE</b> .....	<b>VII</b>
<b>TABLE OF CONTENTS</b> .....	<b>VIII</b>
<b>LIST OF FIGURES</b> .....	<b>XI</b>
<b>LIST OF TABLES</b> .....	<b>XIII</b>
<b>CHAPTER 1: INTRODUCTION</b> .....	<b>2</b>
1.1    BACKGROUND.....	2
1.2    PROBLEM STATEMENT .....	4
1.3    OBJECTIVE OF THIS STUDY.....	5
1.4    SCOPE OF THIS STUDY.....	5
1.5    REFERENCES .....	7
<b>CHAPTER 2: NEEDS, BARRIERS AND OPPORTUNITIES FOR ENERGY MANAGEMENT AND PROCESS IMPROVEMENTS IN A FERRO-METAL PRODUCTION PLANT</b> .....	<b>9</b>
2.1    INTRODUCTION .....	9
2.1.1 <i>Energy White Paper</i> .....	9
2.1.2 <i>Emissions</i> .....	10
2.2    FURNACE PLANTS .....	10
2.2.1 <i>Background</i> .....	10
2.2.2 <i>Description of Furnace Operation</i> .....	12
2.3    NEEDS FOR ENERGY MANAGEMENT AND PROCESS IMPROVEMENTS ON FURNACES .....	18
2.3.1 <i>Reduce Production Costs</i> .....	18
2.3.2 <i>Improve Energy Efficiency</i> .....	26
2.3.3 <i>Improve Production</i> .....	28
2.3.4 <i>Environmental Emission Impact Reduction</i> .....	29
2.4    BARRIERS OF ENERGY MANAGEMENT AND PROCESS IMPROVEMENTS .....	33
2.4.1 <i>Institutional aspects</i> .....	34
2.4.2 <i>Technological aspects</i> .....	34
2.4.3 <i>Financial aspects</i> .....	35
2.4.4 <i>Measurement and Verification</i> .....	35
2.5    OPPORTUNITIES FOR ENERGY MANAGEMENT AND PROCESS IMPROVEMENTS .....	36
2.5.1 <i>Financing Opportunities</i> .....	36
2.5.2 <i>Demand Side Management Opportunities</i> .....	37
2.5.3 <i>Energy Efficiency Opportunities</i> .....	38
2.5.4 <i>Environmental Emission Reduction Opportunities</i> .....	43
2.6    CONCLUSION.....	44
2.7    REFERENCES .....	45
<b>CHAPTER 3: A METHODOLOGY TO IDENTIFY AND QUANTIFY PROCESS AND ENERGY OPTIMISATION OPPORTUNITIES</b> .....	<b>51</b>
3.1    INTRODUCTION .....	51
3.2    BENEFITS OF INTEGRATED PROCESS AND ENERGY IMPROVEMENT APPROACH.....	51

3.3	PROCESS AND ENERGY IMPROVEMENT METHODOLOGY .....	51
3.3.1	<i>Scoping Study</i> .....	52
3.3.2	<i>Detailed Feasibility</i> .....	55
3.3.3	<i>Detail Engineering and Design</i> .....	61
3.3.4	<i>Project Implementation</i> .....	61
3.3.5	<i>Commissioning</i> .....	61
3.3.6	<i>Operation and Maintenance (Sustaining of Performance)</i> .....	62
3.4	CONCLUSIONS .....	62
<b>CHAPTER 4: MEASUREMENT AND VERIFICATION .....</b>		<b>64</b>
4.1	INTRODUCTION .....	64
4.2	WHAT IS MEASUREMENT AND VERIFICATION? .....	64
4.3	WHY MEASURE AND VERIFY? .....	65
4.4	HOW DOES MEASUREMENT AND VERIFICATION WORK? .....	65
4.4.1	<i>Baseline Construction for Furnace</i> .....	68
4.5	M&V PROCESS .....	69
4.5.1	<i>M&amp;V Plan</i> .....	70
4.5.2	<i>Pre-implementation</i> .....	71
4.5.3	<i>Baseline Development and Baseline Report</i> .....	71
4.5.4	<i>Post-implementation</i> .....	72
4.5.5	<i>Performance Assessment</i> .....	72
4.5.6	<i>Saving Calculation</i> .....	72
4.6	ENERGY PROJECT AND M&V INTEGRATION .....	73
4.6.1	<i>M&amp;V Integration Description</i> .....	75
4.7	SUMMARY .....	75
4.8	REFERENCES .....	76
<b>CHAPTER 5: CASE STUDY TO IDENTIFY AND QUANTIFY ENERGY AND PROCESS IMPROVEMENT OPPORTUNITIES .....</b>		<b>78</b>
5.1	INTRODUCTION .....	78
5.2	SCOPING STUDY .....	78
5.2.1	<i>Walk-through Assessment</i> .....	78
5.2.2	<i>High-level Benchmarking, Diagnostics and Analysis</i> .....	79
5.3	DETAILED FEASIBILITY STUDY .....	89
5.3.1	<i>Plant Assessment</i> .....	89
5.3.2	<i>Installation and Integration of a Data Acquisition System</i> .....	90
5.3.3	<i>Data Mining</i> .....	90
5.3.4	<i>Identification of Solutions</i> .....	101
5.3.5	<i>Cost/Benefit Analysis</i> .....	101
5.3.6	<i>Identification and Recommendation for Implementation</i> .....	101
5.4	CONCLUSION .....	101
<b>CHAPTER 6: M&amp;V CASE STUDY TO MEASURE AND VERIFY THE IMPACT OF A FURNACE UPGRADE .....</b>		<b>104</b>
6.1	INTRODUCTION .....	104
6.2	BASELINE CONSTRUCTION .....	104
6.3	SAVING CALCULATION AND IMPACT OF PROJECT .....	105
6.3.1	<i>Energy Saving</i> .....	106
6.3.2	<i>Production Benefit</i> .....	107
6.4	CONCLUSION .....	107
<b>CHAPTER 7: CONCLUSION AND RECOMMENDATIONS .....</b>		<b>109</b>
7.1	INTRODUCTION .....	109
7.2	CHAPTER SUMMARY .....	109
7.3	STUDY CONCLUSION .....	110
7.4	RECOMMENDATIONS FOR FURTHER WORK .....	111

**APPENDIX A .....A1**  
**APPENDIX B ..... B1**

## LIST OF FIGURES

FIGURE 1-1: MODERATE DEMAND FORECAST .....	3
FIGURE 2-1: SCHEMATIC REPRESENTATION OF A TYPICAL BLAST FURNACE .....	13
FIGURE 2-2: COAL CONSUMPTION IN IRON AND STEEL INDUSTRY .....	14
FIGURE 2-3: SCHEMATIC REPRESENTATION OF A TYPICAL BASIC OXYGEN FURNACE .....	14
FIGURE 2-4: SCHEMATIC OF FERROCHROME EAF .....	16
FIGURE 2-5: SCHEMATIC REPRESENTATION OF A TYPICAL EAF (TOP PICTURE SHOWS SIDE VIEW AND BOTTOM PICTURE SHOWS TOP VIEW OF EAF).....	17
FIGURE 2-6: PEAK, OFF-PEAK AND STANDARD TIMES FOR THE MEGAFLEX TARIFF.....	20
FIGURE 2-7: LOAD SHIFTING .....	23
FIGURE 2-8: LOAD SHEDDING .....	24
FIGURE 2-9: STRATEGIC LOAD GROWTH.....	24
FIGURE 2-10: ENERGY EFFICIENCY.....	27
FIGURE 2-11: TOTAL EMISSIONS PER SECTOR.....	31
FIGURE 3-1: FLOW DIAGRAM OF ENERGY AND PROCESS IMPROVEMENT PROCEDURE.....	52
FIGURE 3-2: HIGH-LEVEL PROCESS EFFICIENCY VISUAL REPRESENTATION.....	54
FIGURE 3-3: HIGH-LEVEL PERFORMANCE ANALYSIS VISUAL REPRESENTATION .....	55
FIGURE 3-4: DATA MINING PROCESS .....	57
FIGURE 3-5: CAUSE ANALYSIS VISUAL REPRESENTATION.....	59
FIGURE 3-6: TARGETS AND POTENTIAL SAVING VISUAL REPRESENTATION .....	60
FIGURE 4-1: PROJECT STAGES .....	66
FIGURE 4-2: REPRESENTATION OF BASELINE AND SAVINGS.....	67
FIGURE 4-3: FURNACE BASELINE PRESENTATION.....	68
FIGURE 4-4: FURNACE SAVING PRESENTATION .....	69
FIGURE 4-5: M&V PROCESS FLOW DIAGRAM .....	70
FIGURE 4-6: M&V PROJECT INTEGRATION WITH ENERGY RELATED PROJECT.....	74
FIGURE 5-1: BREAKDOWN OF PLANT ENERGY CONSUMPTION ACCORDING TO CONTRIBUTION TO TOTAL ENERGY USE .....	79
FIGURE 5-2: SCHEDULING RATIONALE DURING PEAK HOURS.....	84
FIGURE 5-3: TYPICAL DEMAND PROFILE OF PLANT FOR A FEW DAYS .....	85
FIGURE 5-4: TYPICAL DAILY DEMAND PROFILE FOR FURNACE 4 .....	85
FIGURE 5-5: DEMAND PROFILE FOR FURNACE 4 CONTROLLED TO MINIMUM OF MINIMUM DEMAND DURING PEAK HOURS ...	86
FIGURE 5-6: DEMAND PROFILE FOR FURNACE 4 CONTROLLED TO AVERAGE OF THE MINIMUM DURING PEAK HOURS .....	87
FIGURE 5-7: LOAD CONTROL TO MINIMUM OF THE MINIMUM DEMAND DURING PEAK, FURNACE 2 - 6 .....	88
FIGURE 5-8: LOAD CONTROL TO AVERAGE OF THE MINIMUM DEMAND DURING PEAK, FURNACE 2 - 6 .....	89
FIGURE 5-9: DAILY APPLIED ENERGY AGAINST TONNES SALEABLE PRODUCTION (FURNACE 4) .....	91
FIGURE 5-10: DAILY APPLIED ENERGY AGAINST TONNES SALEABLE PRODUCTION (FURNACE 4) WITH REGRESSION .....	92
FIGURE 5-11: ADJUSTED (50%) DAILY APPLIED ENERGY AGAINST TONNES SALEABLE PRODUCTION (FURNACE 4).....	93
FIGURE 5-12: SPECIFIC ENERGY CONSUMPTION PER TON/TAP FOR FURNACE 4 .....	95



FIGURE 5-13: DAILY ENERGY CONSUMPTION VERSUS TONNES SALEABLE PRODUCTION PER DAY WITH ISOLATED MWh/DAY ABOVE AVERAGE FOR FURNACE 4 .....	96
FIGURE 5-14: CUSUM PROFILES FOR ALL FURNACES FROM 1 SEPTEMBER 2002 TO 28 JANUARY 2003 .....	97
FIGURE 5-15: FURNACE 4, CUSUM ANALYSIS GRAPH INDICATING A SINGLE PERIOD OF "GOOD PERFORMANCE" .....	98
FIGURE 5-16: FURNACE 4, POTENTIAL ELECTRICITY CONSUMPTION SAVINGS OVER PERIOD (1 SEPTEMBER 2002 TO 28 JANUARY 2003) .....	99
FIGURE 6-1: BASELINE FOR FURNACE.....	105
FIGURE 6-2: BASELINE AND ACTUAL SCATTER PLOT .....	105

## LIST OF TABLES

TABLE 1-1: INTEGRATED ELECTRICITY PLAN REDUCTION .....	4
TABLE 2-1: PRODUCTION COST REDUCTION CRITERIA IMPACTS .....	25
TABLE 2-2: EFFICIENCY IMPROVEMENT CRITERIA IMPACT .....	28
TABLE 2-3: IMPROVED PRODUCTION CRITERIA IMPACT .....	29
TABLE 2-4: ENVIRONMENTAL IMPLICATIONS OF USING 1kW OF POWER.....	32
TABLE 2-5: EMISSION REDUCTION IMPACT ON VARIOUS CRITERIA .....	32
TABLE 2-6: POTENTIAL INVESTOR COUNTRIES.....	43
TABLE 5-1: SUMMARY OF FURNACES KPI'S.....	80
TABLE 5-2: SUMMARY OF NO-COST AND LOW-COST OPPORTUNITIES AND ASSOCIATED ANNUAL COST IMPLICATIONS .....	81
TABLE 5-3: SUMMARY OF IMPACTS ON FURNACE LOAD CONTROL ANALYSIS FOR CONTROL TO MINIMUM OF THE MINIMUM DEMAND AND TO AVERAGE OF THE MINIMUM DEMAND DURING PEAK HOURS THROUGHOUT THE YEAR (HIGH- AND LOW DEMAND SEASONS).....	88
TABLE 5-4: SUMMARY OF POTENTIAL ANNUAL COST SAVINGS FOR FURNACES AT A 50% REDUCTION.....	94
TABLE 5-5: SUMMARY OF POTENTIAL ANNUAL COST SAVINGS FOR FURNACES AT A 25% REDUCTION.....	95
TABLE 5-6: SUMMARY OF FURNACE KPI'S FOR ACTUAL OPERATION AND GOOD PERFORMANCE OPERATION.....	100
TABLE 5-7: SUMMARY OF IMPACTS ON FURNACE ELECTRICITY CONSUMPTION (AT CONSTANT PRODUCTION) AND PRODUCTION (AT CONSTANT ELECTRICITY CONSUMPTION) IN GOOD PERFORMANCE MODES OF OPERATION (EXTRAPOLATED TO ANNUAL BASIS).....	100
TABLE 6-1: ENERGY SAVING IMPACT .....	106
TABLE 6-2: PRODUCTION INCREASE BENEFITS .....	107

# CHAPTER 1

## INTRODUCTION

*This chapter provides an introduction to this study, highlighting the objectives and scope of the study.*

## **CHAPTER 1: INTRODUCTION**

### **1.1 Background**

South Africa's ferrochrome industry is the strongest world leader of all South African businesses outperforming even platinum-group-metals. According to SAChrome (2004) the South African ferrochrome industry's earnings are of more potential to South Africa than diamonds.

South Africa's ferrochrome industry supplies 60% of the world's ferrochrome demand and holds about 80% of the world's chrome reserves. This makes South Africa one of the key ferrochrome producers in the world. The ferrochrome industry in South Africa however suffers from the unstable rand, as trade is done in United States dollars, which hampers investment planning (Industrial Metallurgy (2004)). South Africa's ferrochrome companies export around 3,5 million tons of ferrochrome a year and this is believed to grow by another 1 million tons by 2005. The sales of ferrochrome in South Africa are said to be worth R6,7 billion currently and it is estimated that it will grow to more than R10 billion by the year 2010.

South Africa has an extremely energy intensive economy with a high dependency on local mining and base metal industries according to Africa (2003). Furnace plants, which form part of the metal industry, are especially energy intensive. The main contributor to their energy intensiveness is the actual melting process as this process requires a great amount of energy.

The total world primary commercial energy usage has increased by an average annual growth rate of 1.6% in the last quarter century. The demand for energy is also suspected to increase as economic growth occurs in developing countries. (Industrial Metallurgy (2004))

The current expected power demand growth rate for the electrification (residential) sector in South Africa is 15% p.a. over the next ten years. This will have profound implications for Eskom. A new power-plant will need to be constructed within the next few years to enable Eskom to meet the new load that will only be necessary for short periods in the day and only for a few months (mainly winter months) in the year. The utilisation of such a power-plant would therefore be very low making the investment unattractive (Eskom (2004)).

Demand Side Management (DSM) is an attractive alternative to the construction of a new power-plant. At this stage South Africa possesses a surplus electricity generation capacity but the construction of a new power-plant takes up to 10 years (for pumped storage hydro capacity) which implies that a decision to build a new power-plant had to be taken early in the 1990's to be able to meet the demand in 2007.

According to Eskom (2004) substantial benefits for all customers could be derived if DSM can be used to limit residential demand growth or mitigate the impacts through the provision of incentives for industry/commerce to move load out of peak periods. High price increases can also be avoided if the construction of a new power-plant can be avoided. Therefore, DSM can defer any supply side generation construction decision well into the next millennium if enough suitable DSM projects are implemented.

The long term moderate maximum demand forecast by Eskom, including a 15% reserve margin and current interruptible load agreements, is shown in Figure 1-1.

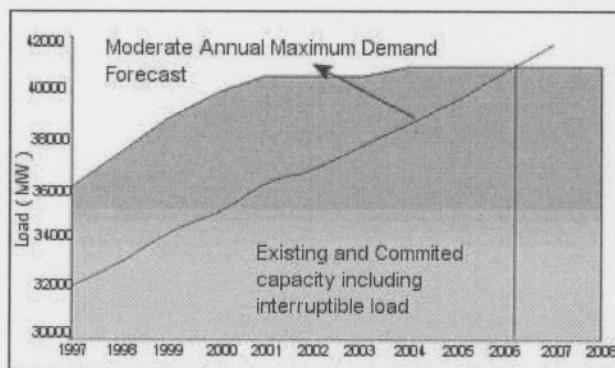


Figure 1-1: Moderate Demand Forecast.

From Figure 1-1 it can be seen that the forecast predicts that in 2006 South Africa will run out of maximum demand electricity capacity if no intervention or counter measure is employed.

Eskom's current Integrated Electricity Plan (IEP) includes a proposed reduction of 7300MW of peak load as outlined in Table 1-1 below. This reduction can be achieved with a considerably lower cost than a supply side initiative such as the construction of a new power-plant.

**Table 1-1:** Integrated Electricity Plan Reduction.

<b>DSM Programme</b>	<b>Impact by 2015 (MW)</b>
Interruptible load	3200
Load Shifting	1600
Energy Efficiency	2500
<b>Total</b>	<b>7300</b>

## **1.2 Problem Statement**

The number of electric smelting facilities for production of Ferro-alloys in South Africa has risen over the years because of South Africa's enormous reserves of ores available for the production of Ferro-alloys and related products (Bisio, Rubatto & Martini (2000)).

The typical contribution of energy to the total production cost of a Ferro-metal plant is about 22% and its contribution to the variable cost lies within the region of 33%. An initial analysis of the monthly energy consumption patterns of typical Electric Arc Furnace (EAF) on a plant shows differences of up to 30% between the different months for the same tonnage output. The energy input to the furnaces per ton of product produced averaged around 3,6MWh as calculated from initial plant data. This indicates that apart from load management and control strategies, energy efficiency forms a very important part.

Therefore, there is a need to determine the potential that exists in terms of energy efficiency and load management. It is also important to determine how to reduce the production energy cost and consequently improve the bottom line.

There is currently a need to accurately identify and quantify energy saving and process improvement opportunities in furnace plants. There is also a need to accurately verify the actual impacts after implementation is completed.

This study will therefore address the development of a methodology to accurately identify, quantify and verify the cost benefits of energy and process improvements on a Ferro-metal production plant.

### **1.3 Objective of this Study**

The objective of this study is to develop a methodology to aid in the search for energy and process improvement opportunities in a Ferro-metal production plant. The main objectives of this methodology are to establish accurate methods for finding energy and process improvement opportunities and estimating the cost benefits of these opportunities. This methodology will therefore consist of the following parts:

- ❑ Identification;
- ❑ Quantification; and
- ❑ Verification of energy and process improvement opportunities.

The objective of this study also includes the estimation of the cost benefits of the identified opportunities.

### **1.4 Scope of this Study**

The scope of this study includes the development of a methodology for the identification and quantification of energy and process improvement opportunities. The study will also present a proposed method for the measurement and verification of the implementations

of the identified opportunities. The study however does not include the finding of actual viable solutions for the identified opportunities, neither does it include the detail engineering of these solutions. The solutions and detail engineering can form part of another study aimed at finding and analysing the actual solutions.

The actual solutions for the opportunities must be found when the plant decides which identified opportunities should be pursued further. Only after a decision is made, can possible solutions be investigated and the detail engineering of the most viable solution commence.



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## **CHAPTER 2**

# **NEEDS, BARRIERS AND OPPORTUNITIES FOR ENERGY MANAGEMENT AND PROCESS IMPROVEMENTS IN A FERRO-METAL PRODUCTION PLANT**

*This chapter presents the needs, barriers and opportunities for energy management and process improvements in a Ferro-metal production plant. Firstly, the needs will be presented followed by the barriers that were identified and finally the opportunities that exist.*

## **CHAPTER 2: NEEDS, BARRIERS AND OPPORTUNITIES FOR ENERGY MANAGEMENT AND PROCESS IMPROVEMENTS IN A FERRO-METAL PRODUCTION PLANT**

### **2.1 Introduction**

Organisations in South Africa are realising the importance of the impact that energy and process improvements have on every aspect of their operations (Moodley & Grobler (2003)). These impacts include increased competitiveness and reduced operating costs. By reducing operational costs an organisation can achieve a competitive advantage over similar organisations through reduced input costs.

Greater energy efficiency also leads to environmental benefits. These benefits include a reduction of carbon dioxide (CO<sub>2</sub>) as well as other Greenhouse Gasses (GHG) and particle emissions that can be harmful to the environment. Read (1991) states that the national energy demand will decrease and natural resources, especially fossil fuels, can be conserved with an increase in energy efficiency.

#### **2.1.1 Energy White Paper**

The White Paper on Energy Policy of the Republic of South Africa promotes energy efficiency awareness (Department of Minerals and Energy (1998)). In the Paper, energy efficiency is identified as one of the areas that needs to be developed and promoted in South Africa. The policy states that:

Energy efficiency and energy conservation considerations must therefore form part of an overall energy policy. Energy efficiency should also be considered within the conceptual framework known as Integrated Resource Planning, which considers both supply side and demand side options for meeting energy service requirements.

The White Paper also underpins the following main objectives:

- ❑ Increasing access to affordable energy services;
- ❑ Improving energy governance;
- ❑ Managing energy related environmental impacts; and
- ❑ Securing supply through diversity.

The South African government believes that efficient use of energy is best achieved through the creation of awareness of the benefits of energy efficiency measures and the deployment of incentives to encourage such measures. Although the Energy White Paper is not specific about the role of the National Electricity Regulator (NER), there exists an opportunity for the NER to play a significant role in meeting government objectives by promoting energy efficiency in the electricity supply and distribution industry.

### **2.1.2 Emissions**

A reduction in energy use means large environmental benefits since electricity generation accounts for approximately 50% of the pollution emissions generated in South Africa. CO<sub>2</sub> emissions increased by 14% in South Africa, between 1993 and 1998. A large portion of the emissions can be allocated to the burning of coal to generate electricity (Campbell (2000)). South Africa uses mainly coal to generate electricity in conjunction with a small amount of hydro and nuclear generation.

## **2.2 Furnace Plants**

### **2.2.1 Background**

South Africa has an extremely energy intensive economy with a high dependency on local mining and base metal industries (Africa (2003)). Furnace plants, which form part of the metal industry, are energy intensive plants. One of the main contributors to their energy use is the actual melting processes which usually takes place in some type of furnace. It takes a large amount of energy to melt the raw materials so that it can be cast into the various end products. There exists a need to bring down the costs of operation as

well as energy use of these plants. The need for an all-encompassing energy management approach exists for these industrial plants.

The number of electric smelting facilities for production of Ferro-alloys in South Africa has risen over the years because of South Africa's enormous reserves of ores available for the production of Ferro-alloys and related products (Bisio, Rubatto & Martini, (2000)). South Africa also have possession of plentiful supplies of cheap coal for generating electricity, furthermore water and labour are readily available.

Many of the EAF in South Africa operate with simple current control whereby each electrode is moved up or down as required to maintain constant current. This is usually done automatically by current sensitive equipment. A well designed automatic regulator is essential to ensure that the furnace can be operated continuously at its highest optimum power level so that the highest possible throughput of material and lowest cost of energy (per unit) can be maintained.

Ferrochromium, or more familiarly ferrochrome, is the alloy, containing the metal chromium that is the international form in which chromium is marketed. The US Bureau of Mines lists 15 varieties of ferrochrome under headings of high carbon, medium carbon, ferrosilicon-chromium, and low carbon ferrochromium-silicon. In 1971, according to Way (1975), 65% of the ferrochromium consumption in the USA went into the manufacture of stainless steel.

There is a relation between ferrochrome and stainless steel, as ferrochrome is used in stainless steel production. A study of the US figures over the period of 1950 to 1972 has shown that the ratio of ferrochrome consumption for steel production averages 66.5%. Time graphs of the US consumption of ferrochrome and production of stainless steel show a strong correlation. The ferrochrome market and demand for ferrochrome are to a great extent dependant on the stainless steel market.

A small amount of literature could be found on Ferro-metal production and electric arc furnaces used in Ferro-metal production. Therefore figures of steel furnaces will mostly be used. As far as possible actual figures for Ferro-metal production will be provided.

### **2.2.2 Description of Furnace Operation**

Most furnaces consist of a raw metal depot, a furnace for melting purposes, and a finished product depot. The raw material is usually crushed into smaller particles and purified by removing unwanted substances. The clean materials are then fed into a furnace and melted. During the melting process different materials are added to achieve the desired composition. When the molten metal has reached its desired composition and temperature, it is cast into the various desired end products. The slag resulted from the process is then disposed of by conveying it to slurry dumps.

The main facilities of a furnace plant are usually connected via transportation devices, such as conveyor belts, that transport the raw materials to the furnace and finished materials from the furnace.

Various types of furnaces, in the steel and Ferro-metal industry, are in use today. The three most frequently used types of furnaces are:

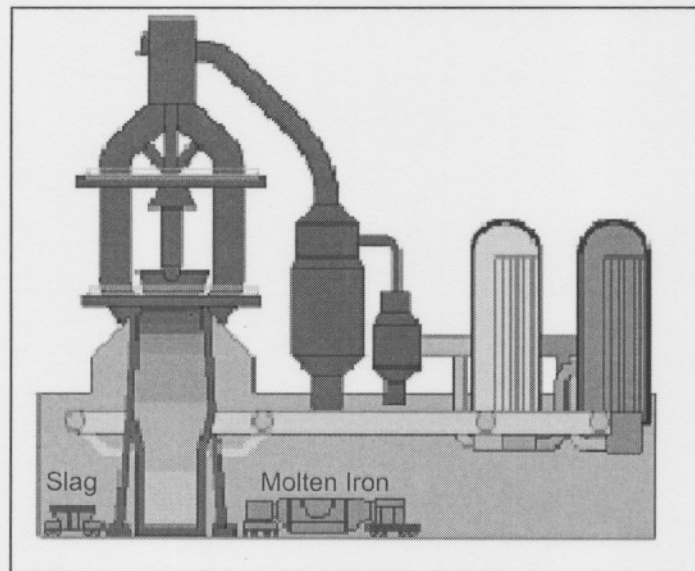
- Blast-furnaces;
- Basic oxygen furnaces; and
- Electric arc furnaces.

#### **2.2.2.1 Blast-Furnaces**

Blast-furnaces are mostly used in the iron and steel industry to produce molten pig iron from iron ore. The main purpose of the furnace is to chemically reduce and convert iron oxides into liquid iron.

Blast-furnaces are usually huge, shaft type steel vessels with refractory brick internal linings (Energy Solutions Centre (2004)). The furnaces can be up to ten stories high and

are usually placed over a crucible-like hearth. The charge necessary to produce molten pig iron usually consists of iron-bearing materials, coke, and flux. Additives can also be added to obtain desired compositions and characteristics. Figure 2-1 shows a schematic representation of a blast-furnace.



**Figure 2-1:** Schematic representation of a typical blast-furnace.

The largest source of energy for the blast-furnace is coal. Total coal consumption in the iron and steel industry in 1994 was 694,41 trillion Btu (732,6 trillion kJ) according to the Annual Statistical Report of the American Iron and Steel Institute (Energy Solutions Centre (2004)). Roughly 96% of this was used for coke production while the remaining 4% was used in operations such as electricity generation. Figure 2-2 shows the coal consumption graphs of 1990 to 1994 in the iron and steel industry.

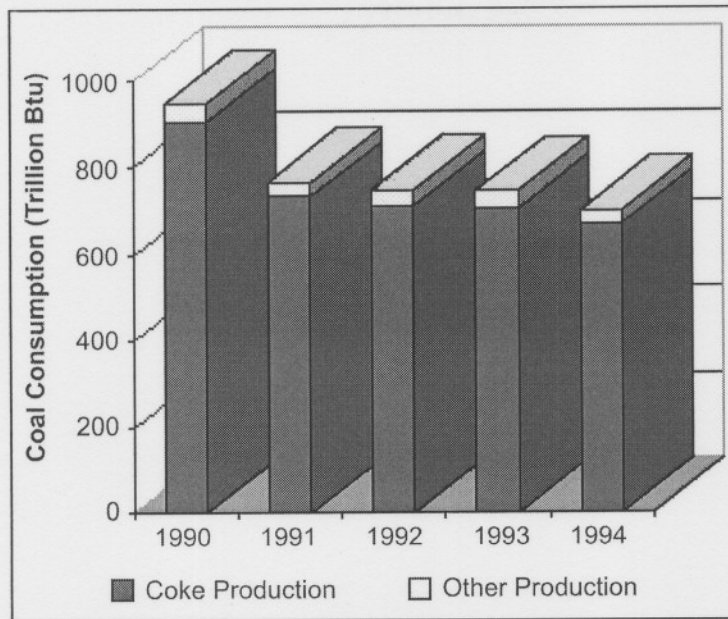


Figure 2-2: Coal consumption in iron and steel industry.

#### 2.2.2.2 Basic Oxygen Furnace

The basic oxygen steelmaking process converts molten iron from the blast-furnace into refined steel (Energy Solutions Centre (2004)). Up to 30% steel scrap can be added to the molten iron. High purity oxygen is blown through the molten bath to lower the carbon, silicon, manganese, and phosphorous content of the iron. Various fluxes can be added to reduce sulphur and phosphorous levels. Figure 2-3 shows a schematic representation of a typical Basic Oxygen Furnace (BOF).

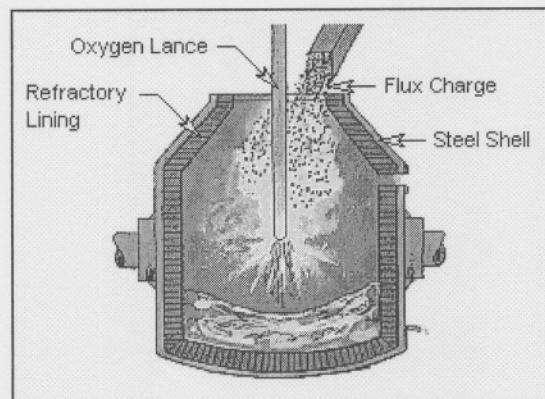


Figure 2-3: Schematic representation of a typical Basic Oxygen Furnace.



The actual furnace forms a small part of the facility as gas cleaning devices and materials handling equipment occupy most of the space in such facilities. Three principal categories of oxygen furnaces are used, namely: A Top Blown Process (BOP), A Bottom Blown Process (Q-BOP), and a combination process. In the BOP a water cooled lance is lowered from the top and blows oxygen at supersonic speed into the melt. Most US steelmakers make use of the BOP. The Q-BOP utilises oxygen through a number of tuyeres (air blast inlet ports) located at the bottom of the furnace. The combination process uses top blown oxygen in conjunction with inert gas injection through the bottom by means of tuyeres.

For steelmaking the basic oxygen furnace requires about 1,5 million Btu (1,582 million kJ) per ton of steel. Just over half of this energy is provided by the molten iron charge (Energy Solutions Centre (2004)). The rest of the energy is supplied by the oxidation reactions generated by the oxygen lances.

### **2.2.2.3 Electric Arc Furnace**

The EAF is the main furnace type used for the electric production of steel and various types of metal including ferrochrome. The main application of the EAF in the steel industry is the melting of steel scrap. The common configuration of an EAF in the steel industry is circular with a dish shaped hearth (Energy Solutions Centre (2004)).

A typical three-phase EAF has three vertically movable graphite electrodes mounted in the roof. These are lowered, after charging, to a height just above the scrap and an arc is struck which provides the heat for melting the scrap primarily through radiation but also through the current resistance through the metal. The following figure (Figure 2-4) shows a schematic representation of a ferrochrome EAF.

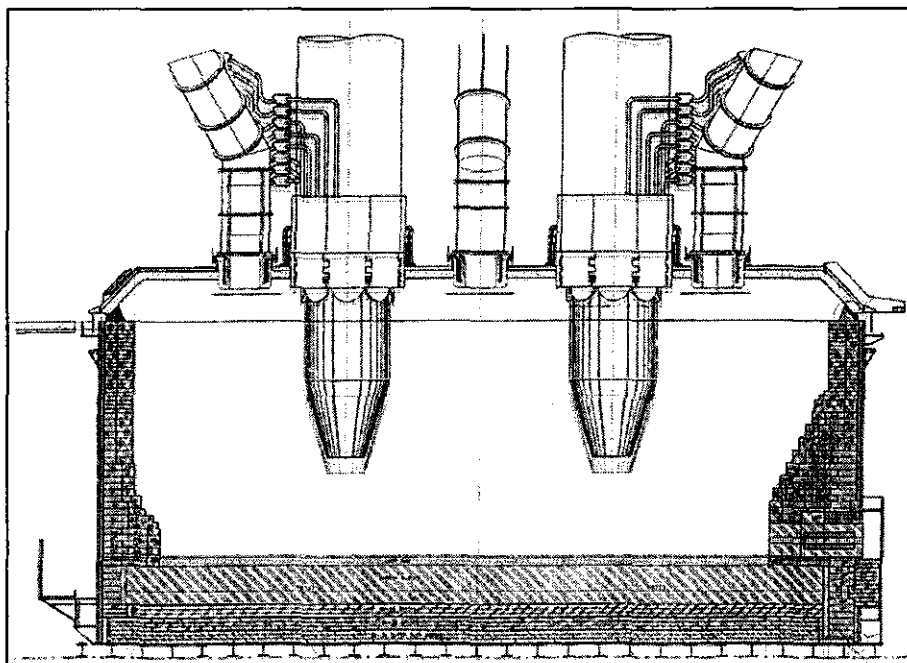
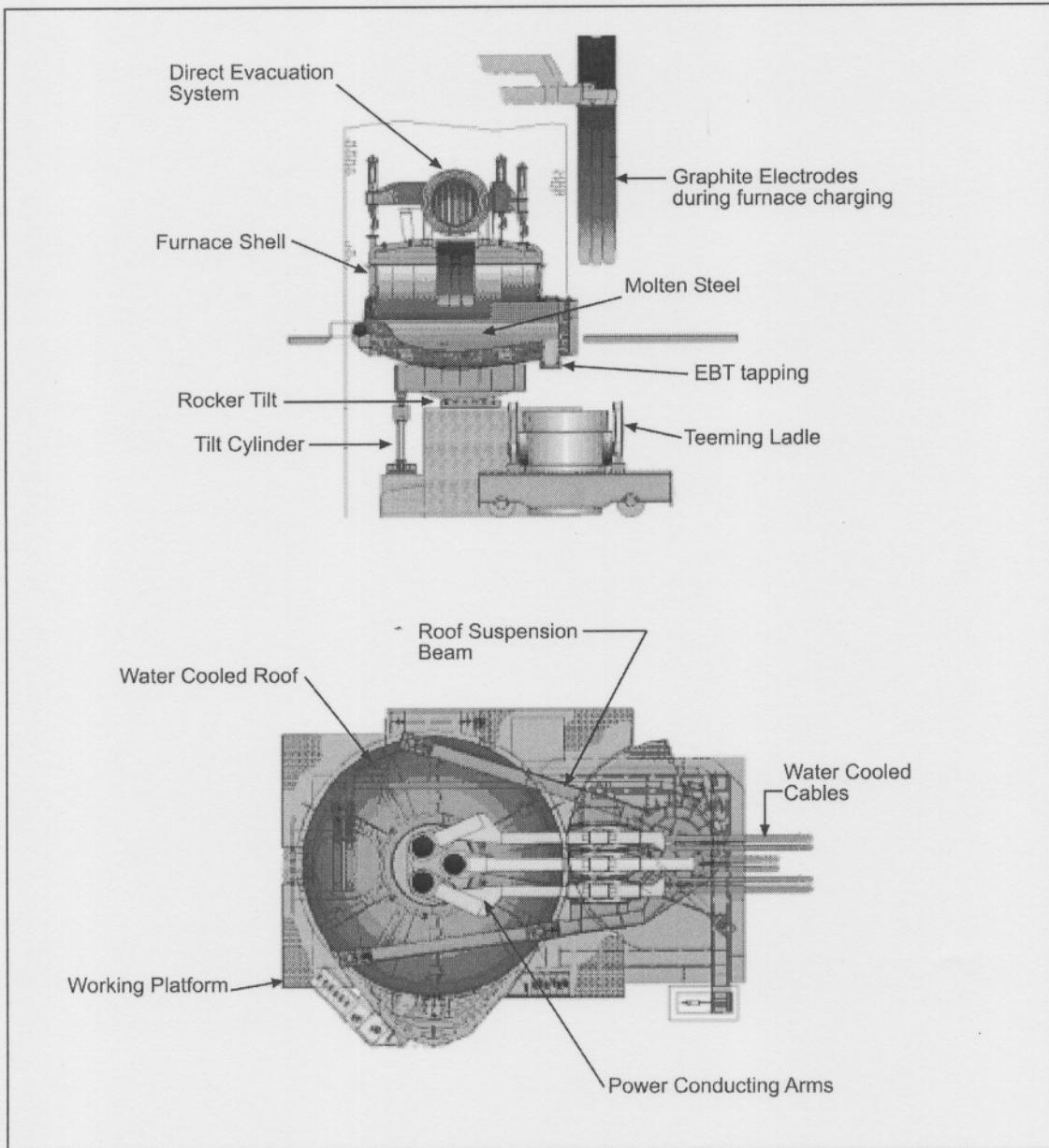


Figure 2-4: Schematic of Ferrochrome EAF.

The largest EAF in the US is capable of providing 370 tonnes per melt. Tap to tap times vary between one to five hours depending on a function of power input and refining equipment.

Energy consumption for a steel EAF varies between 350 and 700 kWh/tonne of steel produced, depending on the size of the EAF (Energy Solutions Centre (2004)). A typical steel EAF, without oxyfuel burners, uses approximately 475 kWh/tonne and with the use of oxyfuel burners this can be reduced to around 425kWh/tonne.

Ferrochrome production typically consumes 3,100 to 3,500 kWh of electricity per tonne of ferrochrome produced (Riekkola-Vanhanen (1999)). Electric energy consumption comprises almost 95% of total energy consumption. Oxy-fuel burners are not used on Ferro-metal furnaces as it has an adverse effect on the products. A schematic of a typical EAF, used in steel production, is shown in Figure 2-5.



**Figure 2-5:** Schematic representation of a typical EAF (Top picture shows side view and bottom picture shows top view of EAF).

## **2.3 Needs for Energy Management and Process Improvements on Furnaces**

Currently most, if not all, energy and production departments of plants work in isolation from other departments which hampers performance and efficiency of the plants.

Why is there a need for energy management on furnace plants? Furnace plants are extremely energy intensive and a small percentage saving can therefore have a profoundly big financial benefit. The objectives of an energy management and process improvement programme are to:

- ❑ Reduce production costs;
- ❑ Improve efficiency;
- ❑ Improve production; and
- ❑ Reduce the environmental impact.

The above mentioned four objectives are discussed in further detail in the following sections.

### **2.3.1 Reduce Production Costs**

As energy costs are generally high, reducing the energy input cost can result in more profit for the plant. Energy management initiatives are aimed at reducing energy costs and improving energy efficiency of plant equipment.

Production costs can be reduced by means of three different approaches. The first approach is to use less staff for operations thereby reducing personnel costs involved in production. The second approach involves the procurement of raw materials whereby better prices can be negotiated to reduce raw material costs and thus reduce the production costs. The final approach, which will be focussed on in this study, is to improve or reduce the energy cost involved in production. The energy cost can be

improved by exploring different tariffs, Demand Side Management (DSM) and Energy Efficiency (EE) strategies.

Firstly, the facility must ensure that the correct tariff structure is used as a wrong tariff can imply higher electricity costs for the facility than necessary. This is done by considering all the different tariffs available and then deciding on the one tariff that is best suited to the facility and its operations. Electricity tariffs have a huge impact on costs especially if the tariff consists of various different periods with variable charges for the periods. Therefore, the right tariff structures are crucial.

#### **2.3.1.1 Overview of Eskom tariff structures**

Tariffs are one means by which Eskom tries to achieve DSM impacts. Eskom has different electricity tariffs for its customers. These tariffs include Megaflex, Ruraflex, Miniflex, and Nightsave to name a few.

For some tariffs Eskom uses off-peak, standard and peak times. Times of use tariffs (TOU), as these are known, are suitable for customers who are able to manage their energy consumption and maximum demand according to Eskom's specified time schedule. During peak times the cost of electricity is higher than during standard and off-peak times, off-peak being the cheapest.

Figure 2-6 shows a graphic representation of the standard, peak and off-peak times for weekdays, Saturdays, and Sundays for the tariff Megaflex. Public holidays are treated as standard and off-peak days. Details of all the tariffs are given on Eskom's website (Eskom.co.za).

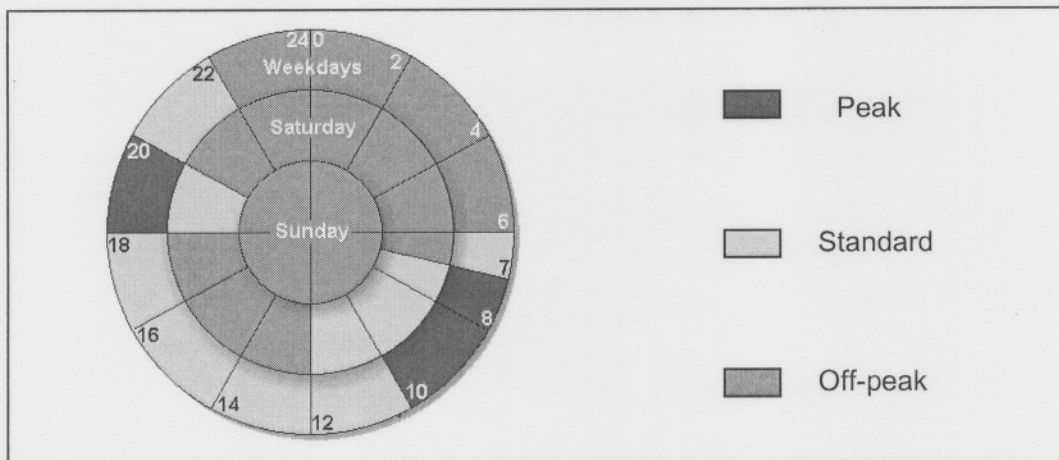


Figure 2-6: Peak, Off-peak and Standard times for the Megaflex tariff.

The following, according to Eskom (2004) are some components, depending on the specific tariff structure, that can comprise an electricity bill:

(Active) energy charge:

This charge is linked to each kilowatt-hour (kWh) or unit of energy consumed by the user.

Basic charge:

A fixed monthly charge payable for each point of delivery, whether electricity is consumed or not.

Demand charge:

Payable for each kilovolt ampere (kVA) or kilowatt (kW) of the maximum demand supplied during the month.

Reactive energy charge:

This charge only applies to three tariff structures namely Megaflex, Miniflex, and Ruraflex. It is levied on every excess kilovar-hour (kvarh) registered. If the customer is operating at a power factor of 0.96 or higher there will be no reactive energy charge.

### 2.3.1.2 Demand Side Management

Energy management has two sides namely Supply Side Management (SSM) and Demand Side Management (DSM). SSM is energy management at the side of a power utility while DSM is at the side of the customer.

DSM has become a necessity in South Africa due to the growth in electricity demand of industry as well as the domestic market. Eskom introduced DSM to counter the growth in energy demand of the local market. DSM provides a means to cope with the rising energy demands through the employment of effective energy management programs. DSM can avoid the need for additional power-stations for the time being (Dalglish (2002)).

DSM, which was formally recognised in 1992 when IEP was introduced, can be implemented as an alternative to electricity system expansion (Eskom (2004)). At the current consumption growth rate a new power-plant will be needed in a few years time. DSM initiatives are of utmost importance, as the lead time for a power-station is seven to ten years and there is not one near completion at this stage. A further direct impact of energy savings is the reduction of emissions to the environment that can be quantified by measurements.

According to the National Electricity Regulator's (NER) Energy Efficiency (EE) and DSM policy (Phillip (2004)) DSM means: the *"planning, implementing, and monitoring of distributors activities designed to encourage consumers to modify patterns of electricity usage, including the timing and level of electricity demand. It refers only to energy and load-shape modifying activities that are undertaken in response to distributors-administered programmes. It covers the complete range of load-shape objectives, including conservation, interruptibility and load shifting"*.

Why should DSM be implemented? Growing demands for energy have a severe impact on the country's natural resources which implies that South Africa's coal supplies will not last forever. DSM is a means to extend the life of South Africa's natural resources.

Potential benefits of the DSM programme include:

- ❑ Reduction in demand during peak times and therefore a delay of infrastructure capital investment (New power-station); and
- ❑ Conserve the environment by reducing emissions and water consumption at power-stations.

The objectives of the National Electricity Regulator's (NER) Energy Efficiency (EE) and DSM Policy are to protect electricity customers from high electricity bills and to show the users the benefits of energy efficiency and DSM (Phillip (2002)). The policy also aims at removing the barriers that bar the energy efficiency implementations.

The most prominent benefits of EE and DSM according to the NER (Phillip (2002)) are:

- ❑ A reduction of environmental impacts;
- ❑ Efficient utilisation of natural resources;
- ❑ A reduction of dependence on imported fuels; and
- ❑ Efficient maintenance of existing capacity.

DSM consists of load management techniques that are aimed at reducing costs through better management of operations. These techniques range from the rescheduling of operations and equipment to the use of dual fuel or cogeneration strategies.

According to Kaiser (2002) the energy use cost can be reduced by modifying the energy usage of customers to maximise efficiency. Energy management strategies aim to achieve a constant electrical demand from organisations.

Constant demand can be achieved by employing one of six general energy management techniques, namely:

- ❑ Load shifting;
- ❑ Load shedding;
- ❑ Strategic load growth;
- ❑ Valley filling;



- ❑ Strategic conservation/increased energy efficiency; and
- ❑ Flexible load shaping.

The three most frequently used techniques, namely load shifting, load shedding and strategic load growth will be discussed shortly.

### Load Shifting

Load shifting involves the shifting of demand from peak to off-peak hours and thereby making the demand more constant over time. Gellings (1987) gives an example of load shifting where timers are installed on water heaters to restrict operation only during off-peak times. Load shifting can be accomplished through the application of Eskom's time of use tariffs and energy management. Figure 2-7 shows a graphic representation of load shifting.

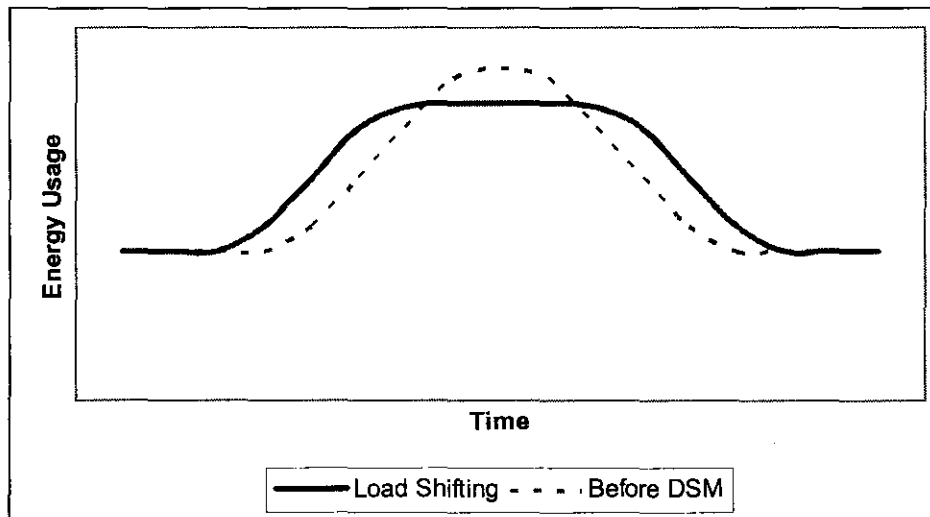


Figure 2-7: Load Shifting.

### Load Shedding

According to Dalglish (2002) load shedding is an interruptible agreement between Eskom and a customer whereby the customer allows Eskom to interrupt the power supplied to a portion of the customer's premises for a limited time and in return the customer is compensated by Eskom. Figure 2-8 represents load shedding.

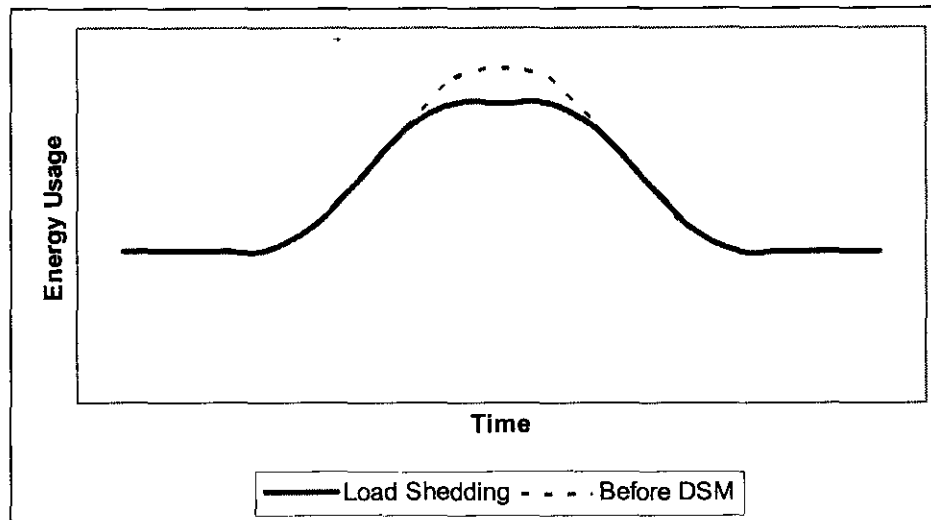


Figure 2-8: Load Shedding.

### Strategic Load Growth

Strategic load growth increases end-use consumption during certain periods (Phillip (2002)). This usually does not have an effect on the peak demand period as the load growth is aimed at other periods. Strategic load growth may use alternative fuels or cogeneration to provide the energy for the load growth. Figure 2-9 represents strategic load growth schematically.

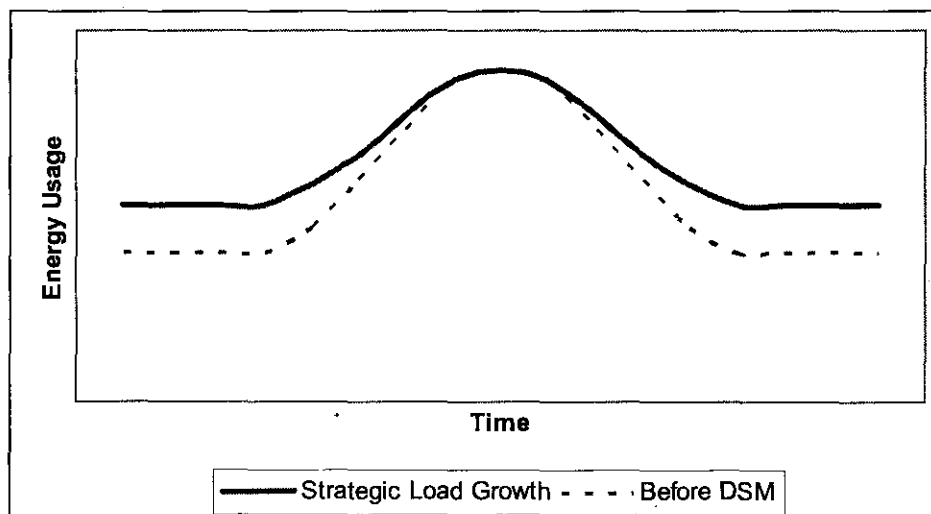


Figure 2-9: Strategic load growth.

The main aim of production cost reductions is to reduce the cost per tonne production. This means to produce the same amount of product but at a reduced cost therefore improving the profitability of the plant. Energy costs can be reduced by employing DSM measures like the rescheduling of equipment (specifically during peak tariff periods) and turning off non-essential equipment when it is not in use. Improving energy efficiency can also reduce production costs, but energy efficiency forms an approach of its own, and therefore it is discussed in the next section.

Various criteria are used to establish the impacts of the four objectives of the energy management and process improvement programme. These criteria are:

- ❑ Energy;
- ❑ Demand;
- ❑ Costs;
- ❑ Emissions; and
- ❑ Production.

Production cost reduction should have the following impacts (as shown in Table 2-1) on the various criteria:

**Table 2-1:** Production cost reduction criteria impacts.

Criteria	Impact
Energy	Energy usage should decrease as a result of the energy efficiencies being improved. This will lead to a reduction in the cost per tonne production. Rescheduling operations to off-peak periods can also reduce the energy costs and thereby decrease the cost per tonne.
Demand	Maximum demand should be reduced in Eskom's peak periods but may increase in off-peak and standard periods to compensate for production losses.
Costs	The production costs will decrease and profitability will increase.
Emissions	There will be a reduction in emissions through the shutting down of non-essential equipment, as a reduction in energy use should reduce emissions.
Production	Production can decrease as a result of obtaining a reduction in production costs which could imply that the plant runs at a lower capacity thus using less energy but also producing less product. Production levels can however also be sustained by increasing energy usage in off-peak times to compensate for lost production due to the production decrease in peak periods.

### 2.3.2 Improve Energy Efficiency

Financial incentives are needed to encourage energy efficiency programmes as energy efficiency is not seen as economically attractive to utilities (Phillip (2002)). This is the case because utilities are faced with a loss in revenue due to the electricity consumption reduction of EE programmes.

Two basic tools are available to the NER to achieve energy efficiency through a utility. The first option is to mandate energy efficiency in terms of results or expenditures and the second option is to provide incentive mechanisms such as cost recovery through tariffs.

According to the NER policy the introduction of incentives for the promotion of energy efficiency is crucial as the experience of other countries suggest. For the promotion of energy efficiency the regulator needs to provide distributors with some form of compensation such as cost recovery through tariffs or increasing their revenue requirements. DSM options do not pose any problems as it is attractive to distributors to promote.

The recovery of costs for EE programmes through a tariff is a feasible option for the NER as it has jurisdiction over tariff increases. The creation of an EE fund falls under the jurisdiction of the government but an EE fund would lead to tariff increases which might be unattractive.

EE according to the NER EE and DSM policy means: “*ways of reducing the energy used by specific end-use devices and systems, typically without affecting the service provided*”.

EE improvements can be divided into two groups, namely: *energy efficiency* and *production efficiency*. *Energy efficiency* focuses on systems and specific components, heat recovery and preheating of materials while *production efficiency* focuses on process control and optimisation of the processes to ensure effective conversion of energy to heat

in order to obtain maximum efficiency in the process. Heat recovery and preheating can also improve production efficiency.

An efficient plant is more competitive in the market especially in financial hard times which enhances the importance of energy efficiency. Energy Efficiency (Figure 2-10) is an energy management technique for improving the efficiency of a plant or equipment.

### Energy Efficiency

According to Lane (1991) energy efficiency is achieved by reducing both the peak and off-peak demand. By encouraging customers to utilise energy more productively, energy efficiency can be achieved. This will lead to a reduction in the electricity supply profile, resulting in savings for both the supplier and the users of electrical energy.

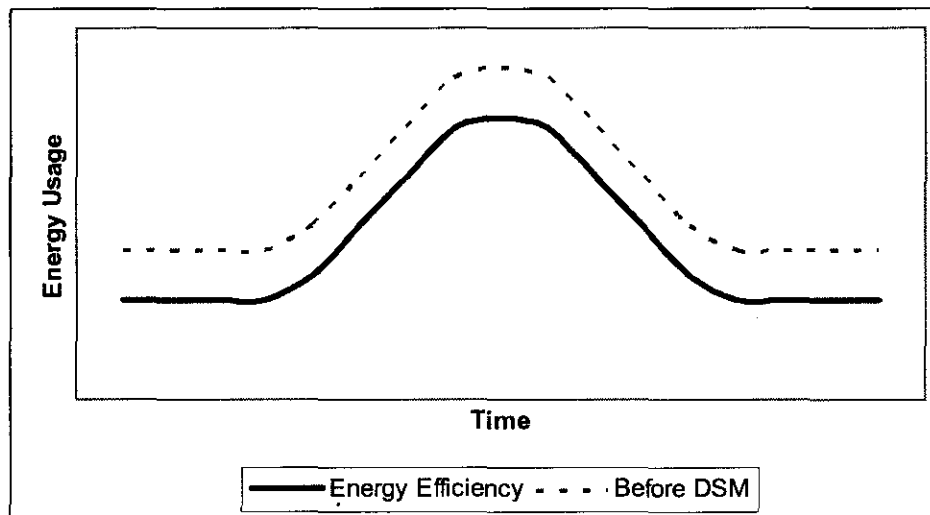


Figure 2-10: Energy Efficiency.

Efficiency improvements should have the following impacts (as shown in Table 2-2) on the various criteria:

**Table 2-2:** Efficiency improvement criteria impact.

Criteria	Impact
Energy	Energy efficiency may decrease energy usage to produce the same levels of production with less energy. Current energy usage levels can also be sustained and used more efficiently thereby producing more product.
Demand	Energy demand will decrease as a result of increased efficiency to produce the level of production that is currently maintained by the plant or the energy demand can stay the same, resulting in higher production as a result of the improved energy efficiency usage.
Costs	Energy costs should decrease as a result of the increased energy efficiency.
Emissions	Emissions should be reduced by improving the use of energy and decreasing the amount of energy wasted.
Production	It is likely that production will stay constant but it can increase due to more efficient use of energy.

### 2.3.3 Improve Production

Usually a furnace plant is operated at full production capacity with maximum product being produced at all times. In most cases the transformer size or capacity of a furnace is the limiting factor barring more production. If the energy efficiency of the plant can be improved the production will increase as it is most unlikely that operation of the furnace will change. This means that the furnace will still be operated at full production capacity all of the time, but with the improved efficiency production should be higher.

By decreasing the energy needed per tonne product (lowering kW/tonne) while utilising the same amount of energy, production should increase without increasing energy usage.

The following should be the impact of improved production (as shown in Table 2-3) on the various criteria:

**Table 2-3:** Improved production criteria impact.

Criteria	Impact
Energy	It is likely that the energy usage will increase to enable an increase in production levels. The kWh/Tonne product can be reduced as a result of improved energy efficiency per tonne of product produced.
Demand	Energy demand will increase as more production ultimately needs more energy.
Costs	Energy costs will increase but the higher amount of production also provides more income making it lucrative to increase production. The net cost per tonne can be reduced by means of higher production levels.
Emissions	Emissions related to production will increase with an increase in production depending on the usage and efficiency of the energy used.
Production	Production will increase but energy usage is likely to increase as well to accommodate the higher production rate.

### 2.3.4 Environmental Emission Impact Reduction

#### 2.3.4.1 Background of South Africa's Environmental Situation

A total of 75.4% of the total energy consumption in 2001 in South Africa was attributed to coal (Energy information administration (2004)). Coal is a highly carbon-intensive fossil fuel and has a negative environmental impact. Electricity generation from coal combustion is a prime contributor to air pollution.

Human activities such as the burning of fossil fuels and the clearing of natural vegetation for agricultural purposes enhance the greenhouse effect (Department of Environmental affairs and tourism (2004)). These activities emit a variety of GHG's such as carbon dioxide, methane and nitrous oxide. All of these gasses contribute to the global warming effect. The energy sector in South Africa is the single largest source of CO<sub>2</sub> and sulphur dioxide (SO<sub>2</sub>) emissions. This is due to the fact that South Africa relies mainly on coal and oil for the country's energy purposes.

South Africa was responsible for nearly 1.2% of the global warming effect in 1990. This placed the country in the top ten global warming contributing countries in the world. The carbon dioxide equivalent emission rate of 10 tons per person per year in South Africa is

above the global average of 7 tons per person per year (Department of Environmental affairs and tourism (2004)). This rate however is under the rate of 20 tons per person per year as in some developed countries such as the United States of America.

Global warming is a result of increased greenhouse gas emissions. According to Den Heijer and Grobler (2001) GHG emissions are disturbing the way the atmosphere maintains the balance between incoming and outgoing energy. This occurs because GHG emissions increase the atmosphere's ability to absorb infrared energy. This could lead to a global temperature increase of 1.5°C to 4.5°C over the next century.

Since the beginning of the twentieth-century 925 billion tons of carbon dioxide (CO<sub>2</sub>) were added to the atmosphere worldwide (Flavin (1998)). The most significant GHG emission for South Africa is CO<sub>2</sub>. CO<sub>2</sub> emissions contributed more than 80% of GHG emissions for 1990 as well as 1994. Carbon dioxide concentrations, measured at Cape Point in South Africa, show an overall increase of 0.6% CO<sub>2</sub> per year. This is a global phenomenon which is regarded as a great concern to the world. Temperature stations in South Africa showed an increase in temperature of 0.2°C on average during the 1990's. This increase in temperature may be associated with global warming although statistically it is hard to prove.

Total GHG emissions for 1990 were 347,3 MtCO<sub>2</sub>e (mega tonnes carbon dioxide equivalent) and 379,8 MtCO<sub>2</sub>e in 1994 (Goldblatt (2002)). Total emissions calculated as CO<sub>2</sub> emissions for each sector individually showed that the energy sector contributed 75% of the total emissions in 1990 and 78% in 1994. The GHG emissions per major sector for 1990 and 1994 are shown in Figure 2-11.



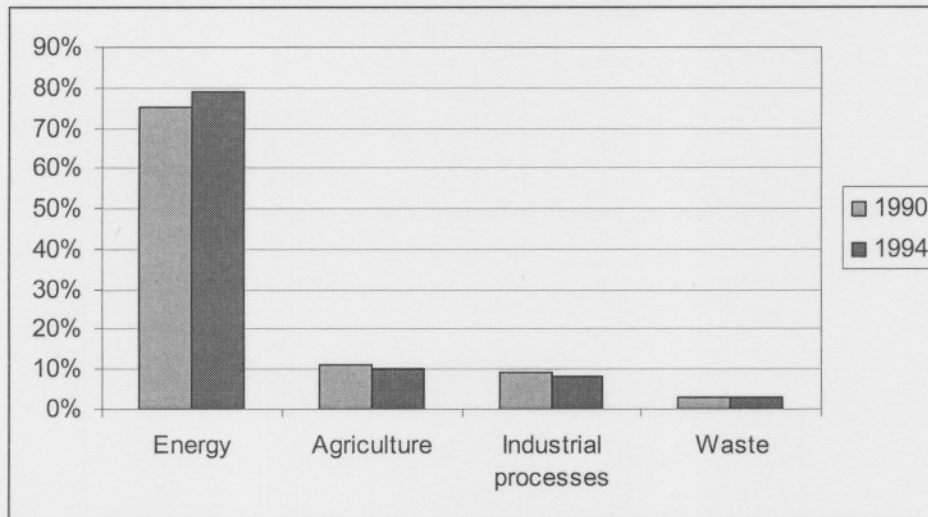


Figure 2-11: Total emissions per sector.

#### 2.3.4.2 What is being done in South Africa?

Nearly 1 million households have been electrified since 1994 in an attempt to replace the use of coal and wood as domestic energy sources. South Africa signed the Montreal Protocol in 1990 which is aimed at limiting harmful substance emissions to the ozone layer. The protocol was highly successful. In 1994 South Africa also signed the United Nations Framework Convention on Climate Change (UNFCCC) and ratified it in 1997.

A range of international and national initiatives for the promotion of GHG mitigation was developed as a response to the predicted impacts of climate change. According to the Energy Research Institute (2002) this was done by developing a “carbon economy” with the commodity being tonnes CO<sub>2</sub> equivalent (tCO<sub>2</sub>e).

Climate change was first acknowledged as a global issue in 1992 with the establishment and adoption of the UNFCCC (The Clean Development Mechanism (2002)). The aim of the UNFCCC and the Kyoto Protocol is to reduce human emissions of GHG emissions, thereby reducing the associated human induced climate change (Goldblatt (2002)).

By improving energy efficiency the environmental emissions are reduced. Emission factors of industrial plants must adhere to local standards of emissions as provided by government. The environmental implications of using 1kW of power according to Eskom are presented in Table 2-4 below. Included in this table are the impacts from various years ranging from 1992 till 2001 showing the impacts on water usage, coal burnt and CO<sup>2</sup> emissions as well as other impacts from using 1kW of power.

Table 2-4: Environmental implications of using 1kW of power.

Per 1kW of Power	2001	2000	1999	1998	1997	1992
Water Usage [litres]	1,26	1,21	1,25	1,23	1,20	1,45
Coal Burnt [kilograms]	0,50	0,49	0,49	0,48	0,48	0,48
Ash Produced [grams]	139,78	129,95	133,65	134,90	126,19	—
Ash Emitted [grams]	0,31	0,35	0,37	0,36	0,44	1,03
SO <sub>x</sub> Emissions [grams]	7,91	7,95	8,28	8,65	7,36	7,25
NO <sub>x</sub> Emissions [grams]	3,61	3,56	3,70	3,65	3,66	3,65
CO <sub>2</sub> Emissions [kilograms]	0,89	0,85	0,88	0,89	0,90	0,90

The following should be the impact of environmental emission reductions (as shown in Table 2-5) on the various criteria:

Table 2-5: Emission reduction impact on various criteria.

Criteria	Impact
Energy	The energy use will decrease or energy efficiency should increase thereby using energy more effectively and wasting less energy which translated to less emissions.
Demand	Demand should decrease resulting in fewer emissions on the supply side. Better energy efficiency should also lead to a reduction in emissions on the demand side.
Costs	Production costs should remain the same or decrease as a result of the energy being used more efficiently.
Emissions	Emissions should decrease.
Production	Production could decrease in order to decrease emissions or remain the same due to energy being used more efficiently.

## **2.4 Barriers of Energy Management and Process Improvements**

The normal energy audit process focuses on energy in a segregated approach. The physical processes and the energy needed in the processes of a facility are rarely combined. The whole energy profile of a facility is usually broken down into subdivisions but rarely integrated to form an energy solution structured around an integrated and interdependent energy usage profile.

It is difficult to identify, quantify and afterwards verify energy projects within a facility. Inaccurate identification and quantification of energy savings or efficiencies can have a huge financial impact on a facility. Energy related projects that are not financially feasible can be implemented or financially feasible projects can be rejected as a consequence of inaccurate identification and quantification. Improper verification can also deceive management of the true performance of an energy related project. A good energy project can look dismal if improper or erroneous verification is done on the project.

Energy and production departments are usually handled separately with little or no interaction or integration between the two departments. This leads to a lack of awareness in both departments and inefficient use of plant equipment and energy. The lack of communication restrains the two departments of reaching their separate production and energy goals.

Another disadvantage to energy management is the lack of adequate methods to accurately quantify potential energy savings and efficiency improvement opportunities in a furnace plant. The lack of accurately quantifying savings leads to the unwillingness of the management of facilities to invest in such opportunities as it is seen as risks.

Barriers of energy management projects can be divided into three main categories, namely: *institutional aspects*, *technological aspects* and *financial aspects*. These three categories are discussed in the following sections.

### **2.4.1 Institutional aspects**

A segregated approach to energy and process management is mostly employed. The energy management is done by the electrical department which is responsible for maintaining the reticulation of the plant. Maintenance and production departments manage the process improvements and related work. There is little influence or pressure to change process and production operations as the energy related to these operations is handled by a separate department. Management also requires a model of proposed projects which clearly indicates benefits and costs.

A methodology is therefore needed to identify, quantify and verify the cost benefits of energy and process improvements on a Ferro-metal plant according to an integrated manner.

### **2.4.2 Technological aspects**

There is a limited awareness to identify and quantify the potential saving and process improvement opportunities that exist in industrial plants. Knowledge of new available technologies for process improvements and energy efficiency are very limited as well as the ability of inexperienced users to select suitable options.

A lack of instrumentation and energy measurements of components also complicates the identification of energy intensive or inefficient components. There is also a lack of monitoring or Decision Support Systems (DSS) that aid the operator in his/her operational decisions and also provides a prediction of the consequences of the decisions taken. The absence of Measurement and Verification (M&V) of technical projects within plants creates a grey area for the projects performance. This leads to a sceptical attitude towards the value of projects within the plant as a whole.

There is a need for a data mining tool that is able to integrate with the Supervisory Control and Data Acquisition (SCADA) and Energy Management System (EMS)

systems. Such a tool should also have the ability to rapidly handle large amounts of process data.

A need also exists for the development of a DSS that provides the plant operators with online recommendations of how to operate the plant at its optimum efficiency.

### **2.4.3 Financial aspects**

The availability of money for plant improvements is limited and has to be adequately justified before a budget will be granted for such projects. Usually the investment criteria depend on the type of project under investigation. Maintenance projects usually require a maximum payback period of two years and capital investment projects require Internal Rate of Return (IRR) and Net Present Value (NPV) considerations. Loss of production due to project implementations is also considered to be a huge barrier.

Companies also need to realise and be made aware of the fact that energy management projects should be evaluated and funded as other capital projects and not from the maintenance budgets where maximum payback period of two years are a typical requirement.

There is a need for financial incentives from utilities to encourage implementation of DSM opportunities.

### **2.4.4 Measurement and Verification**

Inadequate measurement and verification of energy related projects lead to a lack of trust in the financial feasibility of these projects. Verification of savings achieved through the implementation of a project enhances the credibility of projects. Measurement and verification of energy related projects should be transparent for all parties involved in the project to further encourage credibility of the process and point out the benefits of such projects.

There is a need for an accurate and transparent measurement and verification process for projects to enhance the credibility of energy related projects.

## **2.5 Opportunities for Energy Management and Process Improvements**

There exists an opportunity for an integrated energy and production methodology approach in furnace plants. This integration can assure the efficient use of equipment and improve the energy usage, thereby increasing the profit. More energy management projects will be implemented if such a methodology can be found, as management of facilities will be more willing to invest in accurately quantified opportunities.

### **2.5.1 Financing Opportunities**

Two financing opportunities exist that can be used as an aid to industry. These are DSM funding and the Clean Development Mechanism (CDM). Both of these opportunities aid the industry to overcome the financial barriers associated with energy related projects.

#### **2.5.1.1 Demand Side Management Funding**

A budget of R404 million, managed by Eskom, is available for all DSM projects (Eskom (2004)). The responsibility of managing such a budget means that all projects must be evaluated to be financially sound before commitments are made. Financial performance criteria include an overall Internal Rate of Return (IRR), Net Present Value (NPV) and Payback (PB) period for Eskom DSM. The financial parameters are used to evaluate individual projects for viability and also to track the progress of projects over the 25 year roll out period in terms of savings claimed and actual savings obtained.

The Industrial Commercial Energy Efficiency (ICEE) sector is to reduce 95MW from Eskom's electricity supply system demand peak as a goal for DSM. A budget of R208 million was allocated for the reduction goal set for the year 2002 (Eskom (2004)). The ICEE DSM will focus on Eskom's industrial sites and commercial buildings before targeting industry all over South Africa.

Energy savings in the commercial sector involve the implementation of an upgrade strategy. This strategy will save significant amounts of energy through the use and implementation of energy efficient lighting, ventilation and air-conditioning systems, and other building efficiency measures (Eskom (2004)).

Industrial consumers will have an incentive to shift load from peak to off-peak periods during the day by managing their own load shifting activities without disrupting industrial processes. Some examples of load management opportunities include water-pumps, cooling and heating equipment in collaboration with cooling and heating storage facilities, and material handling equipment in conjunction with stockpiles.

#### **2.5.1.2 Clean Development Mechanism**

The CDM (that forms one part of the Kyoto Protocol) is a project based mechanism through which a project, aimed at reducing GHG emissions, is jointly developed by two or more participants. The CDM aims to assist developing countries to achieve sustainable development while reducing GHG emissions and simultaneously assisting developed countries in achieving their commitments under the Kyoto Protocol. The CDM allows developed countries to acquire Certified Emission Reductions (CERs) through GHG mitigation projects in developing countries (Energy Research Institute (2002)). All projects must serve a dual purpose of sustainable development and GHG mitigation to form part of the CDM. Developing countries will benefit from GHG reduction projects in their country through increased direct investments and technology transfers as a result of the projects.

#### **2.5.2 Demand Side Management Opportunities**

Demand Side Management opportunities include:

- ❑ The rescheduling of energy intensive operations from peak periods to off-peak periods (Load Shifting);
- ❑ Shutting down of non-essential equipment in peak periods (Load Shedding);
- ❑ Scheduling routine maintenance into peak periods where possible; and

- ❑ Adding new loads in off-peak periods (Strategic load growth).

### **2.5.3 Energy Efficiency Opportunities**

The most obvious choice for improving production throughput is to increase the plant size, but this option falls outside the scope of this study. The second choice will be to improve the process efficiency of the plant. Initial studies have shown that the efficiencies of a furnace could vary over time by as much as 30%. This means that for the same power input, the production capacity output varies up to 30%.

The opportunity therefore exists for the development of an online system that will identify the causes of the change in process efficiency and also recommend the actions that should be taken to rectify it.

Some available energy management options for production improvements and production cost savings are:

- ❑ Good housekeeping practices;
- ❑ Power factor improvement; and
- ❑ Industrial cogeneration.

All of the above options have potential but the economical viability and applicability of these options, for each individual case, should be examined.

From the start of the Ferro-alloy industry in the late 1800's the industry has been characterised by its energy intensiveness. The three-phase submerged arc furnace is the dominant tool in the Ferro-alloy industry and is very energy intensive. According to Magruder (1975) Europe, the United States and Japan are all facing the problem of energy shortages. Energy efficiency can help to postpone this problem until another solution can be found.



Efficiency improvements can be divided into two groups, namely: *energy efficiency* and *production efficiency*.

*Energy efficiency* focuses on conveyor systems and specific components, heat recovery, and the preheating of materials. The efficiency of conveyor systems and specific components can be improved for instance by installing Variable Speed Drives (VSD's) on fans and motors or connecting weighing facilities to the automatic on/off switches of conveyor systems. By using recovered heat from the process to preheat materials the energy needed in the actual process of melting can be reduced. Various technologies exist for the preheating of materials depending on the heat sources or wastages available. Cogeneration can also be employed to reduce energy consumption by producing some energy in-house.

*Production efficiency* focuses on process control and the optimisation of the processes to ensure the effective conversion of energy to heat in order to obtain maximum efficiency in the process. This can be enhanced by the development and integration of a DSS on the plant. A DSS is not a control system but it is aimed at providing advice and predictions to the controller of what should be done and the implications of the choices for the plant. The DSS should be able to learn the operation and the effects that various decisions have on the plant. Heat recovery and preheating can also improve the production efficiency.

Some energy management options for savings that are used within the industrial and commercial sectors are:

- ❑ Energy efficient motors;
- ❑ Variable speed drives;
- ❑ Furnace optimisation/efficiency;
- ❑ High efficiency fans and pumps; and
- ❑ Efficient lighting.

All of the above options have potential but the viability of these options, for each individual case, should be examined.

The following provides some EE improvement opportunities that were found through a literature survey.

Instrumentation, process control and computer-control systems are all vital tools for improving yield, productivity, process efficiency and energy management. According to Yoshitani (1984) almost 15% of the energy consumed in Japan in 1980 was consumed by the steel industry. By introducing effective instrumentation, process control, and computer-control systems the steel industry's energy consumption can be lowered and efficiency improved.

Barker (1981) states that an electrode controller for a submerged arc furnace was developed by the National Institute for Metallurgy (NIM) which consisted of a self-contained microcomputer-based machine that controls the high-power electrical circuit of a submerged arc furnace. The machine automatically controls the movement of the electrode hoists. In a submerged arc furnace with three electrodes operating from three-phase supply, strong interactions occur between the electrodes.

If one electrode is moved it will affect the currents and powers in all three electrodes. For stable operation it is generally desirable for the resistance in each phase to be restricted to a constant value. In addition to moving the electrodes to control electrode resistances, the positions of the transformer taps can also be adjusted by the controller. By adjusting the transformer tap positions the power input can be maximised within the limits of the furnace operation (Barker (1981)). The operator or furnace engineer can enter set points and limits of operation for the controller.

A 36 MW submerged arc Ferrosilicon (FeSi) furnace was modelled using the technique of system identification by Hauksdottir, Soderstrom, and Thorfinnsson (1995). The system, associated with the control of the three-phase electrode currents through the positioning of the electrodes, was examined. In some cases it was attempted to control the resistance value of each electrode and in other cases the control of the electrode current was the main objective. There are two other sources of control for furnaces.

Firstly the power consumption of the furnace can be changed occasionally by stepping up or down the electrode voltage. The second method is the control of raw materials. This is an important factor in the quality of the final product.

Retrofit of furnaces is considered by Jegla, Stehlik, and Kohoutek (2000) to be a straightforward and efficient way to achieve energy savings in a plant but operational and geometrical constraints are the main reasons why retrofitting of furnaces are very difficult. Budget constraints and available space can also deter retrofit options on furnaces. Another factor to consider is the loss in revenue due to the shutting down of a furnace for retrofitting purposes.

A retrofit can also be aimed at utilising flue-gas more efficiently. As furnaces are such highly energy intensive operations a minor efficiency improvement can result in large energy and capital savings.

Sometimes electrical utilities offer incentives and rebates for customers to replace or upgrade old energy inefficient equipment with more efficient equipment. These incentives are offered because it is cheaper for the utilities to save energy and capacity for new customers than to build extra power-plants to supply an additional load (Capehart, Turner and Kennedy (1997)).

Direct incentives may be in the form of low interest loans that can be paid back on a monthly basis from the savings obtained due to more efficient equipment. Lower rates for electricity used to operate higher efficiency lights, appliances, and more efficient process equipment can also be used as an incentive. Rebates are, according to Capehart, Turner & Kennedy (1997), the most common method used by utilities to encourage customers to install high efficiency appliances and process equipment. A rebate can be tied to a physical device such as R1 for each low wattage fluorescent lamp used. Incentives and rebates can improve the cost effectiveness of customer projects to replace old devices with more efficient devices.

Where maximum kiloVolt Ampere (kVA) demand forms one of the bases on which a consumer has to pay for the use of power to operate submerged arc furnaces, it is economically advantageous to install power factor correcting capacitors. The power factor decreases with an increase in furnace size. This happens because of the decrease in resistance and the increase in reactance of the furnace with an increase in size. For an increase in furnace size from 15MW to 30MW, the power factor will, according to Meintjies (1975) usually decrease from more than 0.8 to less than 0.7.

The capacitors can not alter the furnace power factor, it can only correct the incoming line power on the primary side of the transformer. When a furnace is brought onto load, active power is always greater with shunt than series capacitors. This favours product output. Capacitors in shunt have more advantages than capacitors in series though both have their merits.

By minimising the number of transfer points in a conveyor system, the dust development and wear of the carrying side of the belt can be reduced. According to Bahke, Fehsenfeld & Stortnik (1984) this also leads to a reduction in investment and operating costs. The use of belt conveyor systems for transporting materials is an economical solution, especially over long distances. The trend has been towards constant, continuous transport.

It is estimated that there were about 60 million tons of Ferro-alloy slag containing an entrained metal value of about \$1 billion in South Africa alone. Mashanyare & Guest (1997) reported on a highly efficient process developed to recover valuable metals from slag. The metals are recovered as far as possible in a form that is directly usable.

The recovery plant, built at Kwe Kwe in Zimbabwe, produces saleable Ferrochrome containing less than 2% slag with a recovery from slag of over 96% of liberated metal. Magnetic separation and jigging are two potential methods for recovering metal from crushed slag.

One of the benefits of a plant to recover metal from slag is that in times of poor metal prices a furnace can be shut down but capacity maintained at a reduced cost. Recovery is a low cost way of increasing capacity, during high demand and good price periods.

#### 2.5.4 Environmental Emission Reduction Opportunities

The Clean Development Act (CDM) forms one part of the Kyoto Protocol that was adopted in 1997 by the International Community. The CDM is described by the Kyoto protocol as: “*reductions in emissions that are additional to any that would occur in the absence of the certified project activity*”. It is vital that CDM projects are accurately assessed and monitored by Designated Operational Entities (DOE’s) that will be designated by the Executive Board.

South Africa ratified the Kyoto Protocol in March 2002 (Energy Research Institute (2002)). The South African government foresees important opportunities for the country under CDM, these include:

- ❑ Direct foreign investment potentials;
- ❑ Sustainable development through investments;
- ❑ Technology transfer and human capacity building; and
- ❑ Additional revenue streams via carbon credits.

According to Goldblatt (2002) the potential investor countries to invest in CDM projects in South Africa are shown in Table 2-6 below.

**Table 2-6:** Potential investor countries.

Potential Investor Countries
France
Germany
Italy
Japan
Norway
Sweden
Switzerland
The Netherlands
UK
USA

The successful development of the opportunities depends heavily on the financial returns and environmental impacts that these opportunities will realise when implemented. It is therefore crucial that a proper measurement and verification process will be developed to quantify and verify the technical, financial and environmental impacts of such projects. This is the last research opportunity identified.

## **2.6 Conclusion**

According to the literature study there is currently a lack of adequate methods for the improvement of energy efficiency in a furnace plant as a whole, although much has already been done on parts of plants, especially furnaces.

There is a need to reduce production costs, improve efficiency and production, and reduce the environmental emission impacts of furnace plants. The barriers for energy related projects identified include institutional, technological, and financial aspects. A lack of accurate, transparent measurement and verification processes increases the distrust in credibility of energy related projects and is therefore also considered a barrier. There are however adequate opportunities available for energy improvement projects.

It can now be concluded that there exists a need for a methodology to accurately identify, quantify and verify the cost benefits of energy and process improvements on a Ferro-metal production plant. This methodology will increase credibility and awareness of potential cost benefits of energy and process improvements.

This study will therefore be aimed at constructing an integrated energy efficiency solution to accurately identify, quantify and verify energy opportunities.

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## **CHAPTER 3**

# **A METHODOLOGY TO IDENTIFY AND QUANTIFY PROCESS AND ENERGY OPTIMISATION OPPORTUNITIES**

*This chapter provides a methodology to identify and quantify energy and process improvements on a Ferro-metal production plan. The chapter provides and explains the various steps to identify and quantify energy and process improvement opportunities.*

## **CHAPTER 3: A METHODOLOGY TO IDENTIFY AND QUANTIFY PROCESS AND ENERGY OPTIMISATION OPPORTUNITIES**

### **3.1 Introduction**

The purpose of process improvement and energy optimisation is to maximise production while at the same time reducing production costs and minimising resource costs. This should be done by taking into account process and equipment constraints such as start-ups. The approach should be a holistic integrated systems approach that includes energy management and process efficiency improvements. The approach should be aimed at improving production, production throughput and part load efficiencies. Energy intensiveness should be reduced and the system efficiency optimised within plant constraints.

### **3.2 Benefits of Integrated Process and Energy Improvement Approach**

The benefits of an integrated process and energy improvement approach include the following:

- Allows the use of energy to solve operating problems;
- A fast, effective way to analyse all the possible opportunities available;
- An approach that leverages Energy and Process links; and
- Compliments other existing Continuous Improvement Programmes (CIP).

### **3.3 Process and Energy Improvement Methodology**

A schematic illustration of the process and energy improvement methodology is shown in Figure 3-1. The whole process is discussed in more detail, starting from the top, in the paragraphs that follow the schematic illustration.

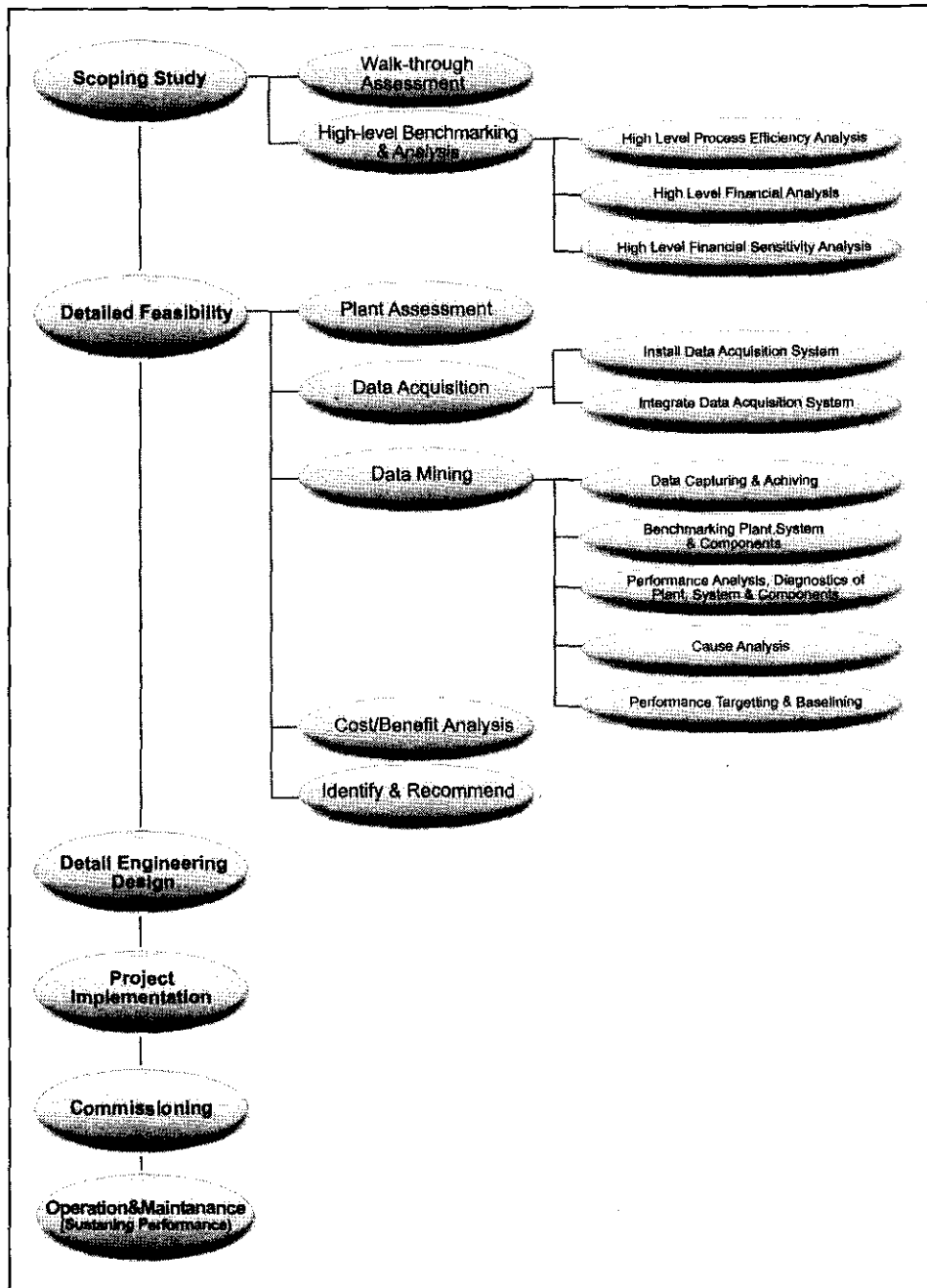


Figure 3-1: Flow diagram of Energy and Process Improvement Procedure.

### 3.3.1 Scoping Study

During the scoping study an assessment of the plant is made in order to answer the question if it is worthwhile to further explore opportunities. The scoping study quantifies

the feasibility of energy saving opportunities and their value to the specific plant under consideration on a high level. The scoping study includes a walk through audit (to identify opportunities and get acquainted with the plant) and high-level benchmarking and analyses to estimate the feasibility of identified opportunities in the plant.

#### **3.3.1.1 Walk Through Assessment**

The aim of a walk through assessment is to get acquainted with the layout of the plant as well as the types of systems and equipment used in the plant. All the main energy consumers on a plant must be identified and possible areas where energy can be saved or the process improved must be documented. A preliminary high-level energy breakdown in a graphic form (i.e. pie chart or bar chart) can prove useful. This helps to visualise the energy usage of the plant and focus attention on the energy intensive parts of the plant.

#### **3.3.1.2 High-Level Benchmarking, Diagnostics and Analyses**

Energy and electricity bills of the previous two years (if available) can be used for high-level benchmarking and diagnostics of the plant. Data from existing computer systems such as historians or other computer-storing systems must be obtained from the plant if possible to analyse the energy profile and usage of the plant. This will help to quantify the feasibility of continuing with the search for energy and process related opportunities in the plant.

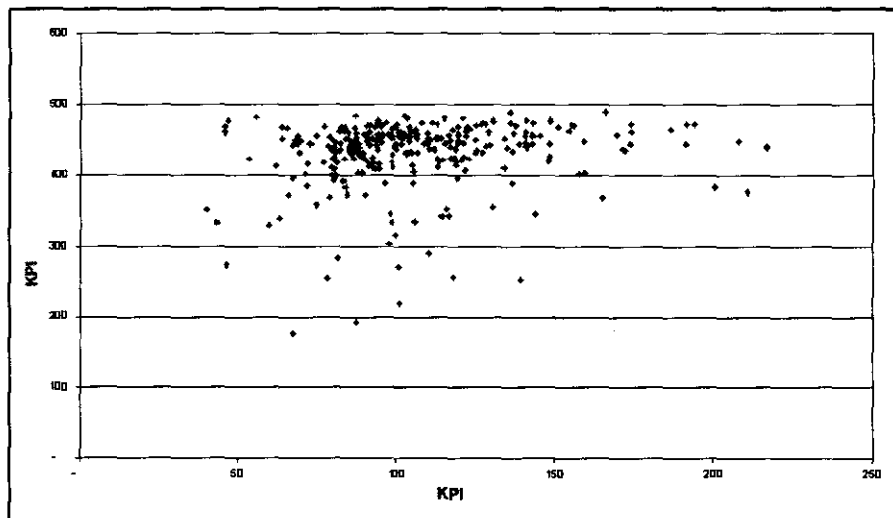
Load management falls within the high-level benchmarking, diagnostics and analysis process. Load management is aimed at optimising plant schedules to reduce high energy costs. The total MWh per day should, where possible, stay constant to ensure that production is not affected negatively. This means that production is shifted from expensive time periods to cheaper time periods to decrease energy costs but keep production at its intended level.

During the high-level benchmarking process it is also necessary to do a high-level analysis in three specific areas. These are:

- ❑ High-level Process Efficiency and Performance Analysis;
- ❑ High-level Financial Analysis; and
- ❑ High-level Financial Sensitivity Analysis.

**i) High-Level Process Efficiency and Performance Analysis**

This analysis is aimed at assessing the process efficiency and performance of the investigated plant. A typical analysis is shown in Figure 3-2. The analysis aims to establish whether the plant's performance can be enhanced and if there exists opportunities to improve the process efficiency of the plant. The analysis should provide an estimated annual cost saving for process efficiency improvements.



**Figure 3-2:** High-level Process efficiency visual representation.

The performance of the plant should also be tracked over time to establish the “good” and the “bad” operations for the plant, as shown visually in Figure 3-3. This figure presents an example of performance analysis. This good performance can then be used as a benchmark for the plant's performance.



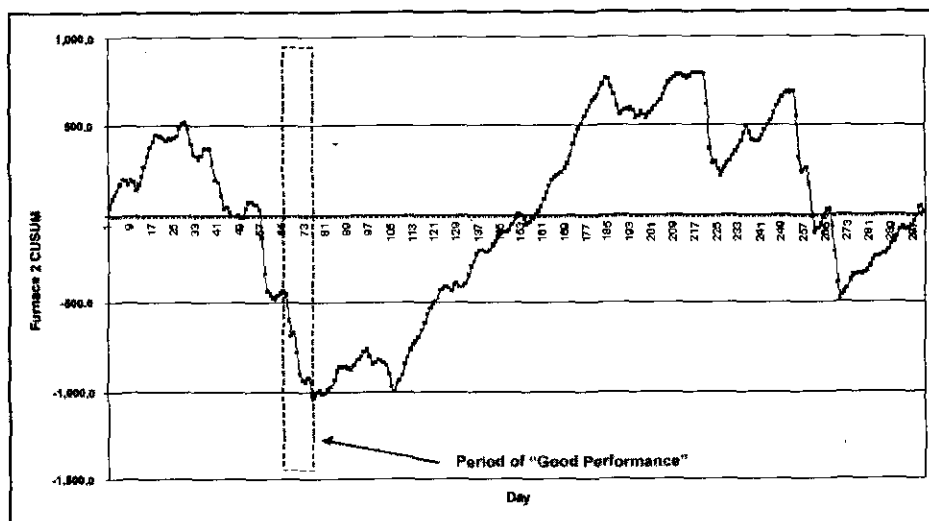


Figure 3-3: High-level performance analysis visual representation.

## ii) High-level Financial Analysis

The financial analysis should be aimed at providing the estimated annual savings that can be attained by the opportunities that exist in the plant. The high-level financial analysis should, if possible, include the IIRR and PB analysis for the initial opportunities identified.

## iii) High-level Financial Sensitivity Analysis

The high-level financial sensitivity analysis is aimed at establishing the financial impact if only a percentage of the estimated saving is achieved. The estimated saving represents a 100% saving penetration, that is to say the total saving is achieved. It is recommended to at least do a sensitivity analysis for a 75% and 50% saving achievement but any percentage saving sensitivity analysis can be done. The sensitivity analysis should, where possible, present the IRR, NPV and PB implications of the percentage saving.

### 3.3.2 Detailed Feasibility

After the initial scoping study is completed, and it is deemed that there exists feasible opportunities, it is necessary to conduct a detailed feasibility study on the plant. The aim of a detailed feasibility study is to accurately quantify, verify and reconfirm opportunities

identified through the high-level scoping investigation. A cause analysis is also used in the detail feasibility process to find solutions for the opportunities.

The detailed feasibility should consist of a plant assessment, installation and integration of data acquisition system, data mining, identification of solutions, a cost/benefit analysis and identification and recommendation for implementation.

### **3.3.2.1 Plant Assessment**

During the plant assessment stage it is necessary to quantify the plant's performance and identify opportunities. The necessary measurement points for a data acquisition system and the required data that should be captured must be identified. Important systems or components that should be focussed on must also be identified.

### **3.3.2.2 Installation and Integration of a Data Acquisition System**

It is necessary to install a data acquisition system with a historian and integrate the system with the existing plant computer systems such as SCADA and EMS. This allows the gathering of data for analysis, benchmarking and the identification of trends within the plant. Peak energy usage and downtimes can be isolated and studied.

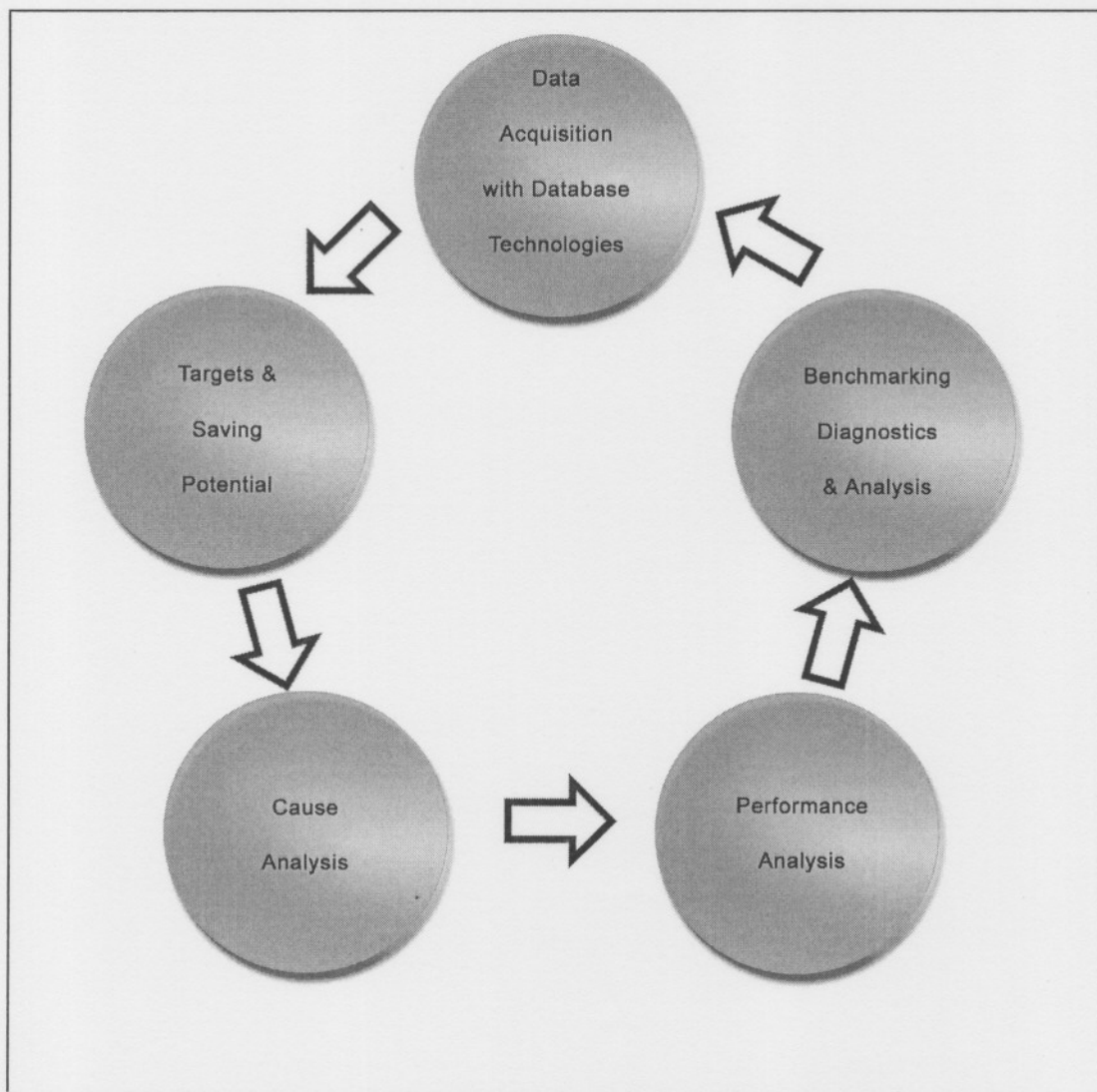
The data acquisition system should however not interfere with the existing systems as this can lead to data loss and immense frustration for all parties involved.

### **3.3.2.3 Data Mining**

What is data mining? Data mining is the capturing and archiving of data, benchmarking, analyses and diagnostics of data as well as performance target identification and cause analysis.

After a data acquisition system is installed and fully integrated with the systems, data mining on the plant can commence. The archived data from the data acquisition system can be downloaded and used for benchmarking and data analysis.

Figure 3-4 shows how the data mining process works. Firstly data is acquired and then the data is used for benchmarking, diagnostics and analysis. Next, a performance analysis is done, followed by a cause analysis and the establishing of targets. This process can be repeated to sustain performance levels over a period of time.



**Figure 3-4:** Data Mining Process.

It is strongly advised to use as much data as possible for benchmarking and analysis to be able to draw accurate conclusions as a small amount of data can lead to conclusions being wrongly drawn.

**i) Data Capturing and Archiving**

The data acquisition system should capture the identified data and archive the data as it comes through the plant computer systems in real time without affecting these systems.

**ii) Benchmarking Plant, Systems and Critical Components**

It is vital to benchmark the plant performance in order to acquire the level at which the plant is operated. It is possible to get hold of an average energy profile of the plant from the acquired data. From this it can be determined whether the plant is under or over utilising its capacity. It is necessary to establish what the plant is capable of producing. The benchmarking processes followed for the plant as a whole can also be employed on the various sub systems and critical components of the plant.

**iii) Performance Analysis and Diagnostics of Plant, Systems and Components**

The performance analysis should be aimed at establishing whether the plant is operated efficiently and productively or not. This should firstly be done on a plant level and then move down to a system and component level, if found to be relevant.

A detailed energy breakdown can be useful in gaining a better understanding of the energy used by the plant as a whole. The breakdown can also be done for specific sub plants or sections if a more detailed breakdown will be advantageous in gaining a better insight in the plants energy usage. The energy intensive operations/sections can be identified, isolated and studied to obtain a better understanding of how these operate. Energy related problem areas within the sections can then be identified. A graphic representation of the energy breakdown usually gives a clearer picture of the energy usage within the specific section.

Relations between energy usage and production should be established wherever possible as these can help with the understanding of the process. A specific amount of production (tonnes produced) should, where possible, be linked to a certain amount of energy used. Problem areas should be highlighted and diagnosed, finding solutions for the problems where possible.

**iv) Cause Analysis**

A cause analysis is used to try and discover why certain trends occur within the plant operation. The analysis is aimed at establishing the reasons for the change in performance of plant operation. If these causes can be isolated and solutions found, ratifying measures can be employed to improve the performance.

Plotting certain Key Performance Indicators (KPI's) over time can be useful to find where "good" and "bad" performance periods occurred. These periods can then be investigated to try and establish the cause of good or bad operations. For any period to be classified as "good" or "bad", the period must be sustained for relative long periods. This can be for a day or a week or a month depending on the complexity and dynamics of the plant under consideration. Figure 3-5 shows a plot of KPI against days with the identified "good" and "bad" periods.

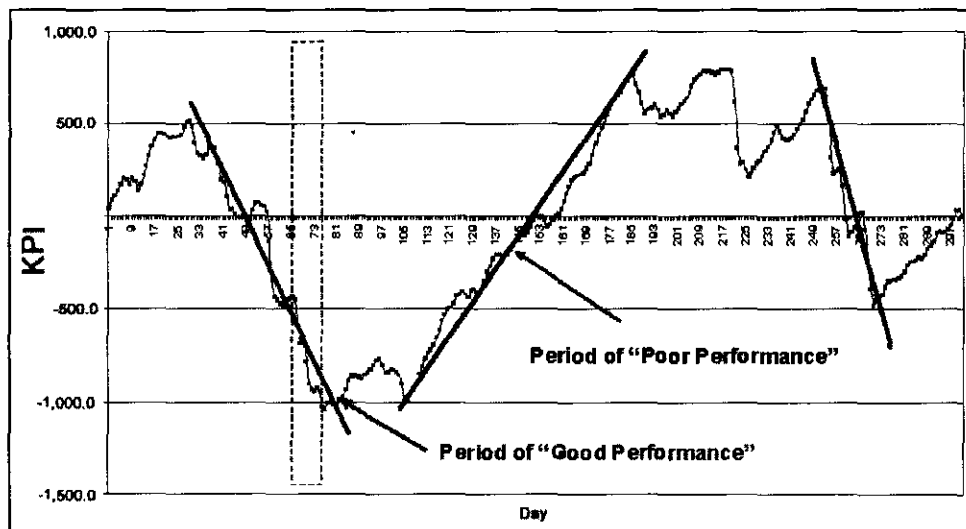


Figure 3-5: Cause Analysis Visual Representation.

### v) Performance Targeting and Baseline

Constructing a performance targeting system for a plant can help to identify when the plant is not operated efficiently through the use of some sort of baseline performance reference point. The baseline performance reference point can be taken as the average energy use per tonne for the first iteration. A level of performance sustained for a long period of time can also be used as the baseline reference point. Figure 3-6 shows a typical target constructed from KPI and production figures.

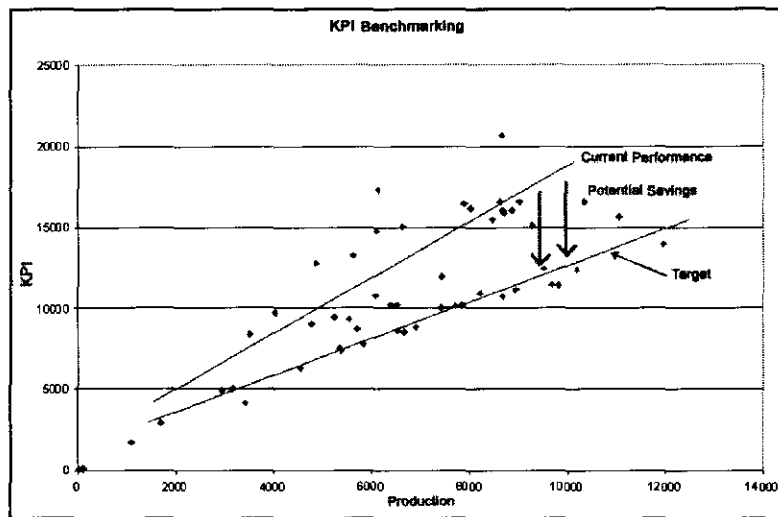


Figure 3-6: Targets and Potential Saving Visual Representation.

The current performance line shows the performance of the current system with the target line representing the target that should be aimed for. The potential savings are indicated between the two lines. The savings can be achieved if the system is operated at the target benchmark for the system.

#### 3.3.2.4 Cost/Benefit analysis

The identified opportunities must be analysed to determine the process and financial benefits, and cost implications for the plant. Payback periods and rate of return calculations should be performed where possible to establish the attractiveness and feasibility of the identified options.

### **3.3.2.5 Recommendation for Implementation**

The feasible opportunities identified through the methodology should be sustainable in order to be attractive. The opportunities with the most benefits to the plant should be recommended to the plant for serious evaluation. All the opportunities should, where possible, be provided in a list from most to least beneficial. The payback periods and financial costs involved as well as the possible savings attainable must be provided to enable well informed choices.

### **3.3.3 Detail Engineering and Design**

In this stage the actual solutions for the chosen and approved projects must be designed and planned in detail. The time of the project implementation and the acquirement of the necessary equipment for the project must be planned to insure minimal impact in downtime and production losses. Contractors should be contracted to implement the project if it is not possible to do implementation in-house.

### **3.3.4 Project Implementation**

The actual implementation of the project is executed in the project implementation phase. The implementation of the project should be executed with as little impact on plant production as possible. Implementation of the project should be done in scheduled plant maintenance downtimes, if possible, as this will have the least effect on plant operation.

### **3.3.5 Commissioning**

The commissioning of the installed equipment is done after implementation is complete. The new equipment is started up using the prescribed start-up procedures of the specific plant.

### **3.3.6 Operation and Maintenance (Sustaining of Performance)**

After the project is completed adequate maintenance of the new system is vital for the sustained performance of the new system. Efficiency levels will deteriorate over time as new equipment wears or system settings drift. It is therefore crucial to maintain the equipment and settings to ensure that the efficiency level is sustained.

The efficiency levels obtained can be sustained by using a Measurement and Verification (M&V) approach. The M&V approach will ensure an adequate baseline to which the plants performance can be compared. Accurate savings can also be obtained through the use of M&V. The next chapter discusses in more detail what M&V is and where it fits into the process and energy improvement methodology.

## **3.4 Conclusions**

This chapter described a process and energy improvement methodology for a Ferro-metal production plant. The chapter showed the chronological order of the various steps of the methodology as well as the specific aims of each step. It is now necessary to investigate M&V in more detail and establish where M&V fits into the process and energy improvement methodology.



## CHAPTER 4

# MEASUREMENT AND VERIFICATION

*This chapter provides an overview of measurement and verification. The chapter firstly answers the question: What is M&V? Then a M&V process for energy related projects within a Ferro-metal plant is also presented in the chapter.*

## **CHAPTER 4: MEASUREMENT AND VERIFICATION**

### **4.1 Introduction**

After an energy related project has been implemented the following important question is usually asked: How much energy and money do we save? This question is usually followed by another question: Are the savings sustainable? These two questions highlight the necessity of measurement and verification of energy related projects.

This chapter provides a description of the Measurement & Verification (M&V) process. The chapter will also describe how the M&V process is integrated into the energy project process.

### **4.2 What is Measurement and Verification?**

In order to accurately quantify energy savings obtained through means of energy efficiency projects on a plant it is necessary to measure and verify the energy use before project implementation and again after implementation to obtain a verified impact. This impact reflects the true energy saving achieved by the implementation of the efficiency project. The M&V process is designed to provide an impartial quantification and assessment of project savings that result from energy efficiency activities.

Performance based contracts rely on impartial and accurate savings information. Therefore Measurement and Verification (M&V), by means of a third party, is necessary to quantify and assess the actual savings obtained by such projects. The M&V process must be an accurate, repeatable, consistent, transparent and reliable process to ensure acceptable saving determinations (Den Heijer (2004)).

Energy projects implemented within a plant can be measured and verified internally by plant personnel with the assistance of an adequate M&V plan.

### **4.3 Why Measure and Verify?**

M&V enables stakeholders (plant managers) to evaluate verified savings against the targets set for a project in order to assess the success or performance of the project. M&V also encourages investment in the DSM industry as it provides an impartial and accurate assessment of a project. The risks for financial investors (plant finance managers) are reduced by a transparent M&V process especially where performance contracts are concerned (Den Heijer (2002)).

For participation in international markets, such as the CDM projects, M&V will become a key requirement as it provides credibility and acceptance in the energy market. Therefore for the broad acceptance of the M&V process it must be based on the internationally recognized International Performance Measurement & Verification Protocol (IPMVP).

The IPMVP is a protocol that provides the best techniques available for verifying results of energy and water efficiency as well as renewable energy projects. According to the IPMVP (2000) energy efficiency offers the largest and most cost effective opportunity for both industrialised and developing nations to limit the enormous financial, health and environmental costs associated with the burning of fossil fuels.

### **4.4 How Does Measurement and Verification Work?**

Usually an energy project consists of three different stages. These stages are:

- The Pre-implementation stage;
- The implementation stage; and
- The Post-implementation stage.

These stages can be seen in Figure 4-1. The duration of the various stages vary according to the complexity of the specific project. The energy project is designed and planned in the pre-implementation stage and then implemented and commissioned in the implementation stage. The post-implementation stage follows after the project has been

successfully implemented. This post-implementation stage is where the savings achieved by the project are calculated.

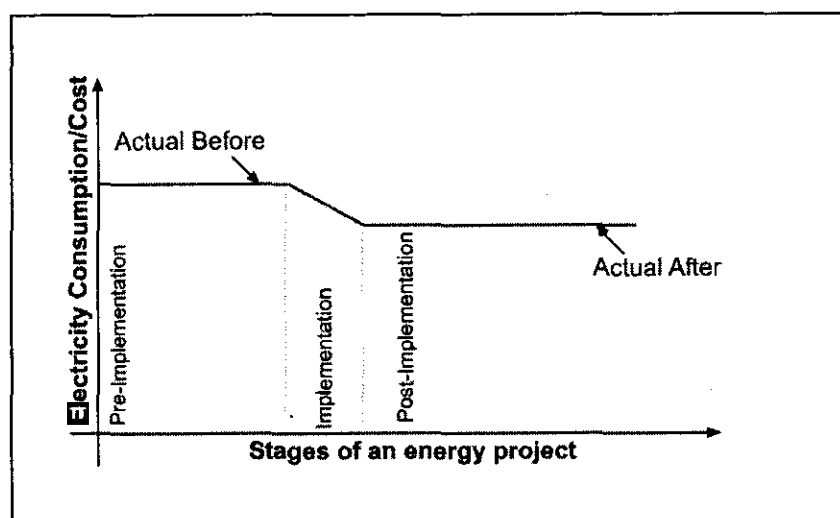


Figure 4-1: Project Stages.

M&V compares the measured energy consumption and demand after implementation of a project with the energy consumption and demand before implementation (Den Heijer (2004)). The difference between the two is the savings obtained through the implementation of the project as shown in Equation 4-1 below.

$\text{Energy Savings} = (\text{Baseline energy use}) - (\text{Post-Implementation energy use}) \pm \text{Adjustments}$	(Eq. 4-1)
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The baseline represents the energy use and conditions under which the system in question was operating before implementation of an energy project. If the conditions remain the same, the post-implementation energy use can be compared to the baseline energy use. If any of the baseline conditions change, adjustments can be made to bring the two time periods under the same set of operational conditions.

A baseline should be constructed to represent the energy consumption and demand before implementation as this information will be lost after implementation. Therefore it is

necessary to establish a relationship between what the energy consumption would have been and something that can be measured and/or quantified after implementation.

The baseline development for a project forms a very critical part of the accuracy of the quantification of the impact of a project. The baseline depicts the energy use as it was before implementation, in other words what it would have been if no measure was implemented. There exist a few different methods for determining baselines depending on accuracy required and complexity of the specific project. In some cases simple measurements will suffice while in others detailed, calibrated and verified simulations may be necessary.

The baseline can be developed by installing metering equipment or by analysing the monthly usage accounts for the specific facility, as supplied by the electrical energy supplier. After completion of a project the savings resulting from the project can be found by comparing the new energy usage to the baseline, the difference being the savings.

Figure 4-2 shows a schematic representation of how a baseline is used to determine the savings achieved.

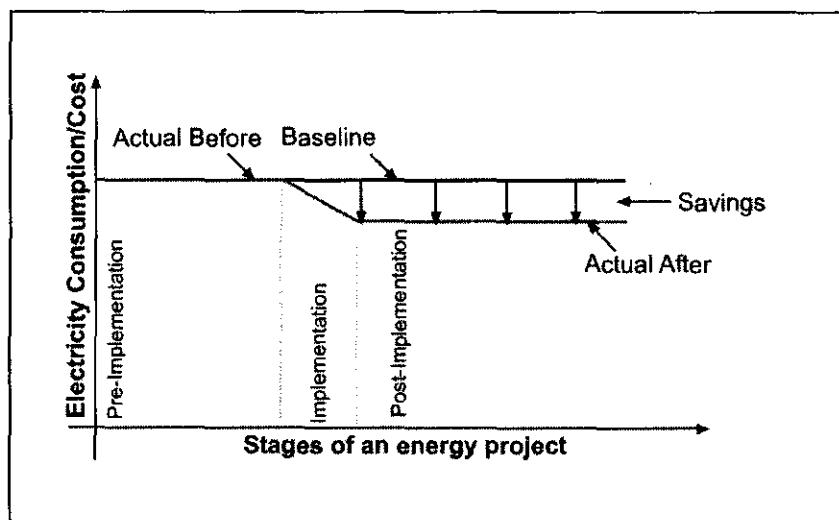


Figure 4-2: Representation of baseline and savings.

From Figure 4-2 it follows that the actual electricity consumption before implementation and the baseline should ideally be the same. The actual consumption after implementation (post-implementation) should be less than before implementation (pre-implementation) resulting in a saving as indicated in Figure 4-2.

#### 4.4.1 Baseline Construction for Furnace

In addition to energy consumption, an *energy vs. tonnes saleable* scatter can be plotted to obtain a baseline for a furnace on a ferrochrome plant. A regression line can be fitted through the data and this line's equation can then present the baseline for the furnace as shown in Figure 4-3.

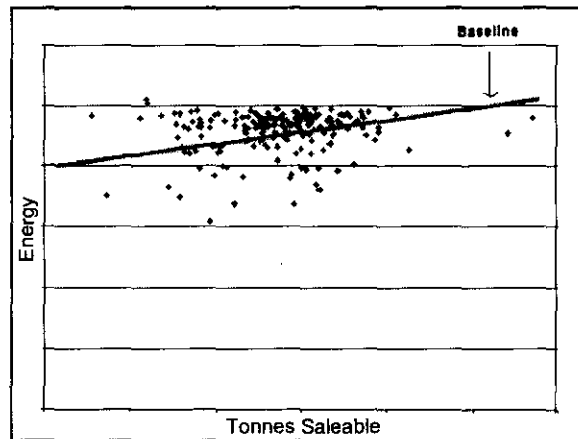


Figure 4-3: Furnace baseline presentation.

After the improvements on the furnace are implemented, data can be gathered and again an *energy vs tonnes saleable* scatter can be plotted. A regression line can then be fitted through the new data. The baseline can then be obtained by substituting the actual new tonne data into the equation which in turn provides the energy that the old system would have used to produce the same amount of tonnes. The difference between the baseline and actual new data then represents the savings. This process is graphically illustrated in Figure 4-4.

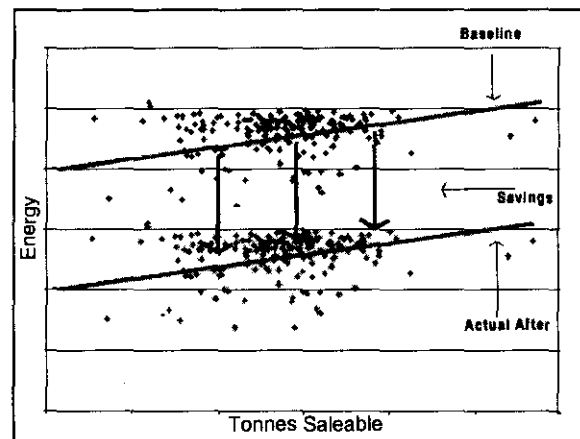


Figure 4-4: Furnace Saving Presentation.

#### 4.5 M&V Process

The M&V process should be properly understood by all parties (plant personnel and contractors) involved in a project to assure the acceptability of the process. The M&V steps that are followed to M&V energy related projects are shown in Figure 4-5. The following paragraphs provide a brief description of the various steps of the M&V process.

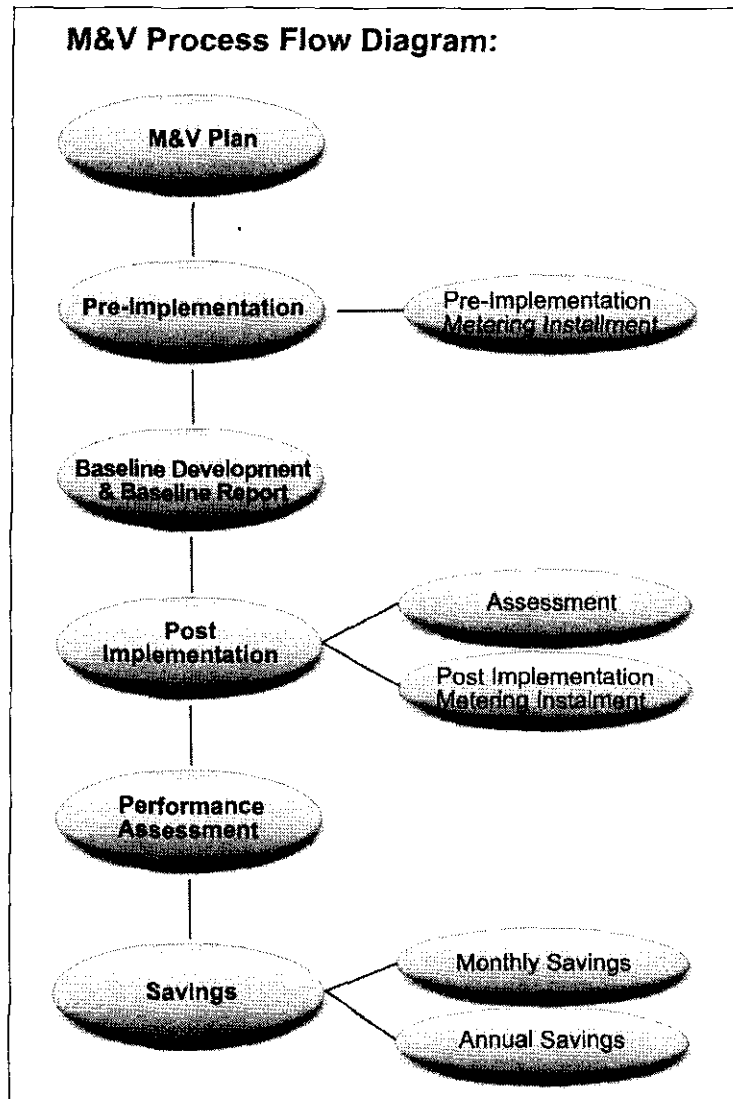


Figure 4-5: M&V Process Flow Diagram.

#### 4.5.1 M&V Plan

The activities and procedures that will be followed to M&V the energy project must be stipulated in a M&V plan. The M&V plan includes a description of the energy project as well as all the assumptions made by the M&V team (personnel assigned to M&V the specific project) to enable them to M&V the project. All variables that can influence the saving potential of the project should be highlighted and discussed in the M&V plan.



The project's baseline construction method should also be provided in the M&V plan. Energy audits are used to gather the required information for the M&V plan. All metering equipment necessary for the project in addition to the project schedule and M&V costs should also be included.

The M&V process and procedures should be mutually accepted by all the parties involved in the specific project therefore all parties must be informed of and provided with a copy of the M&V plan report.

#### **4.5.2 Pre-implementation**

Pre-implementation metering is installed, if necessary, to gather sufficient data for the baseline construction which forms the next step. Existing plant meters should be used for pre-implementation metering if the meters are available and adequate for the purposes of the M&V project. The pre-implementation metering should be installed as soon as possible to ensure that enough data is available for the baseline construction. Plant data, if available, of the system being upgraded can also be used to construct a baseline.

#### **4.5.3 Baseline Development and Baseline Report**

The M&V baseline report provides the actual baseline that will be used for the calculation of the savings for the project. For the purpose of developing a baseline, sufficient measurements need to be gathered before project implementation, to provide an accurate representation of the conditions before implementation. The baseline report should include the actual data used to develop the baseline as well as the development method used. All assumptions and variables used in the baseline development should be stipulated in the report.

#### **4.5.4 Post-implementation**

##### **4.5.4.1 Post-implementation Assessment**

After the project has been successfully implemented and commissioned a post-implementation report should be provided that presents an assessment and verification of the project implementation. The report basically verifies if the project was implemented as planned and if there were any deviations from the original plan. Where deviations from the original plan occurred the report should try to state, and wherever possible, assess the impact that these deviations will have on the project's performance.

##### **4.5.4.2 Post-implementation Metering**

Where the pre-implementation meters or existing plant meters are not sufficient, post-implementation metering should be installed. The post-implementation meter data is used to calculate the savings achieved by the project. This is done by subtracting the post-implementation data from the baseline data that was developed to simulate what the energy use would have been if the project was not implemented.

#### **4.5.5 Performance Assessment**

It is necessary to assess the performance of a project in order to verify whether the planned energy reductions or efficiency levels were attained. This is especially important for projects with performance contracts where penalties can be enforced if the performance is not according to the contract agreed upon by all the stakeholders.

#### **4.5.6 Saving Calculation**

##### **4.5.6.1 Monthly savings**

Monthly saving reports should follow after project implementation to provide a summary of the actual savings obtained on a monthly basis for an agreed period of months. The monthly savings can also indicate if the savings are sustained from the previous month or not.

#### **4.5.6.2 Annual Savings**

An annual saving report should follow after all the agreed monthly saving reports are completed. The annual report provides a summary of the savings attained for a year. The report is constructed from all the monthly savings data available or extrapolated if there are not twelve monthly saving reports available.

### **4.6 Energy Project and M&V Integration**

A graphic representation of how a energy project and the M&V process integrates to ensure adequate M&V of the project, with as little intrusion in the actual energy project as possible is shown in Figure 4-6. The left side of Figure 4-6 shows the project process and the right side shows the M&V process with indication of where the various steps of the M&V process fit into the project process.

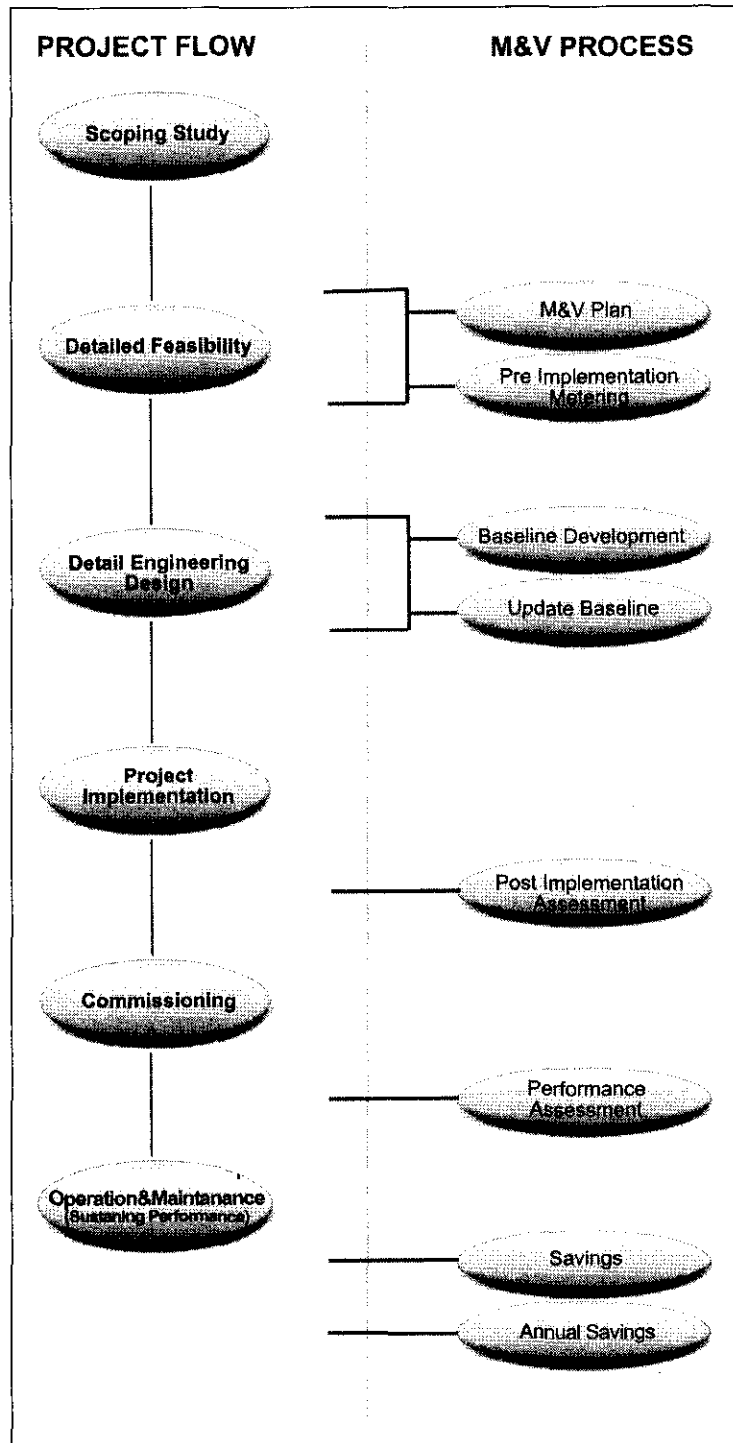


Figure 4-6: M&V Project Integration with Energy Related Project.

#### **4.6.1 M&V Integration Description**

During the detailed feasibility study of the energy project a M&V plan should be constructed followed by pre-implementation metering. If the plant's existing metering system is not adequate, additional metering should be installed.

As soon as enough pre-implementation data is gathered the baseline development can start. The baseline development should be done during the detail engineering design and must preferably be completed before actual implementation of the project starts.

A post-implementation assessment is made after the project is successfully implemented and commissioned. After commissioning, it is necessary to do a performance assessment of the new system once enough post-implementation data of the new system is available.

If the new system is operational, monthly savings can be calculated as soon as enough post-implementation data is available. The monthly savings should be delivered on a monthly basis followed by an annual savings report at the end of the M&V period.

#### **4.7 Summary**

The M&V process forms an important part of any energy related project. Through M&V the performance of a particular project can be assessed and the actual savings that were achieved can be determined.

The baseline development forms a critical part of the M&V process as it represents the system's energy use before implementation. The M&V process should be transparent to encourage a broad acceptance of energy related projects.

## 4.8 References

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## CHAPTER 5

### CASE STUDY TO IDENTIFY AND QUANTIFY ENERGY AND PROCESS IMPROVEMENT OPPORTUNITIES

*This chapter provides a case study of a Ferro-metal production plant using the approach outlined in Chapter 4 to identify and quantify energy and process improvement opportunities. The chapter provides the results of the case study for all the furnaces but only one furnace (Furnace 4) is shown as an example in this chapter while all the remaining furnaces' details are shown in Appendix A and B.*

## **CHAPTER 5: CASE STUDY TO IDENTIFY AND QUANTIFY ENERGY AND PROCESS IMPROVEMENT OPPORTUNITIES**

### **5.1 Introduction**

The process and energy improvement methodology is a fast and effective way of analysing all the energy saving opportunities available in a plant. This approach allows you to use energy to solve operating problems. The process also compliments other continuous improvement programmes.

The following results were obtained through the use of the methodology process on a case study of a Ferro-metal production plant. Only the results of furnace 4 are presented in this chapter. The results for all the remaining furnaces can be found in Appendix B while Appendix A provides more detail of the no-cost and low-cost options.

### **5.2 Scoping Study**

During the scoping study an assessment of the plant was made in order to answer the question: Is it worthwhile to explore opportunities further? The scoping study quantified the feasibility of energy saving opportunities and their estimated value to the specific plant under consideration. The scoping study revealed enough potential to continue with the project.

#### **5.2.1 Walk-through Assessment**

The project commenced with a walk-through assessment of the plant. The project team familiarised themselves with the layout and operation (material, product and energy flows) of the plant, as well as the process constraints. Various interviews were conducted with engineering, production and maintenance personnel.



In the walk-through assessment all the main energy consuming equipment on the Ferro-metal production plant was identified. The typical energy consumers were found to be furnaces and auxiliary equipment. The furnaces contribute the largest amount of energy use of the plant's total energy use. For the plant under consideration, a plant energy breakdown was established as follows: approximately 94% of the energy use could be attributed to the six furnaces and only 6% of the energy was credited to other facilities and equipment as shown in Figure 5-1.

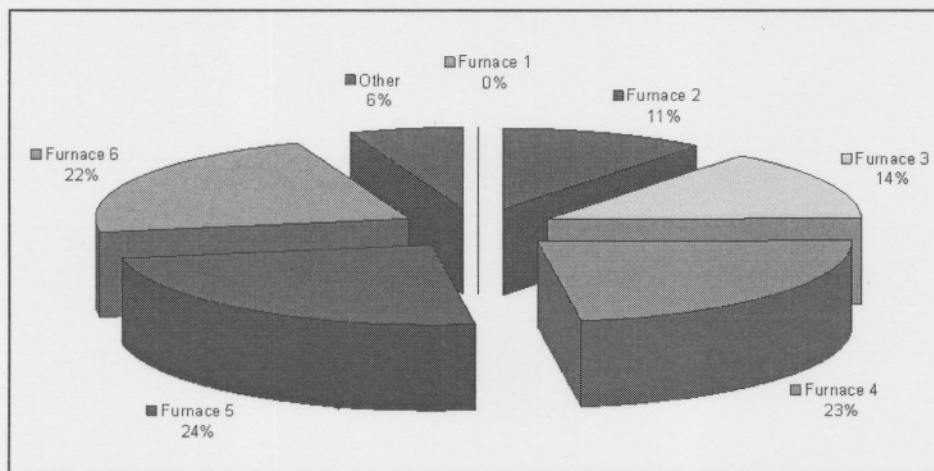


Figure 5-1: Breakdown of plant energy consumption according to contribution to total energy use.

### 5.2.2 High-level Benchmarking, Diagnostics and Analysis

The contribution of energy to the total production cost is approximately 22% and its contribution to the variable cost is approximately 33%. The energy account is in the order of R15 million per month, resulting in an annual energy cost between R180 million to R200 million.

The plant is currently operated on the specific tariff structure, resulting in a energy cost per tonne of production of R1,904 per tonne during the high demand season (June, July and August) in peak periods (07:00 to 10:00 and from 18:00 to 20:00 during weekdays). This is higher than the average total cost of production of R1, 800 per tonne. It is therefore most unlikely that the plant will be able to produce at a profit during the peak

period in winter time. Optimal load management and energy efficiency are therefore high priorities in order to reduce the energy cost per tonne. The energy cost per tonne of production is R549 per tonne in the standard period and R326 per tonne during the off-peak periods in the high demand season.

During the low demand season (September to May) the energy cost per tonne production varies from R583 per tonne (peak periods), R386 per tonne (standard periods) and R291 per tonne (off-peak periods).

Data was gathered from the plant's existing infrastructure and analysed in order to benchmark the plant's energy use. KPI's were obtained for furnace 2 to furnace 6 as furnace 1 was not in use at the time of the study. A summary of the identified furnace KPI's are shown in Table 5-1.

**Table 5-1:** Summary of furnaces KPI's.

Furnace description	Average MWh per month	Average tonnes per month	Average monthly availability	Average monthly utilization	Average MWh per tap	Average tonnes per tap	Average MWh per tonne
	(MWh/month)	(Tonnes/month)	(%)	(%)	(MWh/tap)	(Tonnes/tap)	(MWh/tonne)
Furnace 2	12,980	3,200	97	86	51	13	4.1
Furnace 3	18,500	4,300	96	90	74	17	4.3
Furnace 4	26,600	7,900	97	88	105	31	3.3
Furnace 5	25,800	8,400	94	88	109	36	3.1
Furnace 6	24,200	6,700	94	83	98	27	3.6

A number of no-cost and low-cost opportunities were explored. The opportunities were identified in a chrome recovery plant, a pelletising plant and the plant lighting. A summary of the potential cost impacts and actions are provided in Table 5-2. Each of these opportunities is discussed in more detail in Appendix A of this report.

**Table 5-2:** Summary of no-cost and low-cost opportunities and associated annual cost implications.

Plant section	Opportunity / Activity	Annual cost saving impact
Chrome recovery plant Option 1A	Optimal scheduling of the stocking of the stockpile to switch off the primary side of the plant from 07:00 to 10:00, and again from 18:00 to 20:00 during the weekdays of the low and high demand seasons (throughout the year). This option is seen as a no-cost opportunity.	R262,000
Chrome recovery plant Option 1B	Optimal scheduling of the stocking of the stockpile to switch off the primary side of the plant from 07:00 to 10:00, and again from 18:00 to 20:00 during the weekdays of the high demand seasons (June, July, August). This option is seen as a no-cost opportunity.	R136,000
Pelletising Option 2A	Switching off the pelletising plant from 07:00 to 10:00 and from 18:00 to 20:00 per weekday during high demand season (June, July, August) by "borrowing" pellets from a bunker to supply the furnaces. This option is seen as a no-cost opportunity.	R583,500
Pelletising Option 2B	Switching off the pelletising plant from 07:00 to 10:00 per weekday during high demand season (June, July, August) by "borrowing" pellets from a bunker to supply the furnaces. This option is seen as a no-cost opportunity.	R350,000
Lighting Option 3	Switching off outside lights throughout plant during every day from 08:00 to 17:00 when they are not needed during both the low and high demand seasons. The implementation cost of this opportunity need to be quantified by the plant.	R80,000

The options (1A, 1B, 2A and 2B) concerned with the chrome recovery and the pelletising plants are no-cost opportunities, whilst option 3 for the plant lighting system is an opportunity which will require cost input. The implementation cost to achieve energy cost savings from option 3 however needs to be quantified since the layout of the lighting system will determine which actions can be taken. It is proposed that the plant undertake this project internally (on a maintenance basis) since an active retrofit (by a contractor) of the lighting system with the necessary control gear could render the project financially unviable.

The decision of which opportunity to implement lies with the management of the plant. A number of scenarios can be followed to achieve the above benefits. These scenarios include the following:

**Scenario A:** Scenario A is concerned with maximising the annual cost savings for the opportunities outlined in Table 5-2. This can be achieved by implementing option 1A (from Table 5-2) where scheduling is done on the chrome recovery plant to ensure that the stockpile is fully stocked by 07:00 and again at 18:00 during each weekday of the year. If this can be achieved for every weekday of the year, it enables the chrome recovery plant to switch off the primary side during both the high and low demand seasons of the tariff. The resulting savings would amount to R262,000 on this plant alone. If this option is combined with option 2A where the pelletising plant is switched off from 07:00 to 10:00 and again from 18:00 to 20:00 per weekday during the high demand season (June, July, August) whilst pellets are “borrowed” from a bunker, total energy cost savings of R583,500 can be achieved over this period. Combining the above two options with the switching off of “unnecessary” plant lighting during the day (option 3 from Table 5-2) could increase the annual energy cost savings by R80,000.

The expected total annual cost savings for the implementation of Scenario A is R925,500.

**Scenario B:** Scenario B is concerned with minimising the impact on plant operation whilst still achieving energy cost savings. This can be achieved by implementing option 2A (from Table 5-2) where scheduling is done on the chrome recovery plant to ensure that the stockpile is fully stocked by 07:00 and again at 18:00 for each weekday during the high demand season. This will enable the chrome recovery plant to switch off the primary side during the high demand season of the tariff (June, July, August). The resulting savings would be R136,000 on this plant alone. If this option is combined with option 2B where the pelletising plant is switched off only between 07:00 and 10:00 per weekday during the high demand season whilst pellets are “borrowed” from the 140,000 tonne bunker, total energy cost savings of R350,000 can be achieved over this period. Combining the above two options with the switching off of unnecessary plant lighting (option 3 from Table 5-2) could increase the annual energy cost savings by R80,000.

The expected total annual cost savings for the implementation of Scenario B is R566,000.

**Scenario C:** Scenario C entails the implementation of individual options in which case the annual cost saving impacts can be obtained from Table 5-2.

**Scheduling:**

Scheduling is another means of achieving substantial electricity cost savings. The aim of scheduling at the plant should be to reduce electricity consumption during the peak hours (where the cost of electricity is high), and increase consumption during the off-peak and standard hours. The peak hours (which are critical for scheduling purposes) are from 07:00 to 10:00 (morning peak) and from 18:00 to 20:00 (evening peak) during weekdays.

One means of assessing the potential cost savings was to look at the daily electricity consumption profile. Consider Figure 5-2 where the average daily demand profile is shown together with the “target” at which the system can be operated. The peak period in the tariff structure is also shown. As mentioned above, cost savings can be achieved when less energy is consumed during peak hours. To ensure that the same quantity of electricity is consumed, one can increase the demand during the remaining hours (off-peak and standard hours). This is also shown in Figure 5-2 on the bottom right-hand side (B).

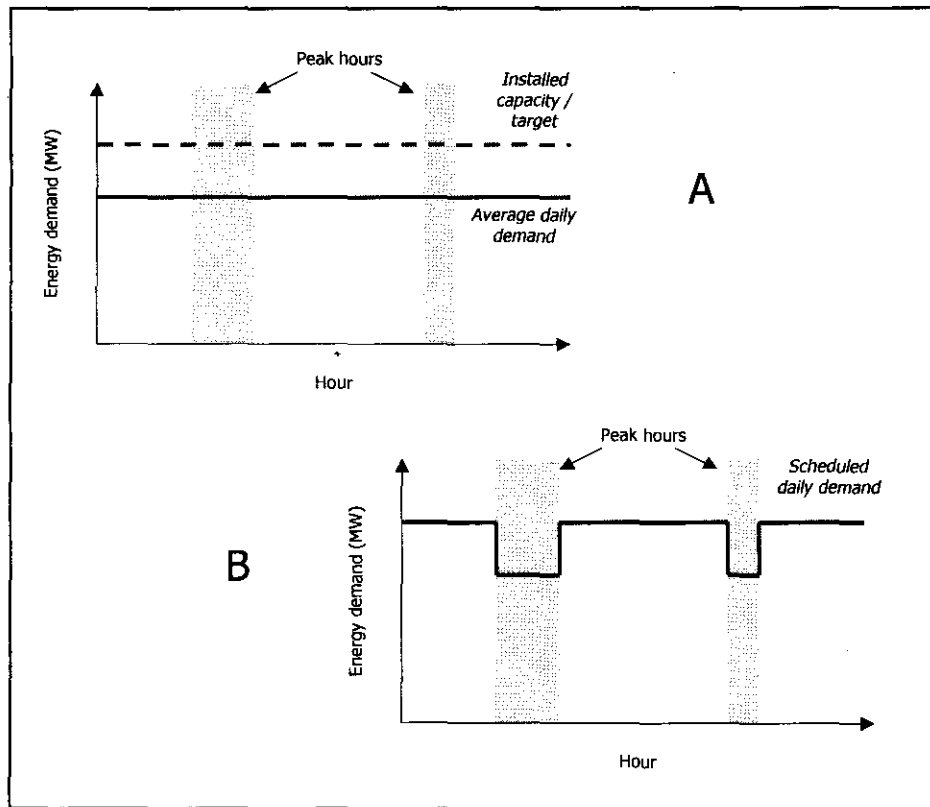


Figure 5-2: Scheduling rationale during peak hours.

A typical demand profile of the plant, for a few days, is shown in Figure 5-3. From the graph it is clear that there is a high level of variance in the plant profile.

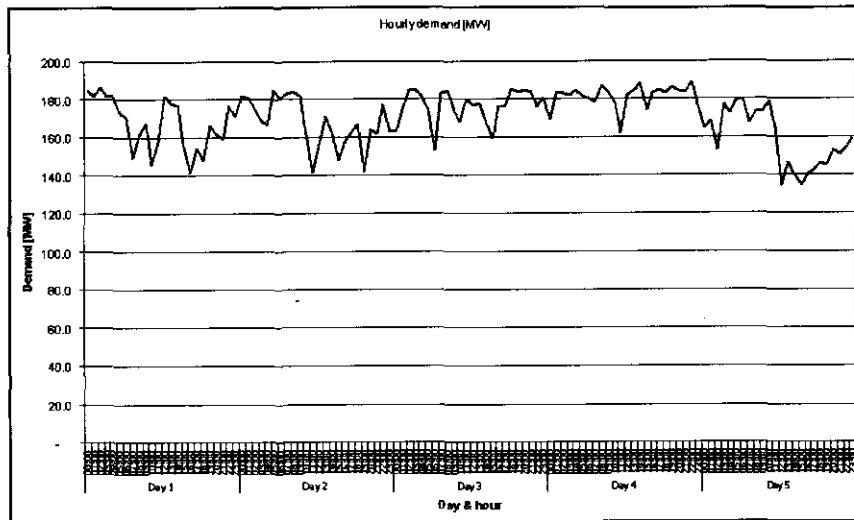


Figure 5-3: Typical demand profile of plant for a few days.

The typical daily profile for Furnace 4 is shown in Figure 5-4.

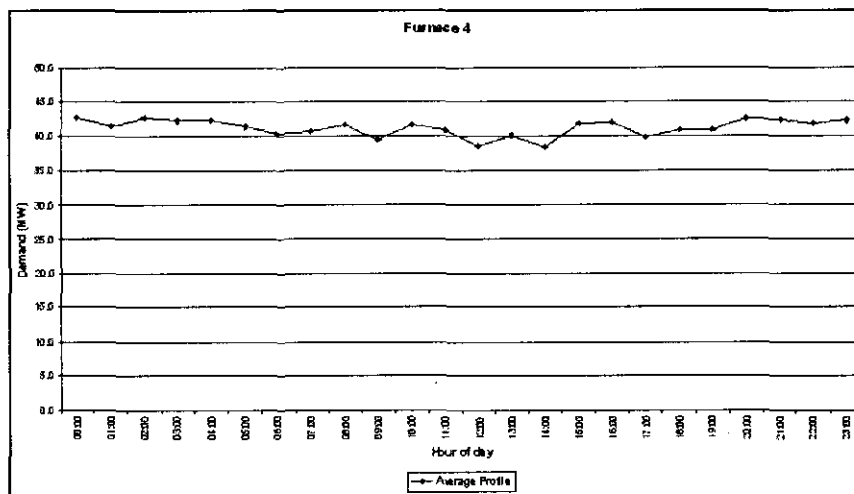


Figure 5-4: Typical daily demand profile for Furnace 4.

In Figure 5-5 the peak hours, in which the demand should be reduced, are indicated. All the hours outside these hours can be used to increase the demand in order to make up production. The profile represents a typical profile that can be expected for furnace 4.

The first mode of load control was to the “minimum of minimum” demand during peak hours. During the load control analysis we determined the average, minimum and maximum demand for furnace 4 during each hour of the day. By the “minimum of minimum” demand we mean the minimum value of the minimum demand values during peak hours. Figure 5-5 demonstrates the concept where the minimum values are indicated for furnace 4.

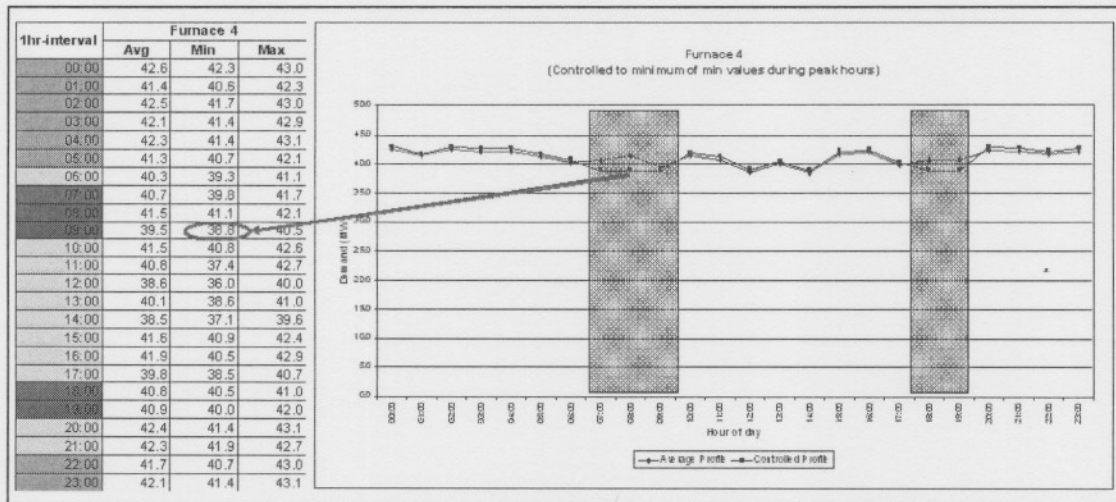


Figure 5-5: Demand profile for Furnace 4 controlled to “minimum of minimum demand” during peak hours.

The demand is then controlled to the minimum value of the demand minimum values during peak hours. The total energy consumption should however remain constant not to influence the production. The demand is thus increased in the hours outside the peak periods. It is also important to note that the increase in demand still did not cause the furnace to exceed its maximum demand during normal operation. The demand added to the hours outside peak would not cause the furnace to run out of capacity.

If this mode of demand control can be sustained throughout the year for the weekday peak periods (in both the high and low demand seasons) the plant could potentially save R382,100 per year on their electricity account.



The analysis was repeated for a load control mode to the average of the minimum demand values during peak hours. The concept remains the same except for the demand which is controlled to the average value of the minimum demand values during peak hours. In Figure 5-6 the average value is determined and control is applied during peak hours. The overall electricity consumption again remains constant and the balance from the load control is made up in the hours outside peak. Again the increase in demand did not exceed the maximum demand.

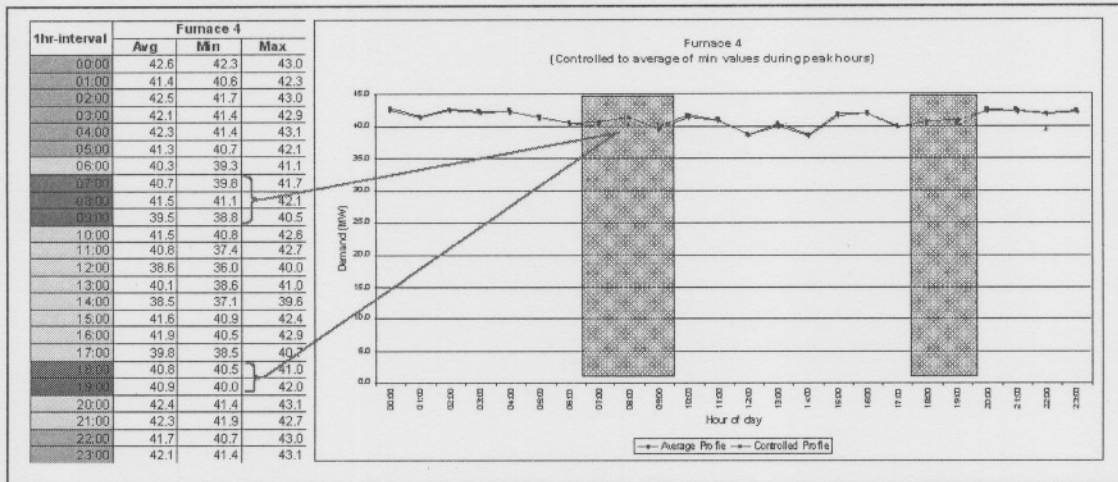


Figure 5-6: Demand profile for Furnace 4 controlled to average of the minimum during peak hours.

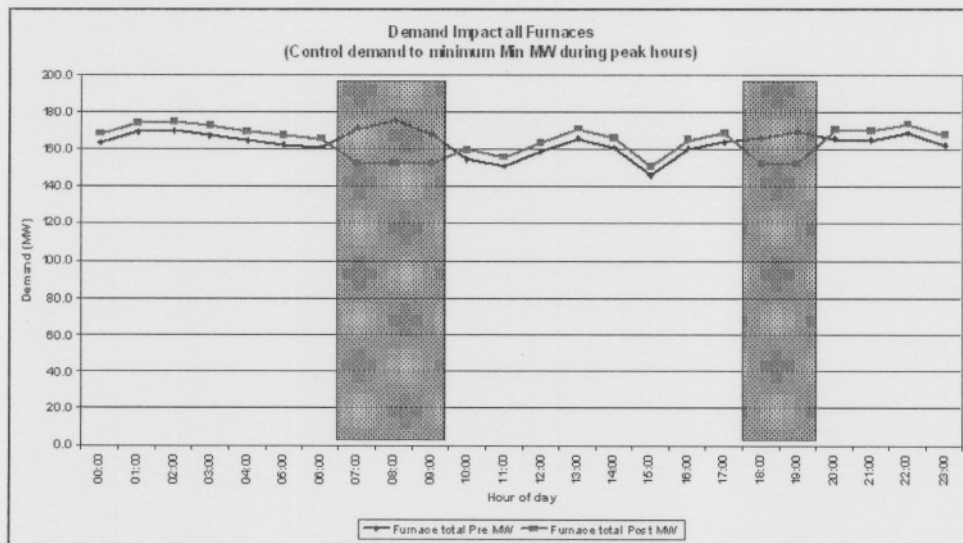
If this mode of demand control can be sustained throughout the year for the weekday peak periods (in both the high and low demand seasons) the plant could potentially save R123,100 per year on their electricity account.

The impacts of both load control modes, for all the furnaces, are summarized in Table 5-3. A monthly demand cost saving is also associated with the load control and this is also indicated in Table 5-3 below.

**Table 5-3:** Summary of impacts on furnace load control analysis for control to minimum of the minimum demand and to average of the minimum demand during peak hours throughout the year (high- and low demand seasons).

Furnace	Annual cost savings due to load control during peak hours to:	
	Minimum of the minimum demand	Average of the minimum demand
Furnace 2	R 519,000 / year	R 150,000 / year
Furnace 3	R 1,517,000 / year	R 438,000 / year
Furnace 4	R 382,000 / year	R 123,000 / year
Furnace 5	R 1,111,000 / year	R 540,000 / year
Furnace 6	R 215,000 / year	R 101,000 / year
<b>Furnace total</b>	<b>R 3,744,000 / year</b>	<b>R 1,352,000 / year</b>
Monthly demand saving total	R 23,400 / year	R 425,800
<b>Total</b>	<b>R 3,767,400 / year</b>	<b>R 1,777,800 / year</b>

The impact for all the furnaces of both control modes are shown in Figure 5-7 and Figure 5-8.



**Figure 5-7:** Load control to minimum of the minimum demand during peak, Furnace 2 – 6.

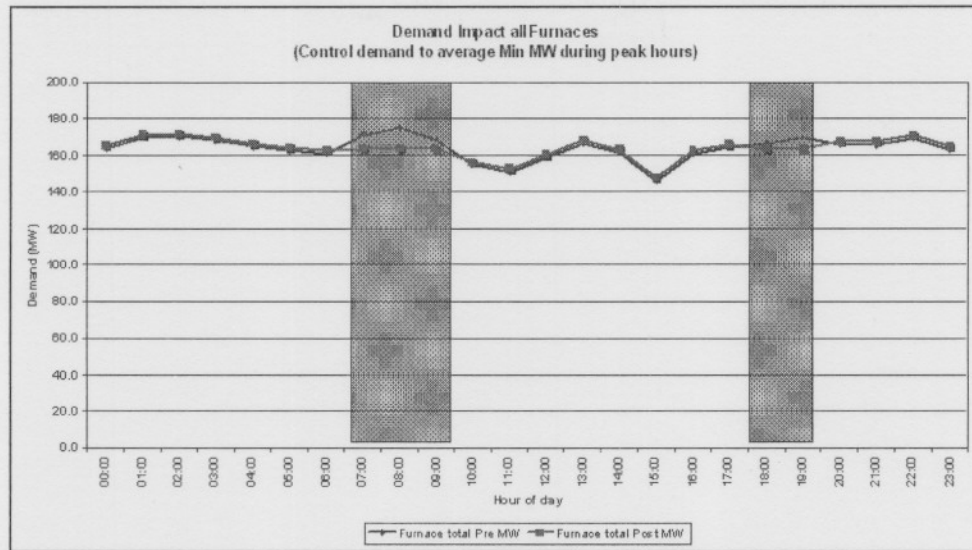


Figure 5-8: Load control to average of the minimum demand during peak, Furnace 2 – 6.

The morning peak would be reduced by 19,4 MW on average and the evening peak would be reduced by 15,7 MW if the “minimum of the minimum demand” strategy is followed. For the average of the minimum demand control strategy the morning peak would be reduced by 7,9 MW on average and by 4,2 MW on average during the evening peak.

### 5.3 Detailed Feasibility Study

#### 5.3.1 Plant Assessment

After the initial scoping study was completed it was necessary to conduct a detailed feasibility study on the plant. An online data acquisition system was installed and integrated with the existing plant SCADA system to capture operational and energy performance data. The data was captured for selected plant indices identified during the assessment stage.

These indices were:

- Availability;
- Utilisation;
- Applied Energy;

- ❑ Specific Energy Consumption;
- ❑ Tonnes Saleable per Day; and
- ❑ Number of Taps.

Acquisition of the MES data, which consisted of daily plant and production performance data, was also done.

### **5.3.2 Installation and Integration of a Data Acquisition System**

The data acquisition system was installed and integrated with the existing SCADA system of the plant. The data acquisition system continuously monitored and captured operational and energy performance data which were automatically send via e-mail to a computer on the Potchefstroom campus of the North-West University.

After all the necessary data was acquired preliminary data mining was employed. The data mining consisted of:

- ❑ Data capturing and archiving;
- ❑ Benchmarking of plant, systems and critical components;
- ❑ Performance analyses and diagnostics of plant, systems and components;
- ❑ A Cause Analysis; and
- ❑ Performance targeting and base lining.

MES data was obtained for furnace 2 to furnace 6 from September 2002 to June 2003. The data consisted of daily values for a number of key indices.

### **5.3.3 Data Mining**

#### **5.3.3.1 Data Capturing and Archiving**

The data that was monitored and captured was identified and selected during the plant and walk-through assessment stages. This data was used in the detailed analysis of the furnace performance and operation.

### 5.3.3.2 Benchmarking of Plant, Systems and Critical Components

The plant's main concern is to increase profit. Energy efficiency and load management are ways of achieving this increased profit by reducing the expenditure per tonne product produced. An integrated approach is however required to optimise all resources, which will result in better results than that of conventional conservation approaches. The strong interdependence requires that both the process and the utilisation of energy need to be focused on, be it through higher throughputs, better use of raw materials, etc.

This methodology will therefore be aimed at using energy to reduce process and operational problems. The integrated optimisation could therefore result in increased energy consumption, but at a higher production rate and by means of a more cost and energy effective way.

### 5.3.3.3 Performance Analyses and Diagnostics of Plant, Systems and Components

A relationship was obtained between the daily energy consumption and the saleable daily production for each furnace. Figure 5-9 depicts the relation that exists between the daily applied energy and the tonnes saleable production for furnace 4.

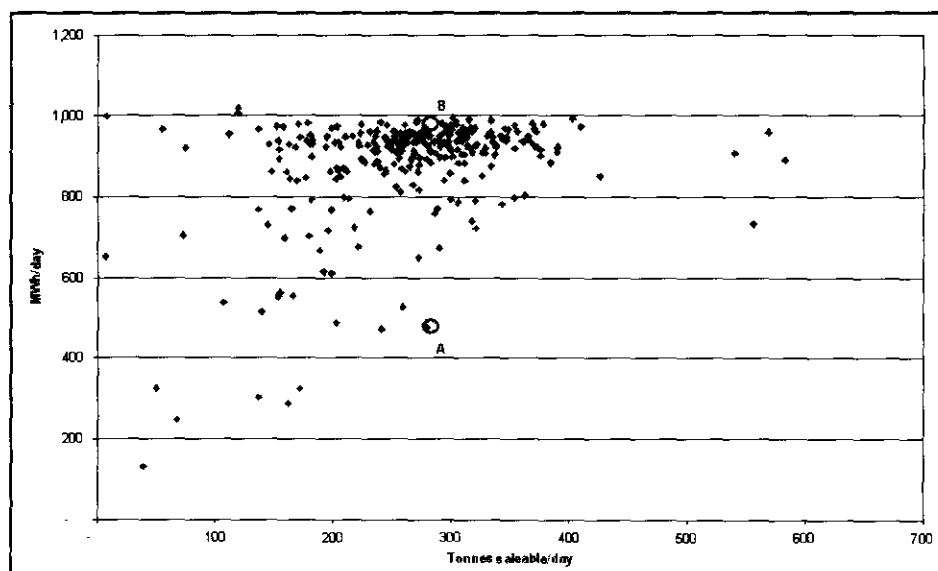


Figure 5-9: Daily applied energy against tonnes saleable production (Furnace 4).

As shown in Figure 5-9 there is a substantial scatter in the data. If we consider points A and B, as an example, in Figure 5-9, we can see that furnace 4 delivered the same production of 277 tonnes per day, but the corresponding values of the daily applied energy differ from 477 MWh (point A) to 972 MWh (point B). That is a difference of 495 MWh for the same daily production for the furnace. Based on an average cost for the energy consumption, the cost of day B was R61,875 more than that of day A for the same production.

It is evident that if the reason for the data scatter can be identified and the contributing factors isolated, measures can be implemented to stabilize the relationship between the daily energy consumption and the daily production. A better level of consistency between MWh/day and tonnes/day can result in substantial energy cost savings for the plant.

In order to quantify the potential savings, a regression line was fitted through the data of Figure 5-9 (See Figure 5-10 below).

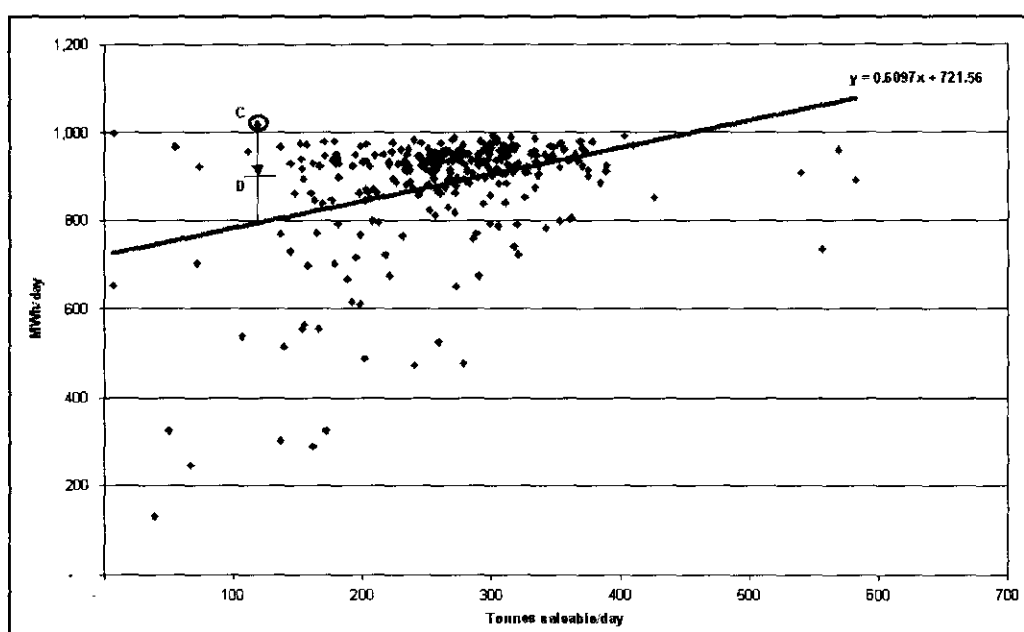


Figure 5-10: Daily applied energy against tonnes saleable production (Furnace 4) with regression.

The regression line in Figure 5-10 represents the average daily energy consumption per daily production as a first estimate. In order to estimate the saving potential, we assumed that we could reduce the daily energy consumption (MWh/day) of all data points above average (regression line) with 50% of the difference between the value and the average value.

Now consider a MWh value (point C) that has a certain MWh value above the average (regression line) in Figure 5-10. We assumed that the energy consumption of the data points, above the average line, could be reduced by 50% of the difference between the value of the data point and the average. This means that point C will move down to point D. This would result in a MWh saving, and subsequently in an energy cost saving. This process was followed for every data point above the regression line. The results are shown in Figure 5-11.

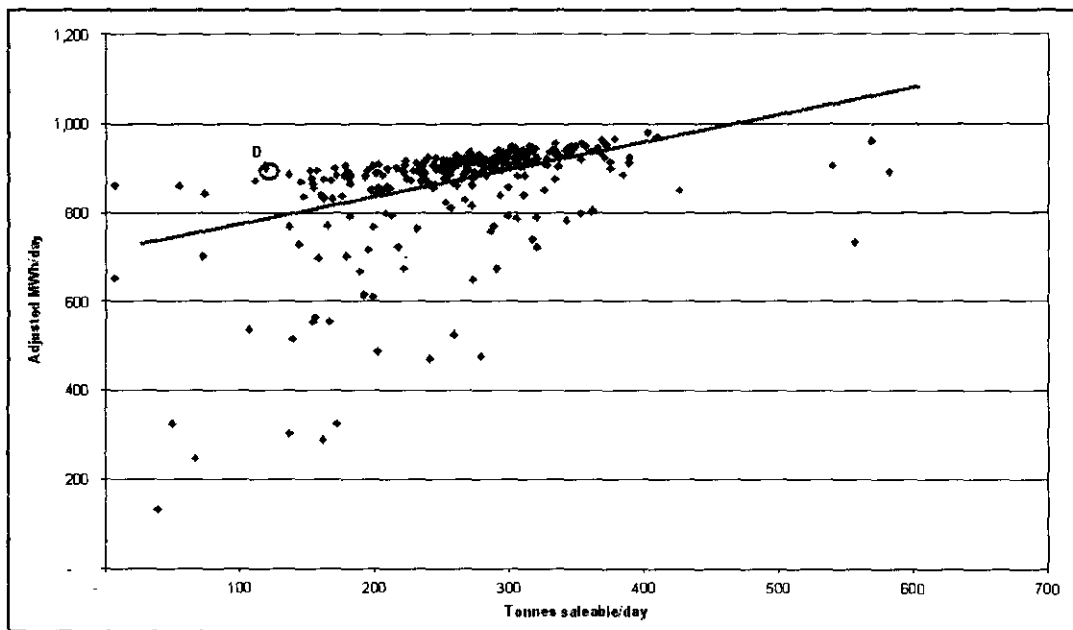


Figure 5-11: Adjusted (50%) daily applied energy against tonnes saleable production (Furnace 4).

If this is possible, the calculated annual energy cost savings will be R910,500 on furnace 4. The same approach was applied to the remaining furnaces (furnace 2, 3, 5 and 6) and the results are summarised in Table 5-4 below. The process was also repeated for



a combination of furnace 4 and 5, since it happens that their production and energy consumption are sometimes interchanged on the MES system.

**Table 5-4:** Summary of potential annual cost savings for furnaces at a 50% reduction.

Furnace description	Energy cost savings at a 50% reduction above average (regression line)		
	Single day data	2-day moving average data	3-day moving average data
	(Rand/year)	(Rand/year)	(Rand/year)
Furnace 2	R 423,600	R 360,600	R 327,400
Furnace 3	R 741,300	R 598,900	R 545,400
Furnace 4	R 910,500	R 810,800	R 733,500
Furnace 5	R 1,297,500	R 1,098,200	R 999,400
Furnace 6	R 1,114,200	R 904,900	R 784,700
<b>Totals (2, 3, 4, 5, 6)</b>	<b>R 4,487,100</b>	<b>R 3,773,400</b>	<b>R 3,390,400</b>
Furnace 4+5	R 1,757,000	R 1,428,000	R 1,269,500
<b>Totals (2, 3, 4+5, 6)</b>	<b>R 4,036,100</b>	<b>R 3,292,400</b>	<b>R 2,927,000</b>

It is common that some of the production data from one day's data is logged together with data from the following day. In order to filter out the effect that this might have on the analysis results the above process was repeated with 2-day and 3-day moving average data from the single day data. We feel confident that the 2-day moving average analysis results are conservative.

From Table 5-4 it is seen that the potential annual cost saving of a 50% reduction between the actual value above the average and the average can result in R3,8million, annual energy cost savings (based on 2-day moving average data). If a combination of furnace 4 and 5 is considered together with the remaining furnaces, the potential annual energy savings become R3, 3million.

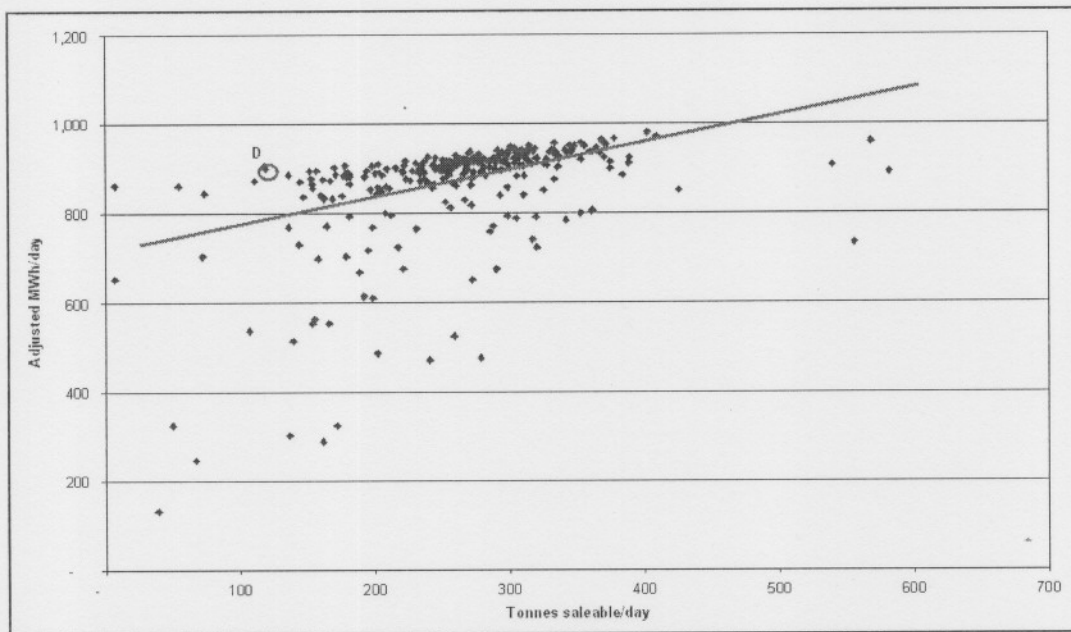
Table 5-5 provides the same results as Table 5-4, but for an assumed 25% reduction between the actual MWh value above the average and the average MWh value. From Table 5-5 it is seen that the potential annual cost saving of a 25% reduction between the actual value above the average and the average can result in R1,9million in annual energy cost savings (based on 2-day moving average data). If a combination of furnace 4 and 5 are considered together with the remaining furnaces, the potential annual energy cost savings becomes R1,6million.



**Table 5-5:** Summary of potential annual cost savings for furnaces at a 25% reduction.

Furnace description	Energy cost savings at a 25% reduction above average (regression line)		
	Single day data	2-day moving average data	3-day moving average data
	(Rand/year)	(Rand/year)	(Rand/year)
Furnace 2	R 211,800	R 180,300	R 163,700
Furnace 3	R 371,100	R 299,400	R 272,700
Furnace 4	R 455,200	R 405,400	R 366,800
Furnace 5	R 648,800	R 549,100	R 499,700
Furnace 6	R 557,100	R 452,400	R 392,400
<b>Totals</b>	<b>R 2,244,000</b>	<b>R 1,886,600</b>	<b>R 1,695,300</b>
Furnace 4+5	R 878,500	R 714,000	R 634,700
<b>Totals</b>	<b>R 2,018,500</b>	<b>R 1,646,100</b>	<b>R 1,463,500</b>

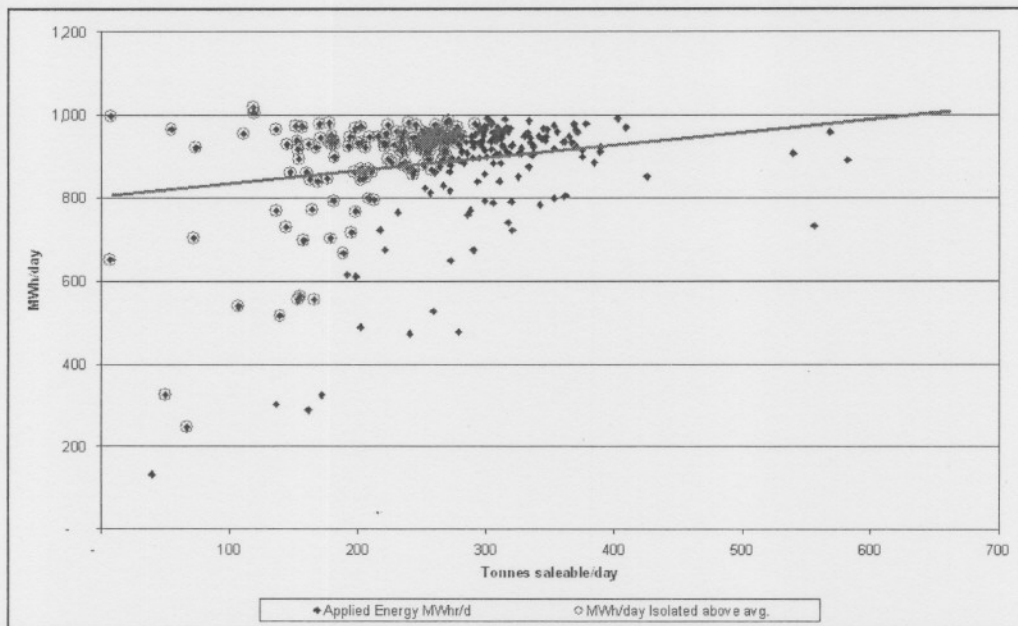
Consider Figure 5-12 showing data of furnace 4. This figure shows the specific energy consumption (MWh/tonne) against the tonnes product per tap. From the data it was found that the average value of the specific energy consumption was 3,3 MWh/tonne.



**Figure 5-12:** Specific energy consumption per ton/tap for Furnace 4.

The data used during the analysis was based on single day data, but also compounded into 2-day and 3-day moving average data sets to filter out fluctuations in the data.

All the MWh/tonne values above the average value of 3,3MWh/tonne in Figure 5-12 were identified and these data points were then plotted on a graph of MWh/day versus tonnes saleable production per day. These results are shown in Figure 5-13.



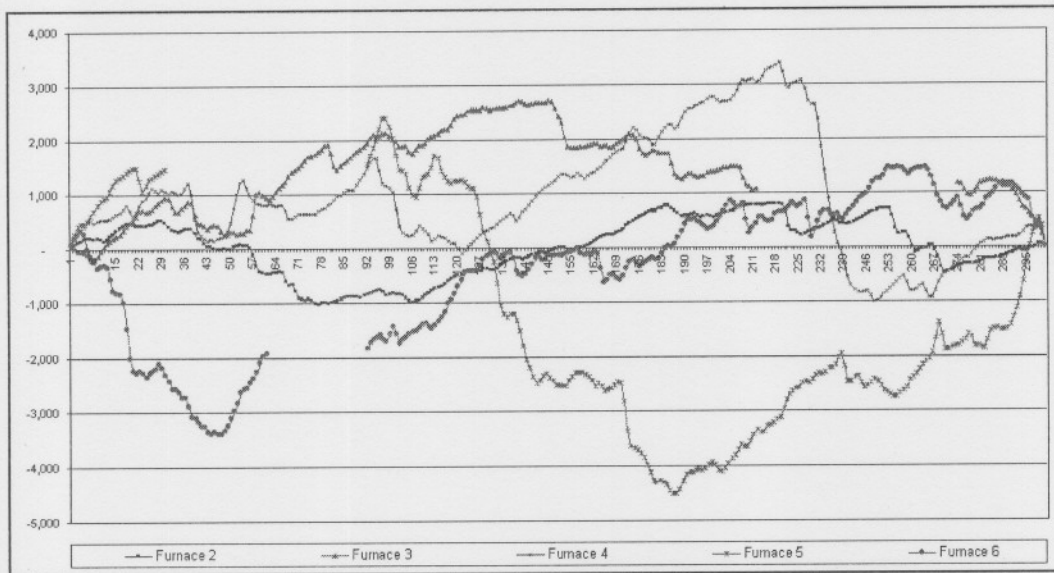
**Figure 5-13:** Daily energy consumption versus tonnes saleable production per day with isolated MWh/day above average for Furnace 4.

The isolated data points all lie to the left of the graph towards the lower daily production. The majority of the values are above the average (regression lines). These are the modes of furnace operation that the detailed study will need to focus on. The above figures for all the furnaces on the plant can be found in Appendix B.

#### 5.3.3.4 Performance Targeting and Baselineing

An analysis was done to determine the potential impacts of energy efficiency actions on the furnaces. In paragraph 5.3.3.3 it was seen that there exist variations in the daily production for the same electricity consumption. The first step in this analysis was to determine whether these variations could be caused by the raw materials that are fed into the furnaces. A Cumulative Sum (CUSUM) analysis was consequently done on data for the furnaces from 1 September 2002 to 28 January 2003.

The CUSUM analysis is basically used to identify changes in trends. Figure 5-14 provides the CUSUM profiles for all the furnaces. It can be seen that there exists no clear relationship between the furnace CUSUM profiles. From Figure 5-14 it can be concluded that the raw materials are not the main driving force behind the large variations in production for the same electricity consumption in the furnaces. This main driving force is unknown and needs to be identified and optimised in order to achieve the potential impact described in the following paragraphs.



**Figure 5-14:** Cusum profiles for all furnaces from 1 September 2002 to 28 January 2003.

The CUSUM analysis was used to identify the potential impacts that can be obtained if the energy efficiency of the furnaces is optimised. To explain the concept we consider only furnace 4. The CUSUM analysis was used to identify periods of “good performance” or “efficient operation” from the data for the period 1 September 2002 to 28 January 2003. A negative slope in the CUSUM profile indicates an efficient period of operation and a positive slope represents a period during which the furnace was operating in a less efficient manner. Figure 5-15 indicates a single period of “good performance” for furnace 4. The key performance indicators were determined for the periods of “good performance”. Furnace 4 operated under these KPI’s for approximately 15% of the period. For the overall period, furnace 4 operated at a value of 3,3MWh per tonnes



saleable production. During the “good performance” periods furnace 4 however operated at 2,8MWh per tonnes saleable production. As mentioned above, this KPI was achieved 15% of the total period.

From the CUSUM analysis the “good performance” periods were used to determine a “baseline” of good operation. This baseline would describe the operation of the furnace if it was operated throughout the period in a good performance mode. This baseline could then be compared to the actual operation to obtain an indication of the potential savings that exist, if furnace 4 was always operating in the good performance mode (thus at 2,8 MWh/tonnes saleable).

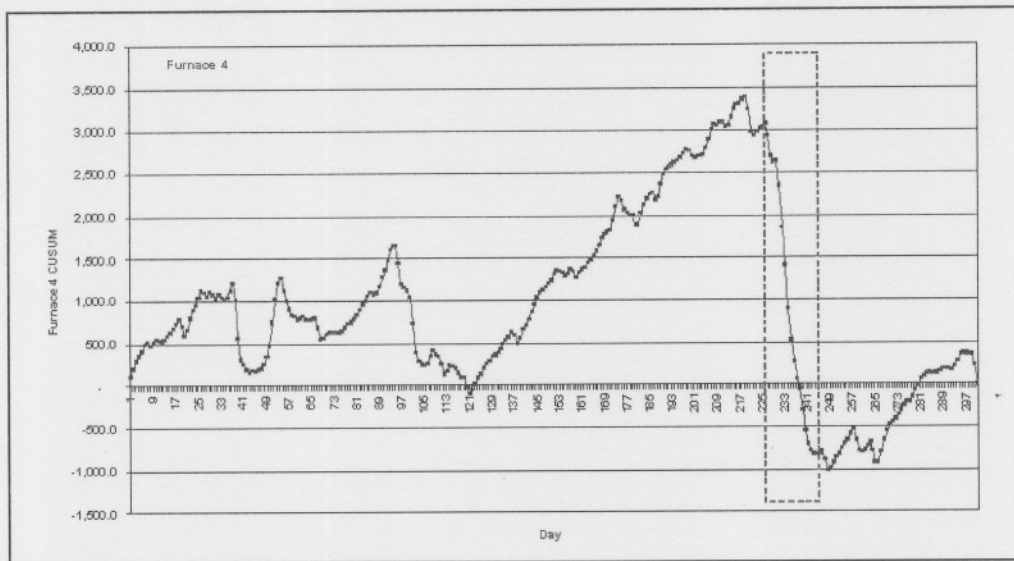


Figure 5-15: Furnace 4, Cusum analysis graph indicating a single period of “good performance”.

Through an adjustment to the CUSUM profile one can now determine the potential electricity consumption reductions that can be achieved if furnace 4 is operating at 2,8 MWh/tonne saleable. The CUSUM graph shown in Figure 5-16 represents actual operation at 3,3MWh/tonnes saleable whilst the horizontal axis (x-axis) represents the good operation baseline at 2,8MWh/tonnes.

The impact for the period from 1 September 2002 to 28 January 2003 would have shown a reduction in electricity consumption of 41,300 MWh. This would have been equivalent to a financial saving of R5,167,500 over the period for the same production, but at reduced electricity consumption. This can be extrapolated to an annual electricity cost saving of approximately R6,266,300 (50,130 MWh).

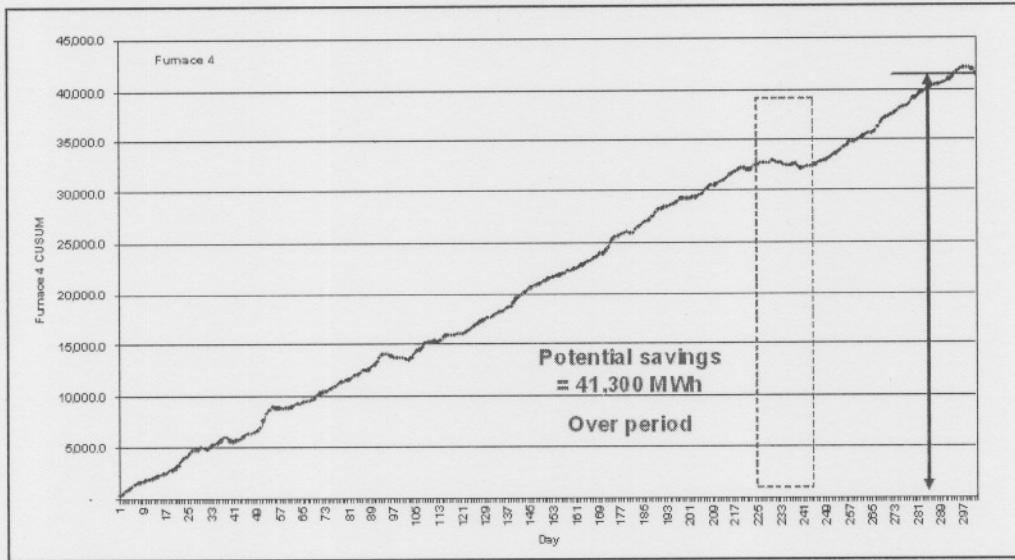


Figure 5-16: Furnace 4, Potential electricity consumption savings over period (1 September 2002 to 28 January 2003).

It is important to note that this level of efficiency is not estimated, but obtained from actual data over a certain period of time. This means that the level of efficiency used in the saving calculations has actually been achieved on previous occasions and sustained over a period of time.

The analysis was also approached from another direction to explore the benefit to the plant if furnace 4 was operated in the efficient mode (2,8 MWh/tonnes saleable), but the same quantity of electricity was fed to the furnace which would then theoretically result in increased production. The potential impact was determined as an annual increase in production of 17,800 tonnes saleable for furnace 4. This could be converted to an annual income from increased production of R26,700,000.

The KPI results for all the furnaces are summarized in Table 5-6 below.

**Table 5-6:** Summary of furnace KPIs for actual operation and good performance operation.

Furnace	MWh/tonne saleable	MWh/tonne saleable	% Days of good performance operation
	Overall period	Good performance periods	
Furnace 2	4.1 MWh/t	3.6 MWh/t	26 %
Furnace 3	4.3 MWh/t	3.6 MWh/t	20 %
Furnace 4	3.3 MWh/t	2.8 MWh/t	15 %
Furnace 5	3.1 MWh/t	2.6 MWh/t	20 %
Furnace 6	3.6 MWh/t	3.2 MWh/t	35 %

The above analysis was done for all the furnaces. The results are summarised in Table 5-7 for the furnaces operating under their “good performance” KPI’s at constant production and reduced electricity consumption. Table 5-7 also provides the results for the furnaces operating in the good performance mode at constant electricity consumption, but at increased production.

**Table 5-7:** Summary of impacts on furnace electricity consumption (at constant production) and production (at constant electricity consumption) in good performance modes of operation (extrapolated to annual basis).

Furnace	At constant production under good operation		At constant electricity consumption under good operation	
	Annual energy consumption reduction (MWh/year)	Annual energy consumption cost savings (Rand/year)	Annual production increase (tonnes saleable/year)	Additional annual income from production (Rand/year)
Furnace 2	18,200 MWh/year	R 2,278,400	5,100 tonnes/year	R 7,616,000
Furnace 3	34,300 MWh/year	R 4,287,400	9,500 tonnes/year	R 14,200,000
Furnace 4	50,100 MWh/year	R 6,266,300	17,800 tonnes/year	R 26,700,000
Furnace 5	48,400 MWh/year	R 6,044,800	18,700 tonnes/year	R 28,085,000
Furnace 6	30,000 MWh/year	R 3,753,000	9,200 tonnes/year	R 13,830,000
<b>Total</b>	<b>181,000 MWh/year</b>	<b>R 22,629,900</b>	<b>60,300 tonnes/year</b>	<b>R 90,431,000</b>

Table 5-7 shows that the plant has the potential to reduce its electricity consumption with 181,000 MWh per year without affecting production, just by increasing the efficiency at which the furnaces operate. This is an annual cost saving from a reduced electricity consumption of R22,629,900 each year. Note that the furnaces are already producing at this efficiency between 25% and 35% of the time.

If the electricity consumption of the plant remains constant at the increased level of efficiency, the production must increase. From Table 5-7 it can be seen that a total of 60,300 saleable tonnes can be produced additionally to that which is already being

produced each year. This is calculated to be an additional income for the plant of R90,431,00 each year.

A detailed study is however required on the furnaces to identify all the factors resulting in the “good performance” periods and the factors and modes of operation that cause the efficiency to deviate from the good performance efficiency.

#### **5.3.4 Identification of Solutions**

The identification of solutions phase was not part of the scope of this study as the study was only aimed at identifying and quantifying opportunities. The actual solutions needed to obtain the savings of the identified opportunities should be done as soon as the plant decides which opportunities it wants to pursue.

#### **5.3.5 Cost/Benefit Analysis**

The cost/benefit analysis should be done after the solutions for the opportunities are found, and implementation and labour costs are known. The IRR and NPV calculations for the opportunities can then be done.

#### **5.3.6 Identification and Recommendation for Implementation**

It is recommended that the plant management strongly consider investigating all the described opportunities in order to obtain the maximum benefits. Implementation of the solutions should be done during scheduled shut down periods to lessen the impact of production loss due to implementation.

### **5.4 Conclusion**

The developed methodology was successfully used in a case study to identify and quantify opportunities for energy and process improvements in a Ferro-metal plant. The

identified opportunities show significant financial benefits for the plant and should be investigated in more detail in order to find solutions for the opportunities.

The project implementation, of the selected opportunities, should start after the detail engineering and design of the solutions are finalised and the appropriate funds are available. The chosen projects should be implemented with as little impact on production as possible. This could be done by implementing the solutions in planned maintenance down times. If more than one project is implemented the implementation will be in the order as decided by the plant management.



## CHAPTER 6

### M&V CASE STUDY TO MEASURE AND VERIFY THE IMPACT OF A FURNACE UPGRADE

*This chapter provides the results for the measurement and verification of an upgrade project on a furnace. The chapter presents the baseline and the saving calculation method as well as the various impacts of the project on production and energy consumption.*

## CHAPTER 6: M&V CASE STUDY TO MEASURE AND VERIFY THE IMPACT OF A FURNACE UPGRADE

### 6.1 Introduction

A furnace on a Ferro-metal production plant was upgraded to increase production. Measurement and verification were used to quantify the impact of the upgrade. For this purpose data before and after the upgrade were used.

This chapter provides a description of the Measurement & Verification of a furnace upgrade.

### 6.2 Baseline Construction

In order to accurately quantify the energy and production impact of the upgrade, it was necessary to construct a baseline with as much data as possible. In total 43 days worth of data was available and subsequently used to construct the baseline.

A scatter plot of two-day moving average data (MWh/day against Tonne/day) was obtained for the 43 days of data available before the upgrade. A regression line was fitted through the data to obtain a relation for the data with a subsequent equation.

The equation obtained for the baseline is Equation 6-1 given below. The y in the equation represents the MWh/day value if a certain Tonne/day (x value) is inserted in the equation. Figure 6-1 shows the scatter plot with the regression line and equation.

$Y = 2.1699(x) + 286.11$
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<i>(Eq. 6-1)</i>
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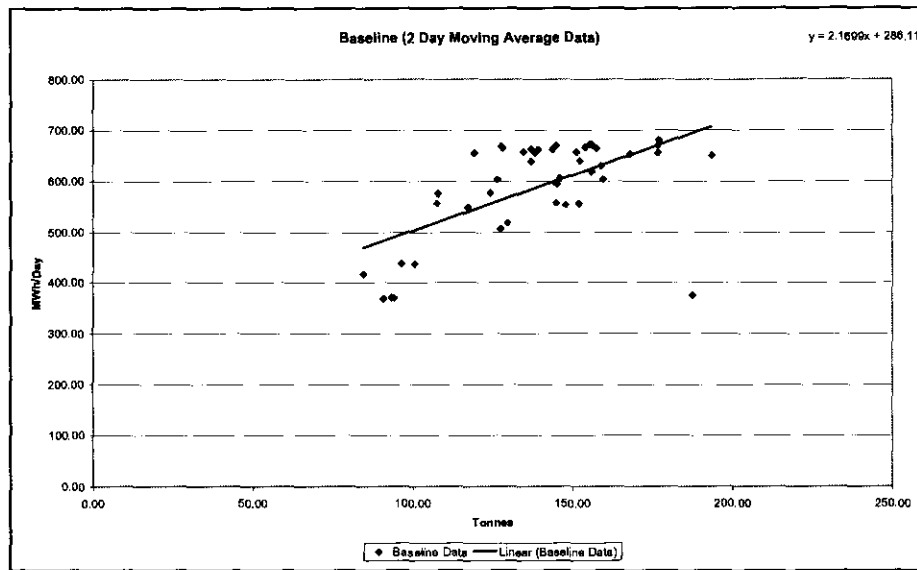


Figure 6-1: Baseline for furnace.

### 6.3 Saving Calculation and Impact of Project

The data after the upgrade was used to calculate the impact of the project on production and energy. The 150 days of data was converted to 2-day moving average data and used for the calculation of the impact. The data was plotted on the same scatter plot as the baseline data and a regression line was fitted through the actual data (Figure 6-2).

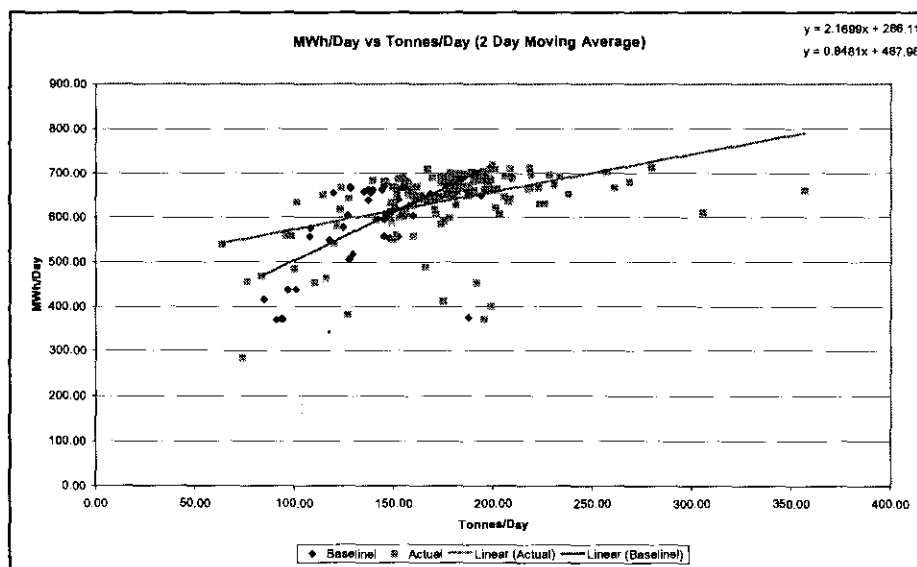


Figure 6-2: Baseline and Actual Scatter Plot.

The upgrade affected both the energy consumption and the production. The savings resulting from the project were calculated by using the baseline equation in conjunction with the actual data after implementation of the project. For the MWh saving calculation the actual tonnes were entered into Equation 6-1 ( $y = 2.1699x + 286.11$ ). This then provided the baseline energy consumption for the specific tonne input. In other words, the actual tonnes were used to calculate what the energy consumption would have been if the old system produced the same amount of tonnes.

The production increase benefit was obtained by rewriting Equation 6-1 that was obtained through the baseline data to derive Equation 6-2 provided below. The actual MWh data was then substituted into the y value in Equation 6-2 to obtain the baseline tonne production for the same MWh input.

$X = (Y - 286.11)/2.1699$	<i>(Eq. 6-2)</i>
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### 6.3.1 Energy Saving

The energy saving (MWh saving) achieved through the upgrade is shown in Table 6-1. From the table it can be seen that the project resulted in an energy saving of 4611.85 MWh which implies a cost saving of R589,209 for the 150 day period. This was extrapolated to give an annual saving of R1,433,743.

**Table 6-1: Energy Saving Impact.**

Energy Saving	Saving
MWh Saving	4611.85
Rand Saving	R 589,209
Annual MWh Saving	11222.16
Annual Saving	R1,433,743

### 6.3.2 Production Benefit

The production benefit from the project resulted in an increase in production of 2125.37 tonnes as shown in Table 6-2. The production increase resulted in a financial benefit of R1,487,760 for the period. This was extrapolated for a year and resulted in a financial gain of R3,620,218.

**Table 6-2: Production Increase Benefits.**

<b>Production Increase</b>	<b>Benefit</b>
Tonnes Production Gain	2125.37
Rand Saving	R1,487,760
Annual Production Gain	5171.74
Annual Saving	R3,620,218

### 6.4 Conclusion

The project on the furnace was not intended as an energy efficiency project but was aimed at increasing production. The production gain achieved through the project resulted in an annual production increase of R3,620,218. The project also resulted in an annual energy saving of R1,433,743.

It is possible to evaluate a project's performance with measurement and verification as can be seen from this chapter.

## **CHAPTER 7**

# **CONCLUSION AND RECOMMENDATIONS**

*This chapter presents the conclusions for this study.*

## **CHAPTER 7: CONCLUSION AND RECOMMENDATIONS**

### **7.1 Introduction**

This chapter provides a summary of all the chapters and also presents some recommendations for further work.

### **7.2 Chapter Summary**

Chapter 1 provided a short introduction to the study before providing the objectives and scope of the study. The main objective of this study was to develop a methodology to aid in the search for energy and process improvement opportunities in Ferro-metal production plants. The methodology consists of the identification, quantification and verification of cost benefits for the possible energy and process improvement opportunities identified.

The study's scope included the development of a methodology for the identification and quantification of energy and process improvement opportunities, but it did not include the finding of actual solutions for the identified opportunities.

From chapter 2 it was concluded that there exists a need to reduce production costs, improve efficiency, and reduce the environmental emission impacts in furnace plants. Although adequate opportunities are available for energy improvement projects three main types of barriers, namely institutional, technological and financial barriers to energy projects were identified. It was established that a lack of accurate, transparent measurement and verification processes also increased the distrust in the credibility of energy related projects.

It was concluded that there is a need for a methodology to accurately identify, quantify and verify the cost benefits of energy and process improvements on a Ferro-metal

production plant. Such a methodology will increase credibility and awareness of potential cost benefits of energy and process improvements

Chapter 3 described a process and energy improvement methodology for a Ferro-metal production plant. The chapter showed the various steps and chronological order of the proposed methodology.

Chapter 4 investigated the M&V process and its importance in energy related projects. The chapter established that through M&V the performance of a particular project can be assessed and actual savings determined. The importance of the baseline development was highlighted as it forms a critical part of the M&V process as the baseline represents the system's energy use as it was before implementation. The baseline forms the basis for the saving calculations of the energy projects.

The developed methodology was used on a case study in chapter 5, to identify and quantify energy and process improvement opportunities. The methodology was not employed pass the identification of solutions and detail engineering stage, as this was not part of the scope of this study.

An upgrade on a furnace was used, in chapter 6, to show how M&V can be employed to verify and assess the impact that an upgrade project has on the furnace. The production gain as well as the energy savings achieved by the project was calculated through M&V and presented in chapter 6.

### **7.3 Study Conclusion**

This study derived a methodology to identify and quantify energy and process improvement opportunities in a Ferro-metal production plant. It is possible to identify saving opportunities in plants by utilising the proposed methodology, as was proved by the case study. The identified opportunities must be investigated in more detail to analyse the problems in order to find actual real world solutions for the opportunities.



The methodology aids the investigation process by focusing the investigation on the identified opportunities which show the best cost benefits for the plant. The case study showed there are many substantial savings opportunities that exist in plants. These opportunities were quantified in financial terms to establish the possible cost benefits to the plant in order to justify detailed investigations into the most attractive opportunities.

Measurement and Verification of energy projects were also investigated as a means of verifying and assessing the impact and performance of energy related projects. The M&V process was employed on a furnace upgrade project to show the benefits in terms of cost savings and production gains of the project. The M&V process is aimed at assessing the performance of a project and to establish the actual impact that the project attained.

The process can also be used to sustain the new performance level gained through the upgrade by acting as a benchmark for the new system. A monthly analysis should be done and compared to the benchmark in order to assess the performance of the new system. If the performance of the system deters, actions should be taken to restore the optimum performance level.

The study did not cover the detail engineering, design and implementation of energy projects on the Ferro-metal plant, as this was not in the scope of the study. The study only focused on a methodology to identify, quantify and verify cost benefits of energy and process improvement opportunities.

#### **7.4 Recommendations for Further Work**

It is recommended that a study is done, which is aimed at finding the physical solutions for the identified opportunities of this study. The study should be aimed at finding viable solutions that can be implemented to obtain as much of the potential savings as possible.

The study could also apply the Measurement and Verification process to the implemented projects in order to establish an accurate assessment of the actual impact and savings of the project. This can then be used to verify the accuracy of the methodology's quantification of identified opportunities.

# Appendix A

## No-cost and low-cost options

## **A.1. INTRODUCTION**

This appendix will provide a more detailed discussion of the potential no-cost and low-cost options that exist for energy optimisation at the plant. The sections that follow will provide a basic layout of the identified options, the actions that need to be taken, and also provide an indication of the potential impacts that can be achieved under the current tariff structure. The first two options are concerned with scheduling at the chrome recovery and pelletising plant. They are both considered to be no-cost options. The third option is concerned with the switching off of unnecessary lighting during the day.

## **A.2. CHROME RECOVERY PLANT**

The purpose of the chrome recovery plant is to recover chrome out of the slag from the furnaces. The slag is fed via front-loaders into the system of crushers, conveyors and screens. The chrome is recovered in the Jig House and then dispatched for sale. The plant currently operated for 24 hours per day, every day of the year.

The slag enters the system at a grizzly feeder. This is the start of the primary side of the chrome recovery plant. The material of the correct size is passed directly onto a conveyor. The oversized material is passed through a primary crusher. The conveyor dumps the material onto a stockpile, which has a 3.5-hour capacity.

Material is then removed via bottom feeders from the stockpile onto another conveyor that takes the material to a screening house. In the screening house the material is screened and fed through a jaw crusher. Material of the correct size is deposited onto a conveyor that dumps it onto another stockpile. The oversized material is placed onto a conveyor that takes it to secondary and tertiary crushing where two cone crushers reduce the material size and returns it to the screening house via a conveyor. A stockpile is the end of the primary side of the chrome recovery plant.

The stockpile has a capacity of 4.5 hours. The material is fed via bottom feeders onto a conveyor that takes it to a Jig House where the chrome is recovered. Oversized material that manages to pass through to the Jig House is returned to secondary and tertiary crushing via a conveyor.

It is not possible to influence the operational times of the Jig House, since this will negatively impact on the production of the plant. It will only be possible to impact the system in front of the second stockpile. It would therefore be possible to switch off all the crushers, conveyors and screens on the primary side if the stockpile has been sufficiently stocked to ensure operation of the Jig House during the peak hours of the tariff.

Optimal scheduling of the stocking of the second stockpile can result in savings of R262,000 per year if the primary side is switched off from 07:00 to 10:00, and again during 18:00 to 20:00 during the weekdays of

both the low- and high demand seasons (whole year). However, if this strategy is followed only for the high demand season (June, July and August), the annual electricity cost savings would become R136,000.

The savings can also be optimised if all scheduled shutdowns and maintenance occur between 07:00 to 10:00 or between 18:00 to 20:00 during weekdays.

No costs are expected for the implementation of this option. A detail study of the product- and raw-material flows is however required to determine the optimal scheduling of the equipment to ensure that the stockpile has sufficient capacity during the peak periods of the week.

### **A.3. PELLETISING**

The pelletising plant receives raw materials from mines via road and rail. The material is fed into bins via conveyer belts. A mixture is made up from the various bins and fed into a ball mill where it is mixed with water and grinded. The slurry is screened and passed through filters and deposited into filter bins. Binding material is then added and the product is passed through a pelletiser. Once pelletised, the product is passed through screens. The product of the correct size is sintered and fed into the furnace bunkers.

The pelletising plant is operated for 24 hours a day, everyday of the year. The average total energy consumption for the pelletising plant is 2436 MWh per month. This is an average demand of 3,3 MW. The largest contributing piece of equipment in the process is a ball mill.

Currently the pelletising plant is operated in such a manner that the ball mill can be turned off for approximately 4 hours during peak hours every three to four days. This is achieved by utilising the product capacity of the filter bins. These bins, once empty, require approximately three to four days to regain their capacity before the ball mill can be turned off again.

The filter bins is loaded through a faster feed rate from the ball mill, via the filters, than the rate that material is drawn out of the bins to the pelletiser. This means that there is little scope at the pelletising plant for electricity cost optimisation without affecting the production and the availability of the pelletising plant.

One option that however needs serious exploration is the bunker at the end of the pelletising process. This bunker has the purpose of sustaining the availability of the pellets to the furnaces during the shutdown of the pelletising plant.

This bunker is loaded throughout the year by feeding it with the balance of the pellets not required by the furnaces. This bunker has an capacity of over 100,000 tonnes.

The furnaces require approximately 1,300 tonnes of pellets per day. That calculates to 54.2 tonnes per hour. There are approximately 65 weekdays during the high demand season. Approximately 10,600 tonnes need to be utilised from the bunker during the total high demand season (June, July and August) in

order to switch the pelletising plant of for 3 hours per weekday from 07:00 to 10:00. This implies that the pelletising plant needs to extract 163 tonnes per weekday from the bunker during the high demand season. The impact of the above actions would result in a electricity cost saving of R350,000 per year.

The savings can however be increased if the pelletising plant can be switched of from 07:00 to 10:00 AND from 18:00 to 20:00 during each weekday during the high demand season. The result is that the pelletising plant now needs to extract 271 tonnes per weekday (to carry it for 5 hours) from the bunker, which calculates to 17,615 tonnes over the complete high demand season. The impact of the above actions would result in a electricity cost saving of R583,500 per year.

No costs are expected for the implementation of this option. A detailed analysis will however be required to determine the exact operational schedule for the pelletising plant to ensure that the bunker recuperate its capacity to allow for an annual scheduled shutdown of the pelletising plant.

#### **A.4. PLANT LIGHTING**

Lighting is another part of the plant where cost savings can be achieved. A count was made of the lights outside and next to buildings that provided area lighting. It was seen during the site visit that the lights remained on throughout the day without serving any function.

Although it is important to provide sufficient lighting throughout the plant for safety reasons, the specific lights counted during the site visit provided no lighting benefit for operation during the day. The total installed capacity calculated for these lights is at 0.18 MW. The cost savings impact of switching these lights off for each day of the week from 08:00 to 15:00 was calculated as R80,000 per year.

There is however costs involved with the implementation of this option. The costs needs to be determined after a detailed analysis of the layout of the lighting system and the distribution boards feeding them has been made, since this will influence the actions and system that need to be implemented to allow for the switching of these specific lights. The main concern with this option is that the lights identified for switching, share the same circuits with lights that must remain on throughout the day. A detailed study will thus be required to determine the best manner of implementing this option in a financially viable way.

# **Appendix B**

## **Benchmarking of furnace energy performance**

## **B.1. INTRODUCTION**

Appendix B will provide a benchmark of the energy consumption for the five furnaces. There are currently six furnaces on the site of which only five were operational at time of this study. These furnaces are: furnace 2, 3, 4, 5 and 6 (Furnace 1 was not operational at the time of this study). The sections that follow will benchmark the energy consumption of each furnace in terms of the following:

- Key performance indicators.
- Daily energy consumption versus tonne saleable production per day (MWh/day vs. Tonne saleable/day).
- Energy consumption per ton product versus ton product per tap (MWh/t vs. t/tap).
- Isolated MWh/tonne above average on graph of daily energy consumption versus tonne saleable production per day.
- Ton product per tap.
- Energy consumption per tap (MWh/tap).

Where required, the above benchmarks were provided based on a 2-day and 3-day moving average. The above analysis was also done for a combination of Furnace 4 and Furnace 5.

The potential energy cost savings are provided for each furnace where applicable. These savings demonstrate the potential impacts that can be achieved; a detailed investigation will however be required of the energy performance of each furnace to determine exactly how these savings can be realised.



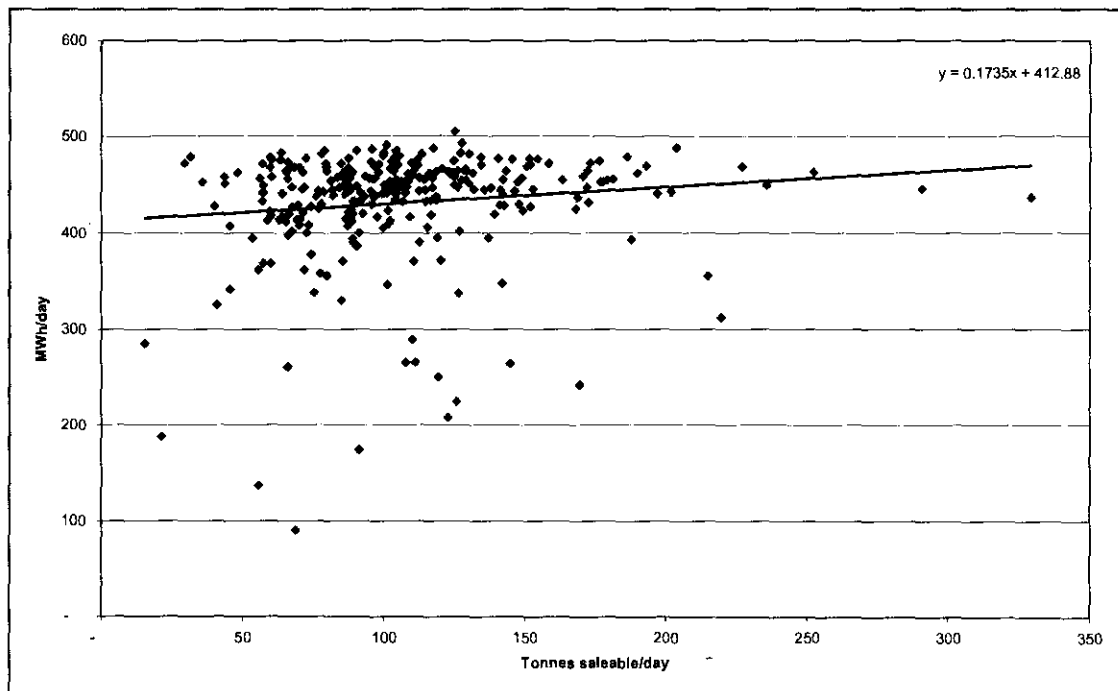
## B.2. FURNACE 2

The average daily availability of Furnace 2 was determined as 97% whilst the average daily utilisation was 87%. The average specific energy consumption was calculated as 4,1 MWh per tonne saleable product.

**Table B1:** Summary of Furnace 2 KPIs.

Furnace description	Average MWh per month (MWh/month)	Average tonnes per month (Tonnes/month)	Average daily availability (%)	Average daily utilisation (%)	Average MWh per tap (MWh/tap)	Average tonne per tap (Tonnes/tap)	Average MWh per tonne (MWh/tonne)
Furnace 2	12,980	3,200	97	86	51	13	4.1

Figure B1 shows the relationship between the daily energy consumption for Furnace 2 and its daily saleable production.



**Figure B1:** Furnace 2, daily applied energy vs. tonnes saleable (with regression).

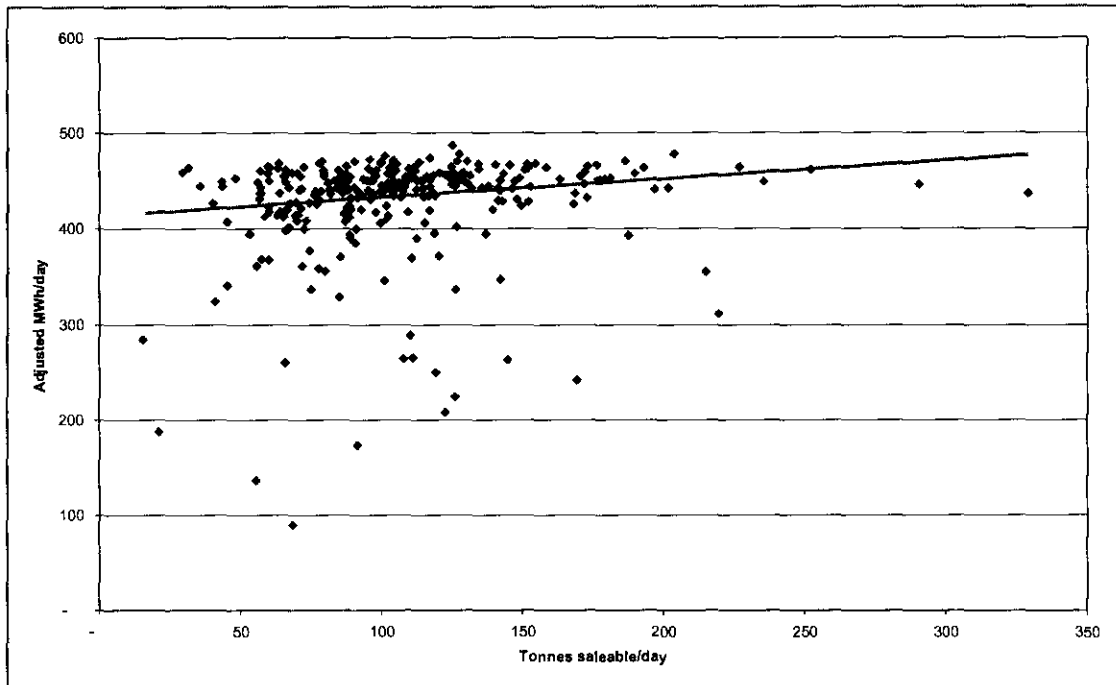


Figure B2: Furnace 2, daily applied energy vs. tonnes saleable reduced with 50% towards the average.

Figure B2 shows the impact of a potential 50% reduction in the specific energy consumption for all the values above the average (regression line) as discussed in chapters 3 and 5. The cost saving impacts can be seen in Table B2 for a 50% and a 25% reduction above average.

Table B2: Furnace 2 potential annual cost saving summary.

Description	50%	25%
Single day data (R/year)	R 423,600	R 211,800
2-day average (R/year)	R 360,600	R 180,300
1-day average (R/year)	R 327,400	R 163,700

Figure B3 shows the relationship between the specific energy consumption (MWh/tonne) and the tonnes per tap. All the values above the average value are identified and these data sets are shown on Figure B4 which shows the daily energy consumption against the daily production.

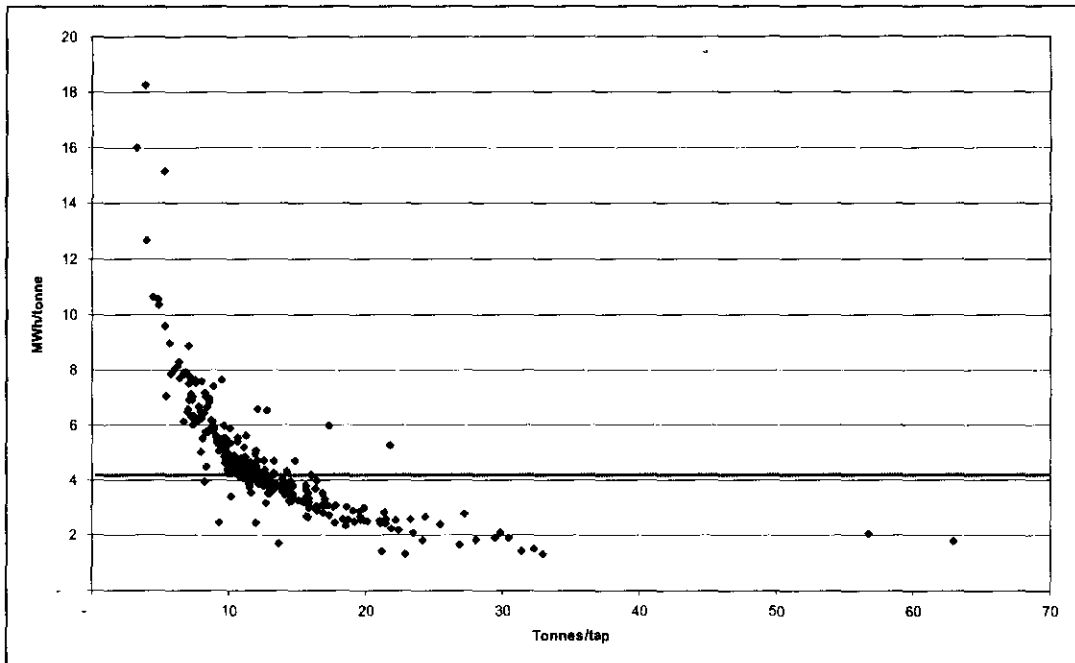


Figure B3: Furnace 2, energy consumption per tonne product versus tonnes saleable per tap (average indicated).

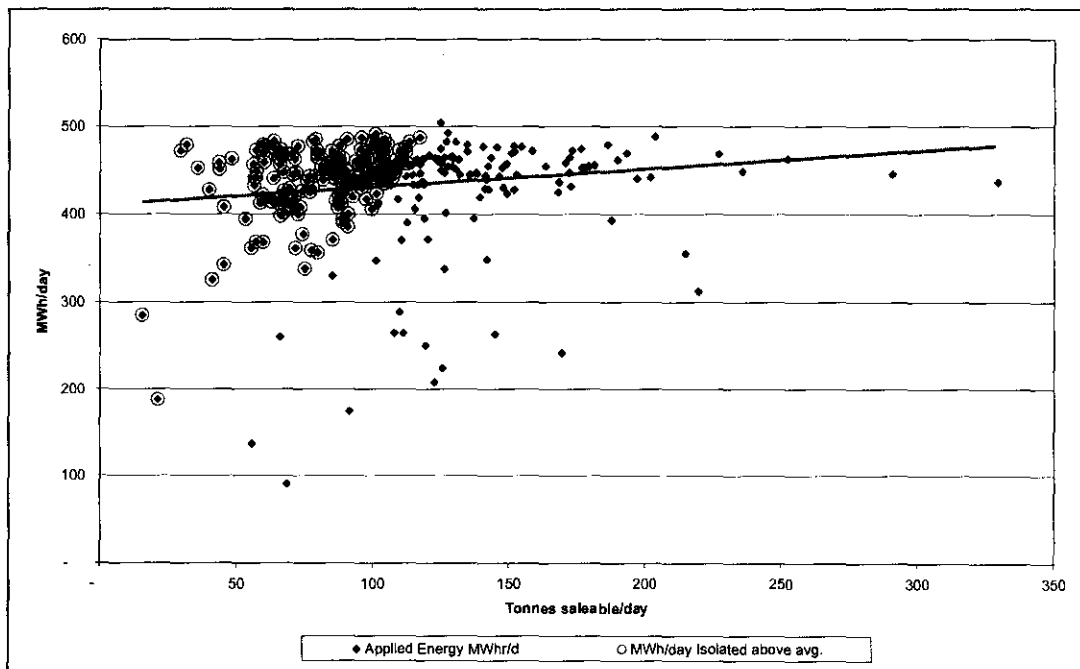


Figure B4: Furnace 2 energy consumption versus tonnes saleable production per day with isolated MWh/day above average.

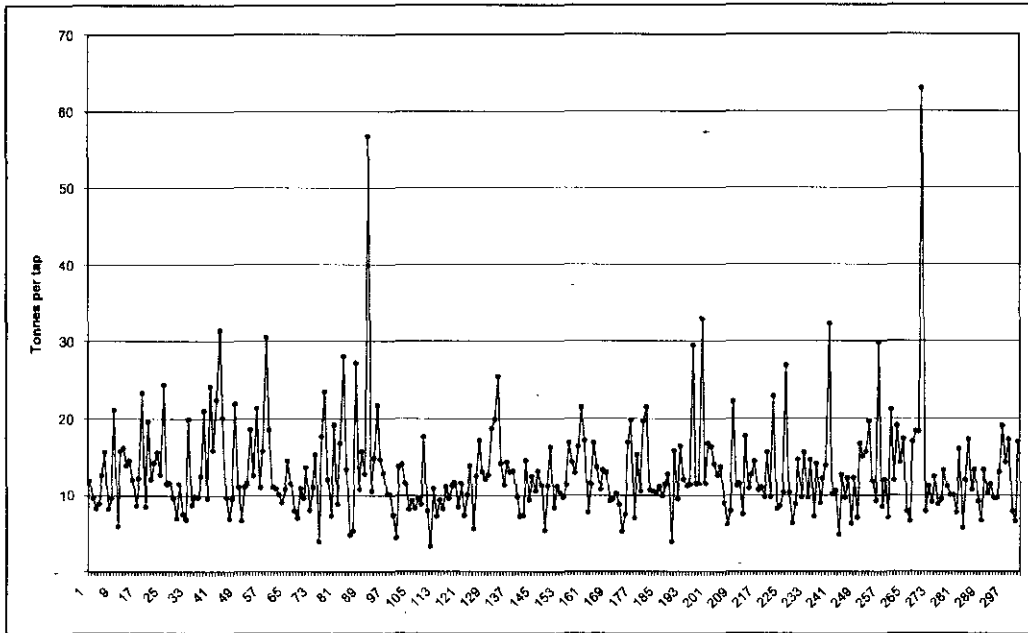


Figure B5: Furnace 2, tonnes product per tap.

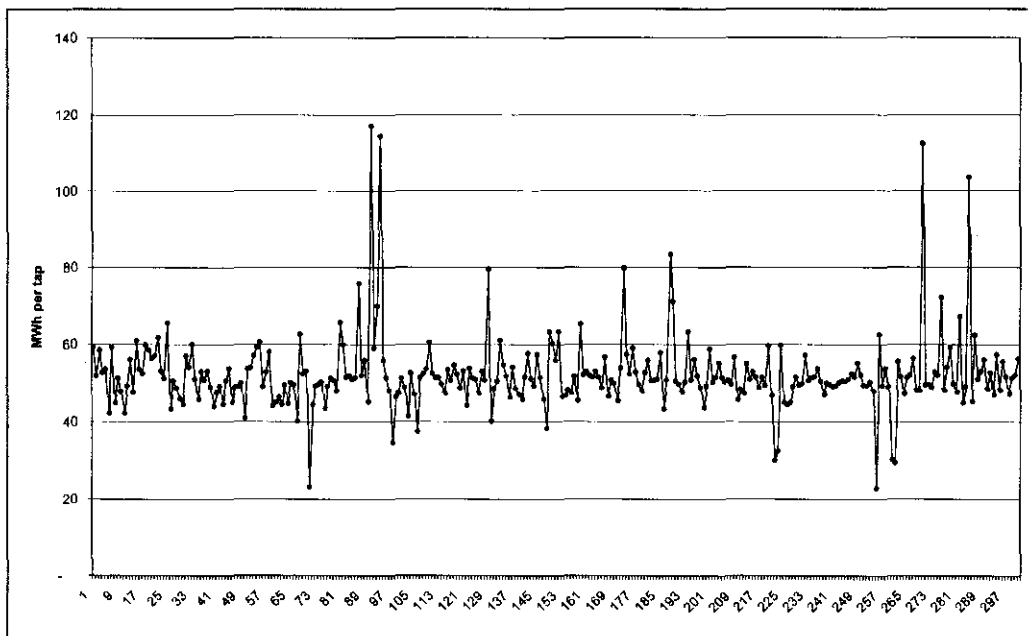


Figure B6: Furnace 2, energy consumption (MWh) per tap.

In Figure B5 it can be seen that the tonnes per tap ranged between 3 and 63 tonnes per tap. It seems that the “normal” range is between 7 to 24 tonnes per tap. The energy consumption per tap ranged between 23 MWh/tap to 117 MWh/tap (Figure B6).

A Cumulative Sum (Cusum) analysis was done on the data for Furnace 2. The purpose of this analysis was to identify periods of “good performance” or efficient performance in terms of energy use against production. These periods of “good performance” could then be used to determine a baseline of “good performance” which could then be compared to the actual performance to provide the savings that could potentially be achieved if Furnace 2 were operated in this efficient manner throughout the year. It is important to note that the level of efficiency is not estimated, but obtained from actual data over a certain period of time. This means that the level of efficiency used in the saving calculations has actually been achieved on previous occasions and sustained over a period of time. From the data that was used (1 September 2002 to 28 June 2003), Furnace 2 operated at this level of efficiency for approximately 26% of the time.

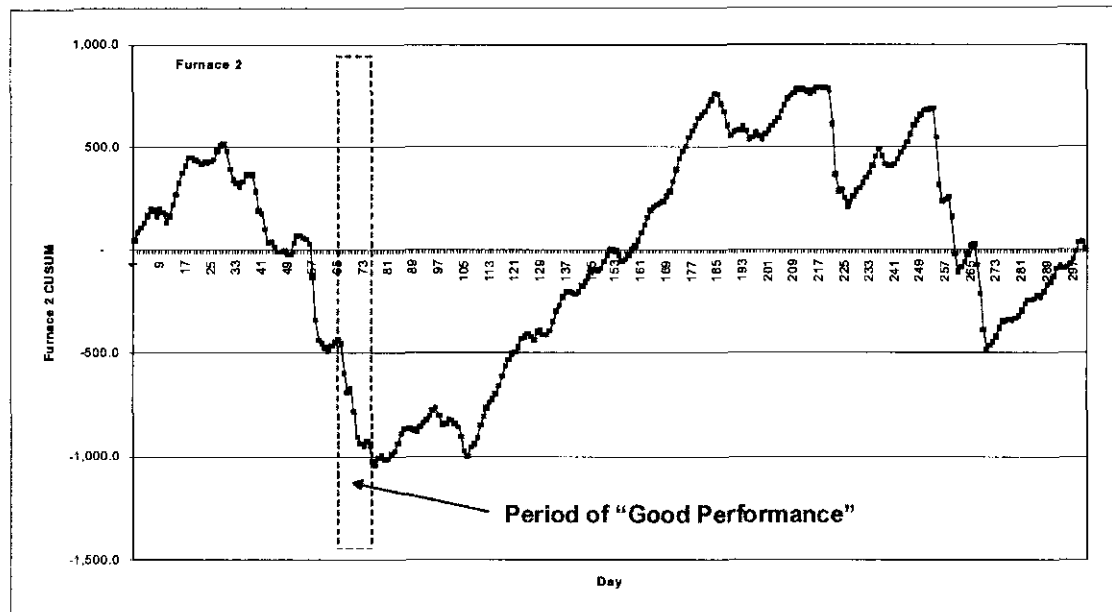


Figure B7: Furnace 2, Cusum analysis graph indicating a single period of “good performance”.

One of the longest periods of “good performance” is indicated in Figure B7. Through an adjustment of the Cusum graph it is possible to determine what the impact would be if the furnace was operated throughout the period as it was operated during the “good performance” period. This impact is shown in Figure B8. The impact for the period from 1 September 2002 to 28 June 2003 would have resulted in a reduction in electricity consumption of 15,000 MWh. This would have been equivalent to a financial saving of R1,879,000 over the period for the same production, but at reduced electricity consumption. This can be extrapolated to an annual electricity cost saving of approximately R2,278,400 (18,200 MWh).

Furnace 2 had a key performance indicator of 4,1 MWh/tonne over the total period. Over the “good performance” periods Furnace 2 however operated at a value of 3,6 MWh/tonne saleable for 26% of the period. The above financial savings are therefore possible under a KPI of 3,6 MWh/tonne saleable.

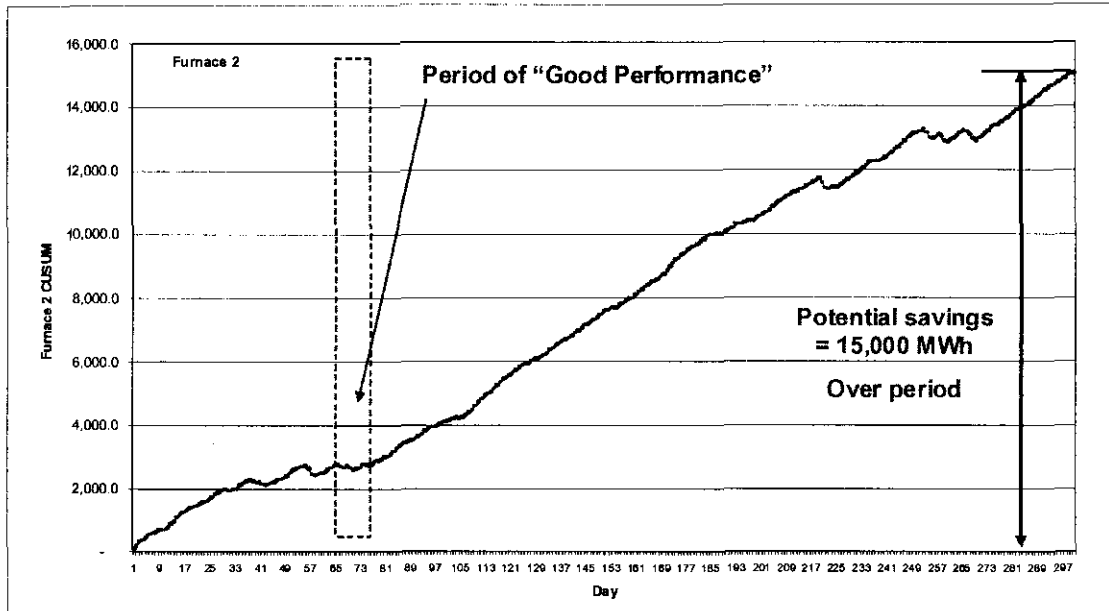


Figure B8: Furnace 2, Potential electricity consumption savings over period (1 Sep 2002 – 28 Jun 2003).

The analysis was however expanded to include the potential impact if the electricity consumption remained unchanged but production is increased under the “good performance” KPI of 3,6 MWh/tonne. The potential impact was an annual increase in production of 5,100 saleable tonnes. This could be converted to an additional annual income from increased production of R7,616,000.

Load management holds another opportunity for Furnace 2 to reduce its annual electricity accounts. If Furnace 2 is controlled to the “minimum of minimum” demand during the peak hours (process explained in Chapter 3 and 5), savings of R518,600 can be achieved each year. On average, 0,65 MW needs to be added to the hours outside of peak to ensure that the overall electricity consumption and production remain constant. The control graph is shown in Figure B9.

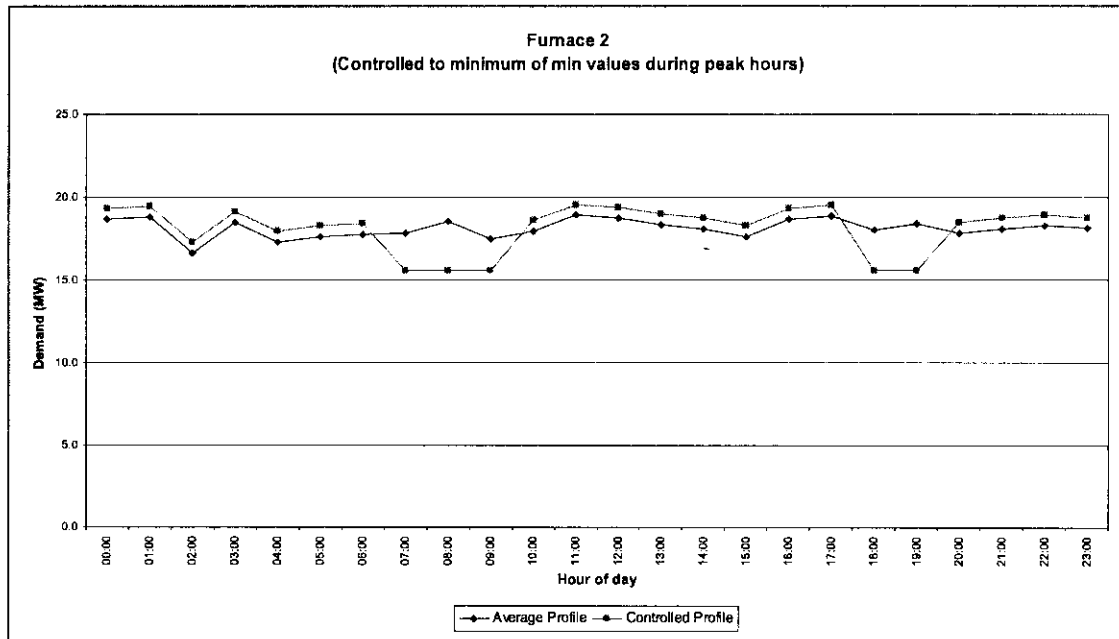
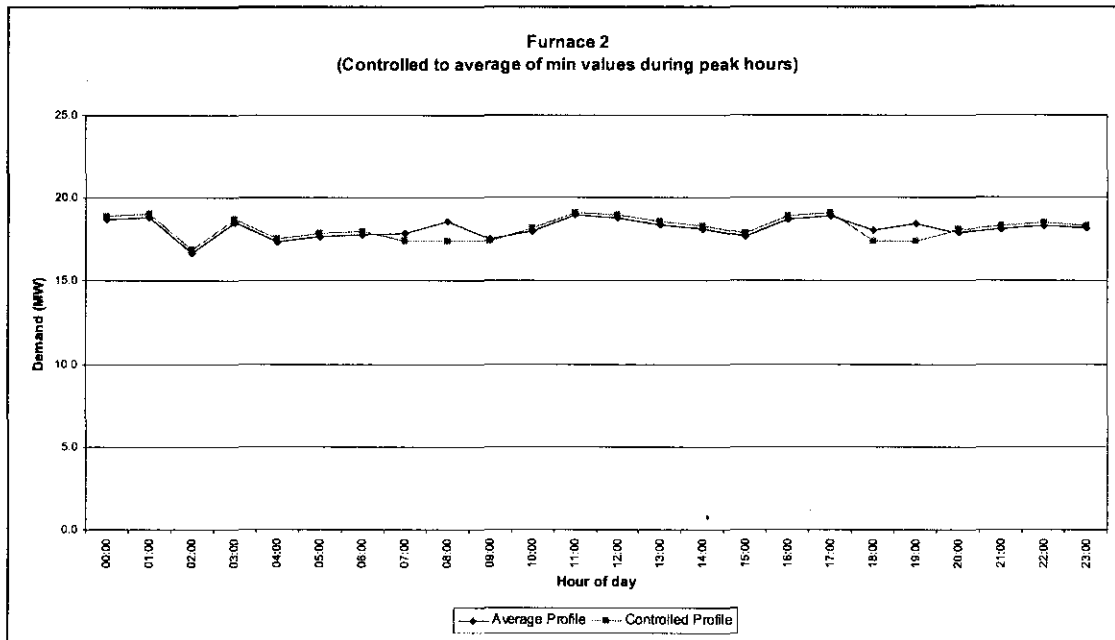


Figure B9: Furnace 2, load management to minimum of minimum demand during peak hours.

If control is applied to the “average minimum” demand during peak, Furnace 2 could achieve an annual cost saving of R149,700. In this case only 0,19 MW need to be added during the hours outside peak. The control graph is shown in Figure B10 for the above load management mode.



**Figure B10:** Furnace 2, load management to average of minimum demand during peak hours.



### B.3. Furnace 3

The average daily availability of Furnace 3 was determined as 96 % whilst the average daily utilisation was 90%. The average specific energy consumption was calculated as 4,3 MWh per tonne saleable product.

Table B3: Summary of Furnace 3 KPIs.

Furnace description	Average MWh per month (MWh/month)	Average tonnes per month (Tonnes/month)	Average daily availability (%)	Average daily utilisation (%)	Average MWh per tap (MWh/tap)	Average tonne per tap (Tonne/tap)	Average MWh per tonne (MWh/tonne)
Furnace 3	18,500	4,300	96	90	74	17	4.3

Figure B11 shows the relationship between the daily energy consumption for Furnace 3 and its daily saleable production.

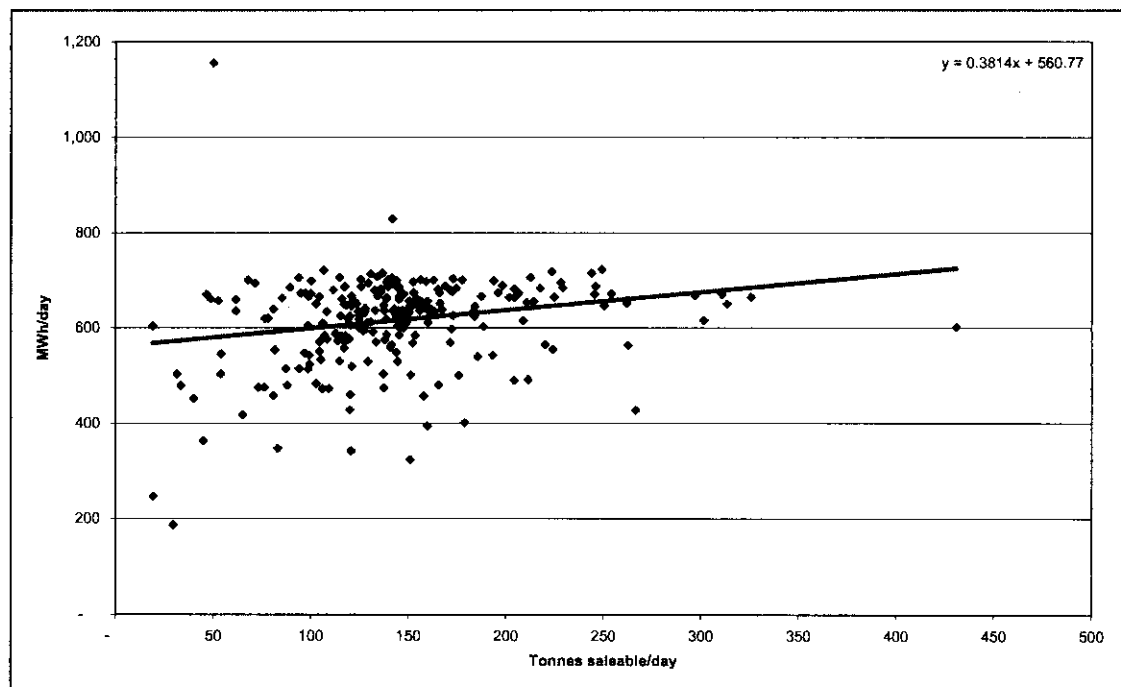


Figure B11: Furnace 3, daily applied energy vs. tonnes saleable (with regression).

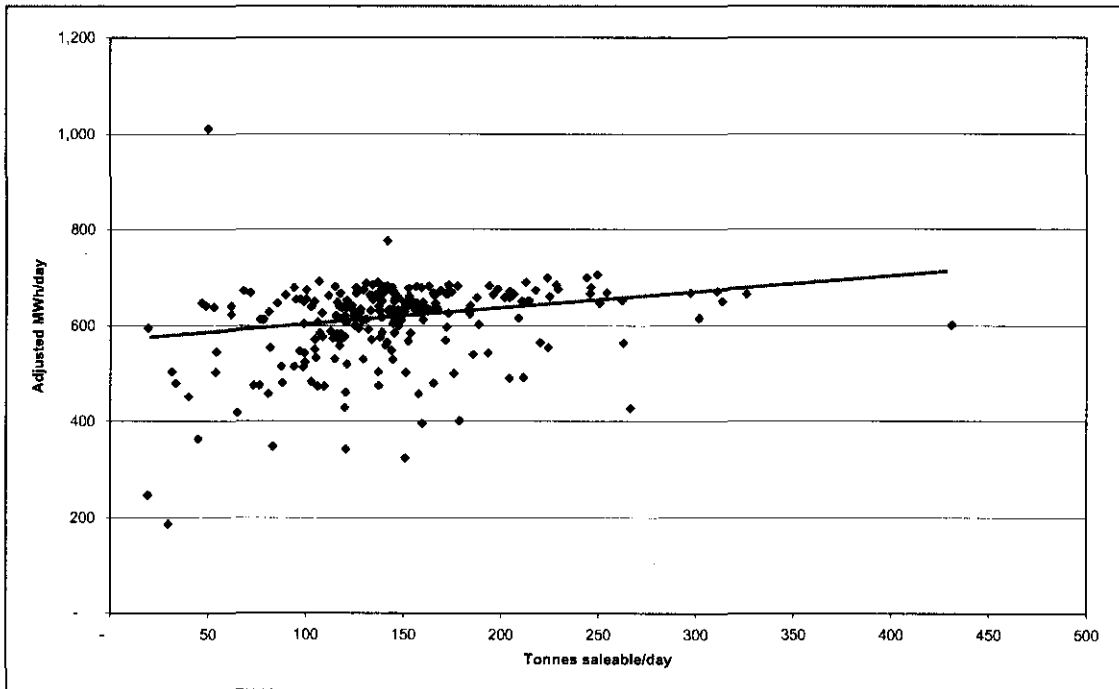


Figure B12: Furnace 3, daily applied energy vs. tonnes saleable reduced with 50% towards the average.

Figure B12 shows the impact of a potential 50% reduction in the specific energy consumption for all the values above the average (regression line) as discussed in chapter 3 and 5. The cost saving impacts can be seen in Table B4 for a 50% and a 25% reduction above average.

Table B4: Furnace 3 potential annual cost saving summary.

Description	50%	25%
Single day data (R/year)	R 741,300	R 371,100
2-day average (R/year)	R 598,900	R 299,400
3-day average (R/year)	R 545,400	R 272,700

Figure B13 shows the relationship between the specific energy consumption (MWh/tonne) and the tonnes per tap. All the values above the average value are identified and these data sets are shown on Figure B14 that shows the daily energy consumption against the daily production.

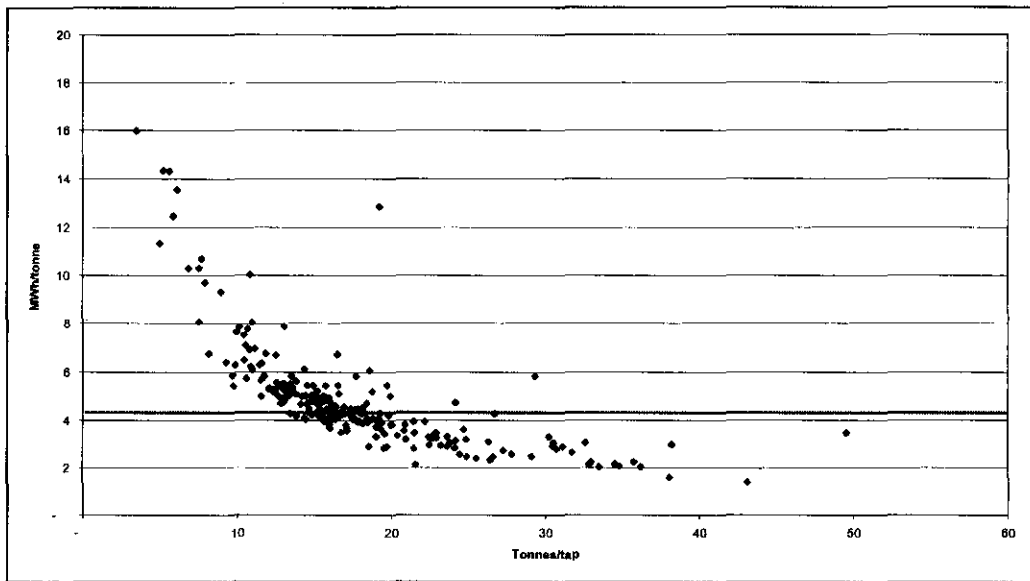


Figure B13: Furnace 3, energy consumption per tonne product versus tonnes saleable per tap (average indicated).

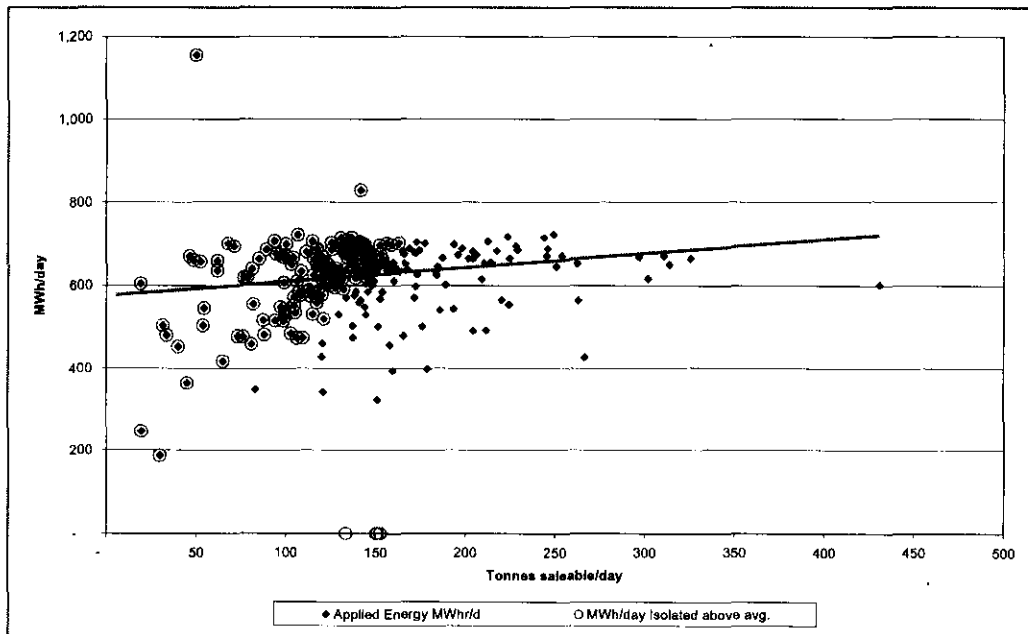


Figure B14: Furnace 3 energy consumption versus tonnes saleable production per day with isolated MWh/day above average.

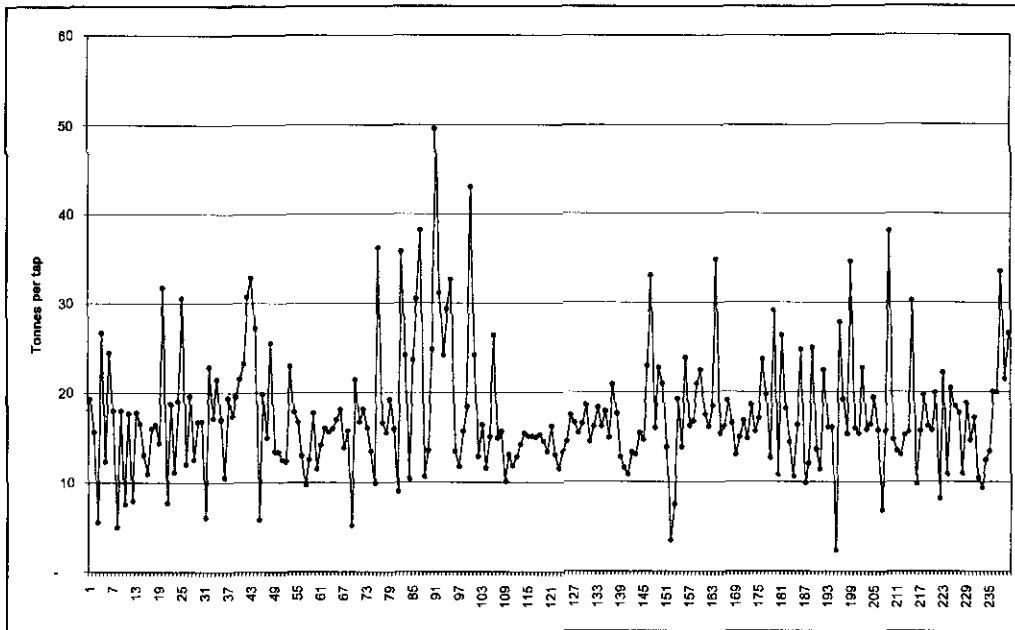


Figure B15: Furnace 3, tonnes product per tap.

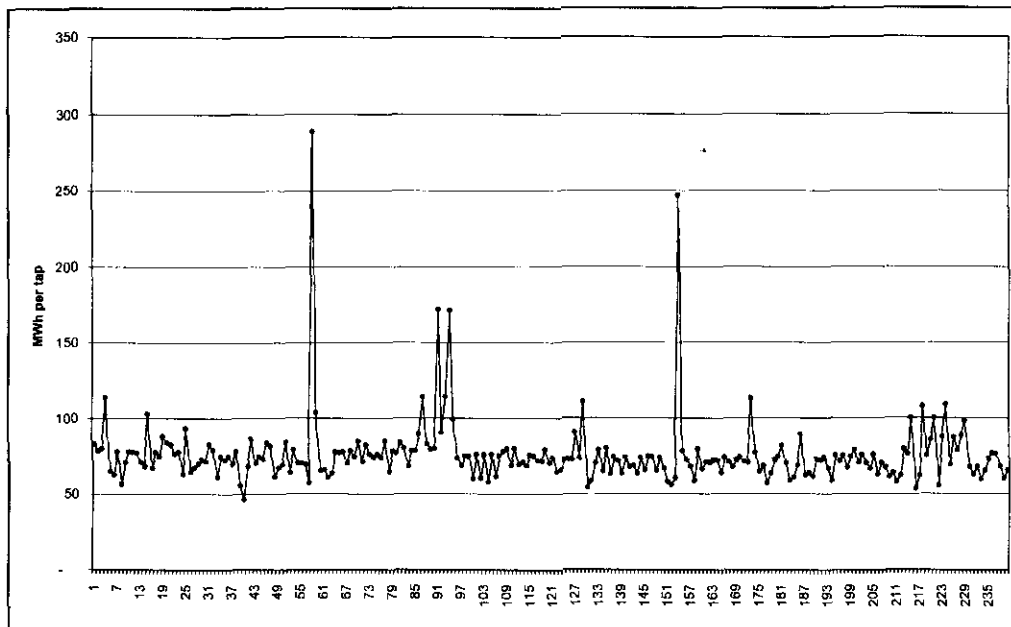


Figure B16: Furnace 3, energy consumption (MWh) per tap.

In Figure B15 it can be seen that the tonnes per tap ranged between 2 and 50 tonnes per tap. The energy consumption per tap ranged between 46 MWh/tap to 289 MWh/tap (Figure B16).

The Cusum analysis was repeated for Furnace 3. The periods of “good performance” or efficient performance in terms of energy use against production was identified. These periods of “good performance” were then used to determine a baseline of “good performance” which could then be compared to the actual performance to provide the savings that could potentially be achieved if Furnace 3 were operated in this efficient manner throughout the year. The level of efficiency used in the saving calculations has actually been achieved on previous occasions and sustained over a period of time. From the data that was used (1 September 2002 to 28 June 2003), Furnace 3 operated at this level of efficiency for approximately 20% of the time.

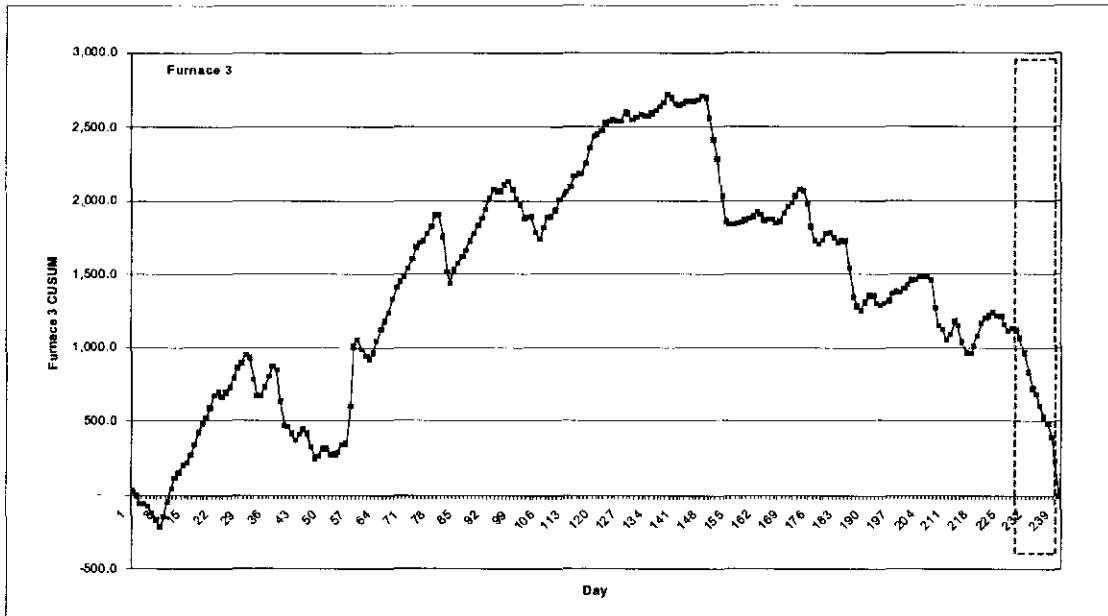


Figure B17: Furnace 3, Cusum analysis graph indicating a single period of “good performance”.

One of the longest periods of “good performance” is indicated in Figure B17. Through an adjustment of the Cusum graph one can determine what the impact would be if the furnace was operated throughout the period as it was operated during the “good performance” period. This impact is shown in Figure B18. The impact for the period from 1 September 2002 to 28 June 2003 would have been a reduction in electricity consumption of 22,500 MWh. This would have been equivalent to a financial saving of R2,819,000 over the period for the same production, but at reduced electricity consumption. This can be extrapolated to an annual electricity cost saving of approximately R4,287,400 (34,300 MWh).

Furnace 3 had a key performance indicator of 4,3 MWh/tonne over the total period. Over the “good performance” periods Furnace 3 however operated at a value of 3,6 MWh/tonne saleable for 20% of the period. The above financial savings are therefore achieved under a KPI of 3,6 MWh/tonne saleable.

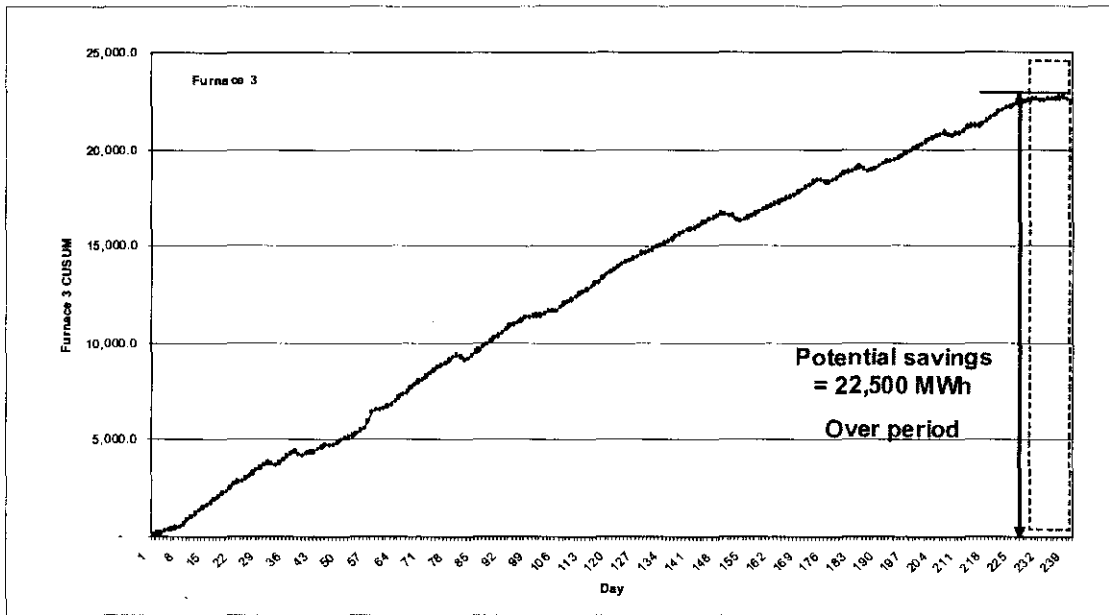


Figure B18: Furnace 3, Potential electricity consumption savings over period (1 Sep 2002 – 28 Jun 2003).

The analysis was however expanded to include the potential impact if electricity consumption remained unchanged to increase production under the “good performance” KPI of 3,6 MWh/tonne. The potential impact was an annual increase in production of 9,500 tonnes saleable. This could be converted to an additional annual income from increased production of R14,200,000.

Load management holds another opportunity for Furnace 3 to reduce its annual electricity accounts. If Furnace 3 is controlled to the “minimum of minimum” demand during the peak hours savings of R1,517,500 can be achieved each year. On average, 1,91 MW needs to be added to the hours outside of peak to ensure that the overall electricity consumption and production remain constant. The control graph is shown in Figure B19.

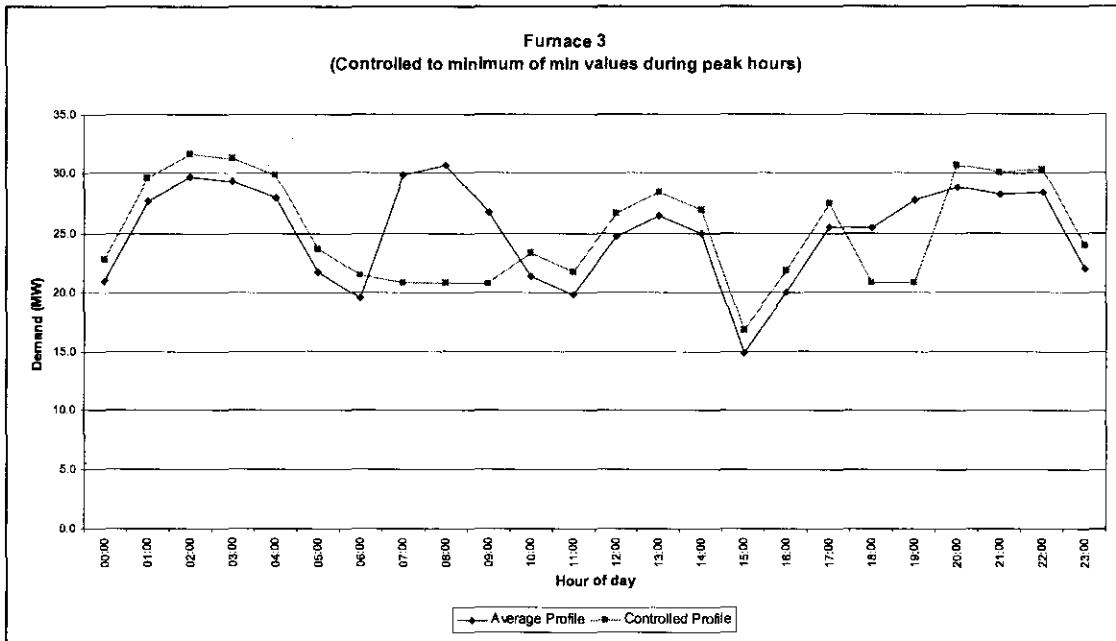


Figure B19: Furnace 3, load management to minimum of minimum demand during peak hours.

If control is applied to the “average minimum” demand during peak, Furnace 3 could realise an annual cost saving of R438,100. In this case only 0,55 MW need to be added during the hours outside peak. The control graph is shown in Figure B20 for the above load management mode.

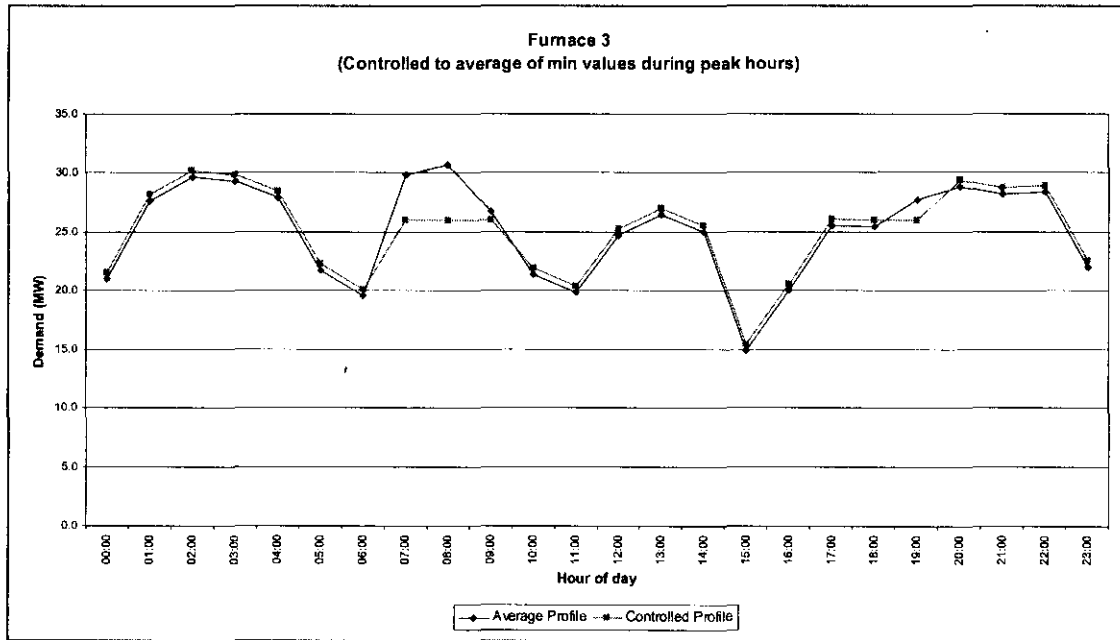


Figure B20: Furnace 3, load management to average of minimum demand during peak hours.



### B.4. FURNACE 4

The average daily availability of Furnace 4 was determined as 97% whilst the average daily utilisation was 88%. The average specific energy consumption was calculated as 3,3 MWh per tonne saleable product.

Table B5: Summary of Furnace 4 KPIs.

Furnace description	Average MWh per month (MWh/month)	Average tonnes per month (Tonnes/month)	Average daily availability (%)	Average daily utilisation (%)	Average MWh per tap (MWh/tap)	Average tonne per tap (Tonne/tap)	Average MWh per tonne (MWh/tonne)
Furnace 4	26,600	7,900	97	88	105	31	3.3

Figure B21 shows the relationship between the daily energy consumption for Furnace 4 and its daily saleable production.

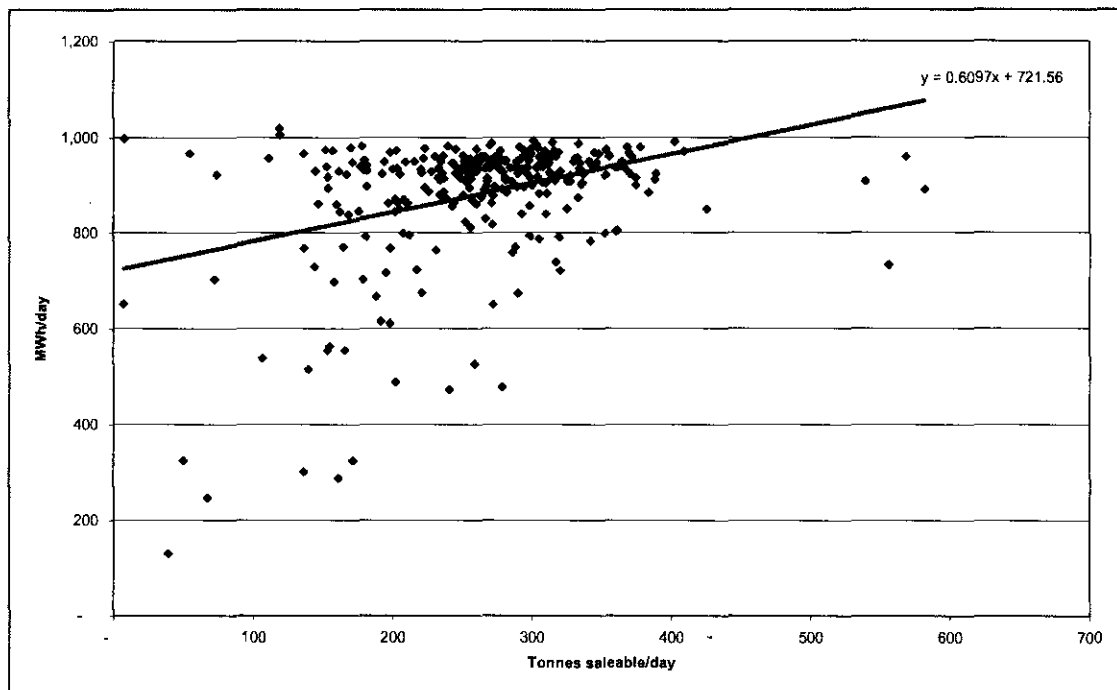


Figure B21: Furnace 4, daily applied energy vs. tonnes saleable (with regression).

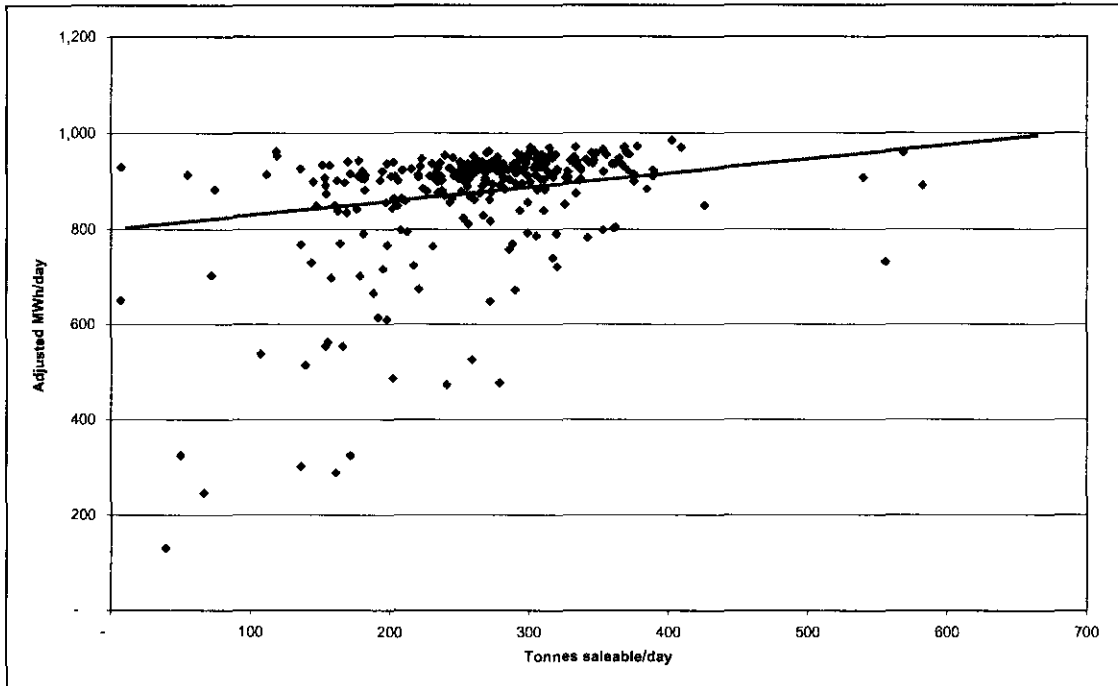


Figure B22: Furnace 4, daily applied energy vs. tonnes saleable reduced with 50% towards the average.

Figure B22 shows the impact of a potential 50% reduction in the specific energy consumption for all the values above the average (regression line). The cost saving impacts can be seen in Table B6 for a 50% and a 25% reduction above average.

Table B6: Furnace 4 potential annual cost saving summary.

Description	50%	25%
Single day data (R/year)	R 910,500	R 455,200
2-day average (R/year)	R 810,800	R 405,400
3-day average (R/year)	R 733,500	R 366,800

Figure B23 shows the relationship between the specific energy consumption (MWh/tonne) and the tonnes per tap. All the values above the average value are identified and these data sets are shown on Figure B24 that shows the daily energy consumption against the daily production.

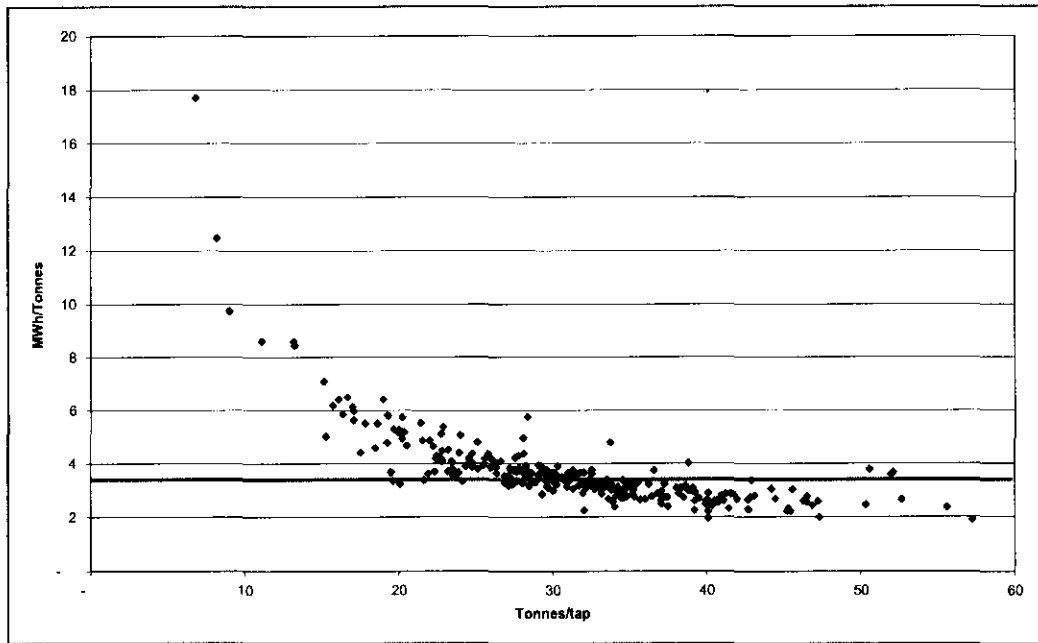


Figure B23: Furnace 4, energy consumption per tonne product versus tonnes saleable per tap (average indicated).

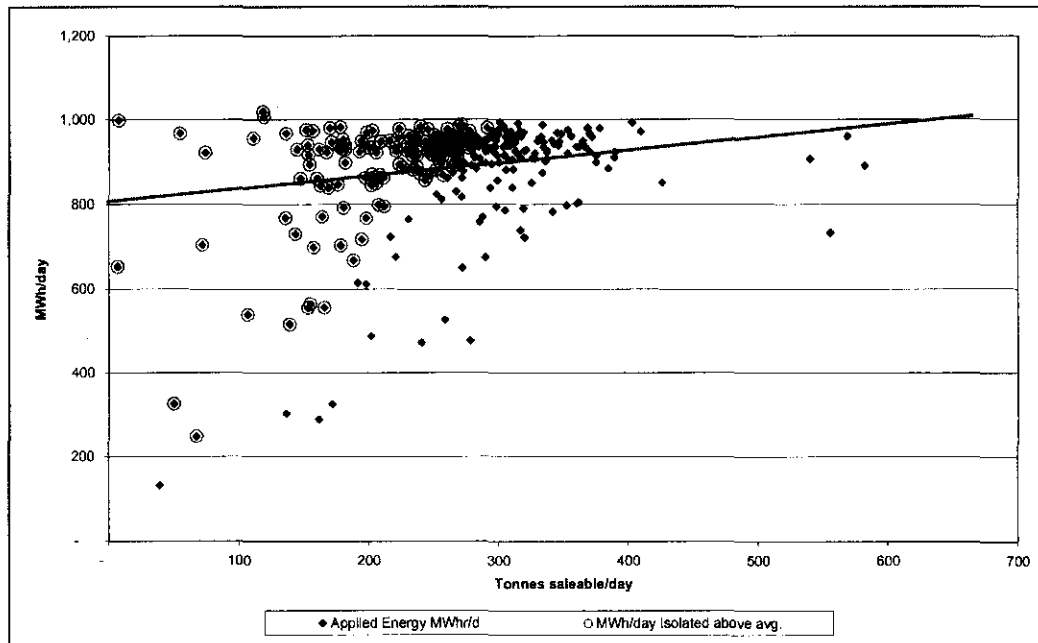


Figure B24: Furnace 4 energy consumption versus tonnes saleable production per day with isolated MWh/day above average.

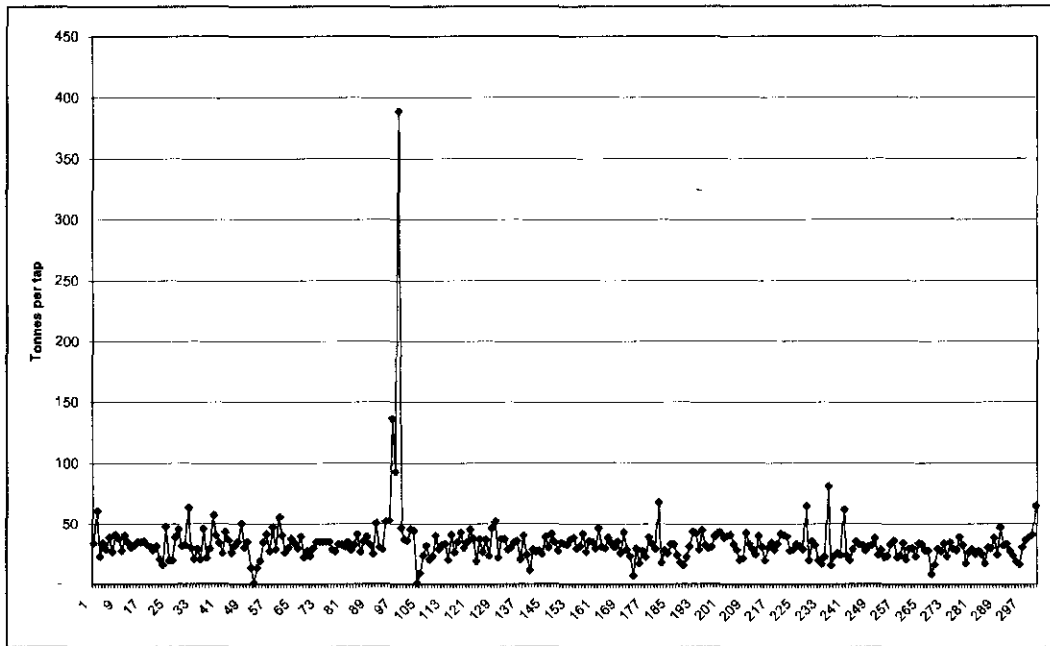


Figure B25: Furnace 4, tonnes product per tap.

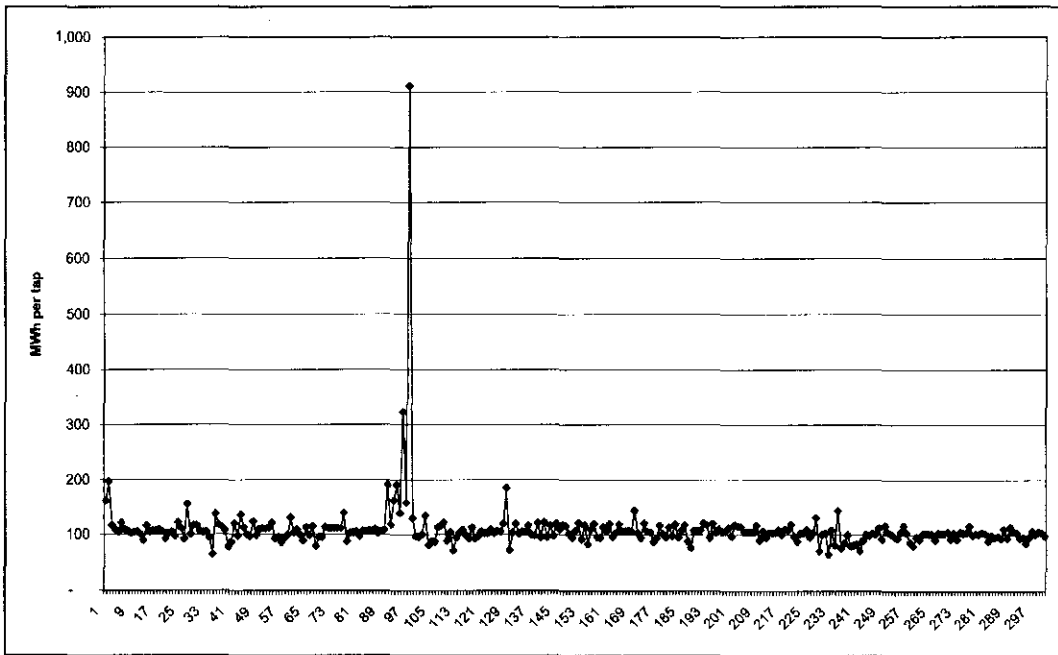


Figure B26: Furnace 4, energy consumption (MWh) per tap.

In Figure B25 it can be seen that the tonnes per tap ranged between 1 and 389 tonnes per tap. This is however not accurate. The more conservative operational bandwidth is between 7 tonnes per tap and 67 tonnes per tap. The energy consumption per tap ranged between 73 MWh/tap to 911 MWh/tap (Figure B26). This could also however be due to inaccurate data. The more conservative bandwidth is between 73 and 186 MWh per tap.

The Cusum analysis was repeated for Furnace 4. The periods of “good performance” or efficient performance in terms of energy use against production was identified. These periods of “good performance” were then used to determine a baseline of “good performance” which could then be compared to the actual performance to provide the savings that could potentially be achieved if Furnace 4 were operated in this efficient manner throughout the year. It is important to note that the level of efficiency is not estimated, but obtained from actual data over a certain period of time. This means that the level of efficiency used in the saving calculations has actually been achieved on previous occasions and sustained over a period of time. From the data that was used (1 September 2003 to 28 June 2003), Furnace 4 operated at this level of efficiency for approximately 15% of the time.

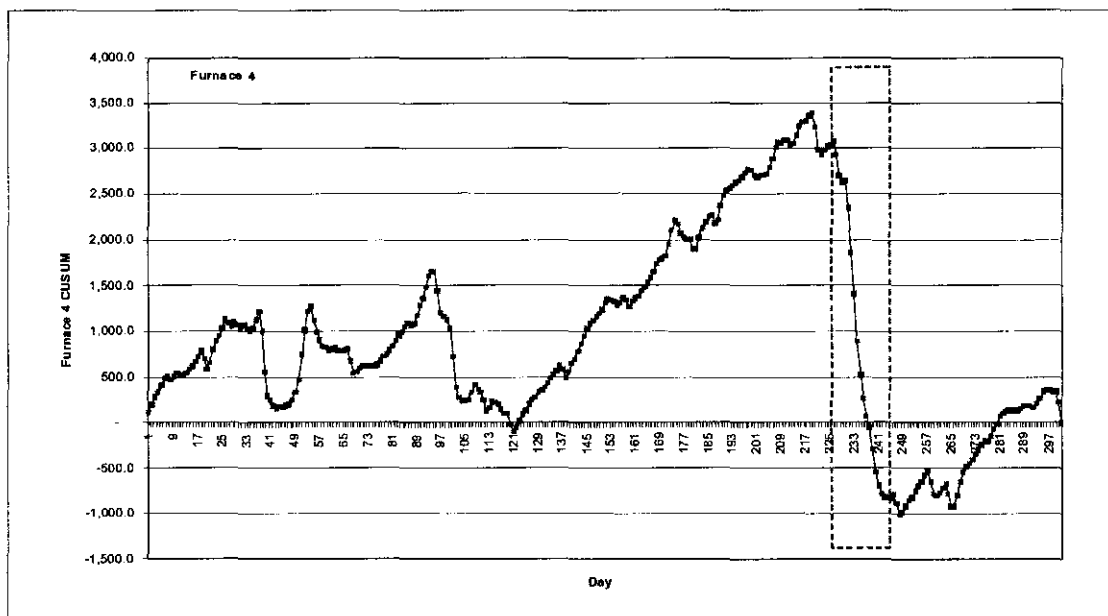


Figure B27: Furnace 4, Cusum analysis graph indicating a single period of “good performance”.

One of the longest periods of “good performance” is indicated in Figure B27. Through an adjustment of the Cusum graph one can determine what the impact would be if the furnace was operated throughout the period as it was operated during the “good performance” period. This impact is shown in Figure B28. The impact for the period from 1 September 2002 to 28 June 2003 would have resulted in a reduction in electricity consumption of 41,300 MWh. This would have been equivalent to a financial saving of R5,167,500 over the period for the same production, but at reduced electricity consumption. This can be extrapolated to an annual electricity cost saving of approximately R6,266,300 (50,100 MWh).

Furnace 4 had a key performance indicator of 3,3 MWh/tonne over the total period. Over the “good performance” periods Furnace 4 however operated at a value of 2,8 MWh/tonne saleable for 15% of the period. The above financial savings are therefore achieved under a KPI of 2,8 MWh/tonne saleable.

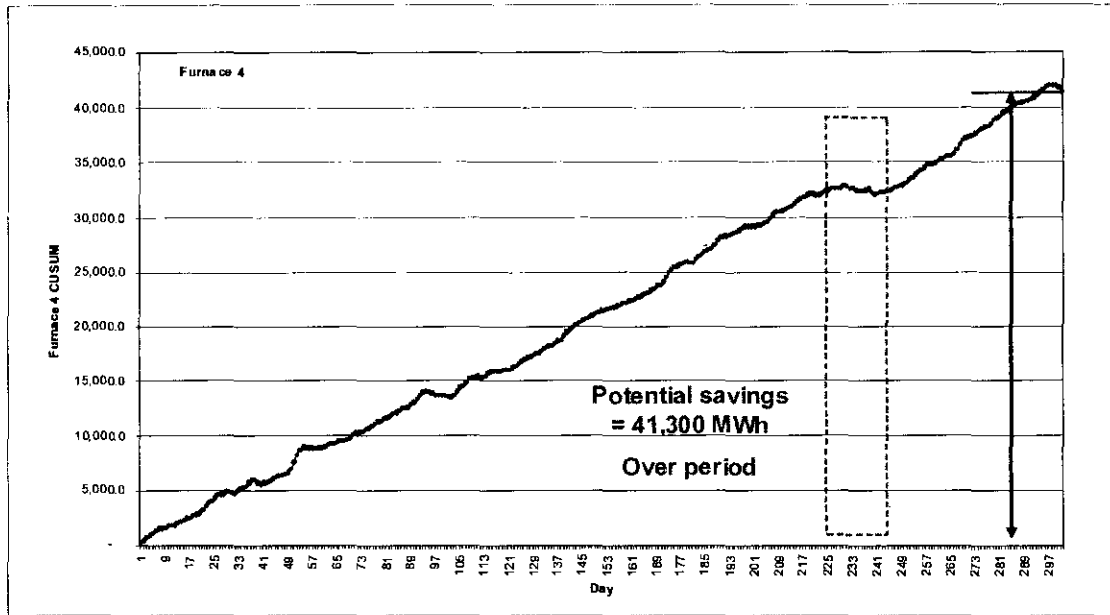


Figure B28: Furnace 4, Potential electricity consumption savings over period (1 Sep 2002 – 28 Jun 2003).

The analysis was however expanded to include the potential impact if electricity consumption remained unchanged to increase production under the “good performance” KPI of 2,8 MWh/tonne. The potential impact was an annual increase in production of 17,800 tonnes saleable. This could be converted to an additional annual income from increased production of R26,700,000.

Load management holds another opportunity for Furnace 4 to reduce its annual electricity accounts. If Furnace 4 is controlled to the “minimum of minimum” demand during the peak hours, savings of R382,100 can be achieved each year. On average, 0,48 MW needs to be added to the hours outside of peak to ensure that the overall electricity consumption and production remain constant. The control graph is shown in Figure B29.

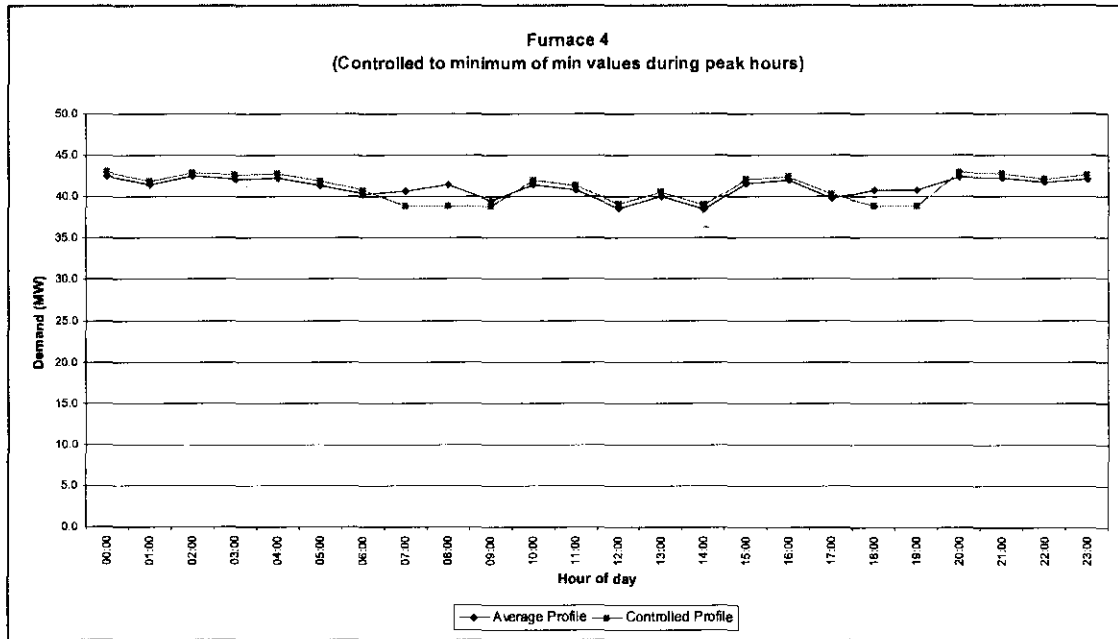


Figure B29: Furnace 4, load management to minimum of minimum demand during peak hours.

If control is applied to the “average of minimum” demand during peak, Furnace 4 could realise an annual cost saving of R123,100. In this case only 0,15 MW need to be added during the hours outside peak. The control graph is shown in Figure B30 for the above load management mode.

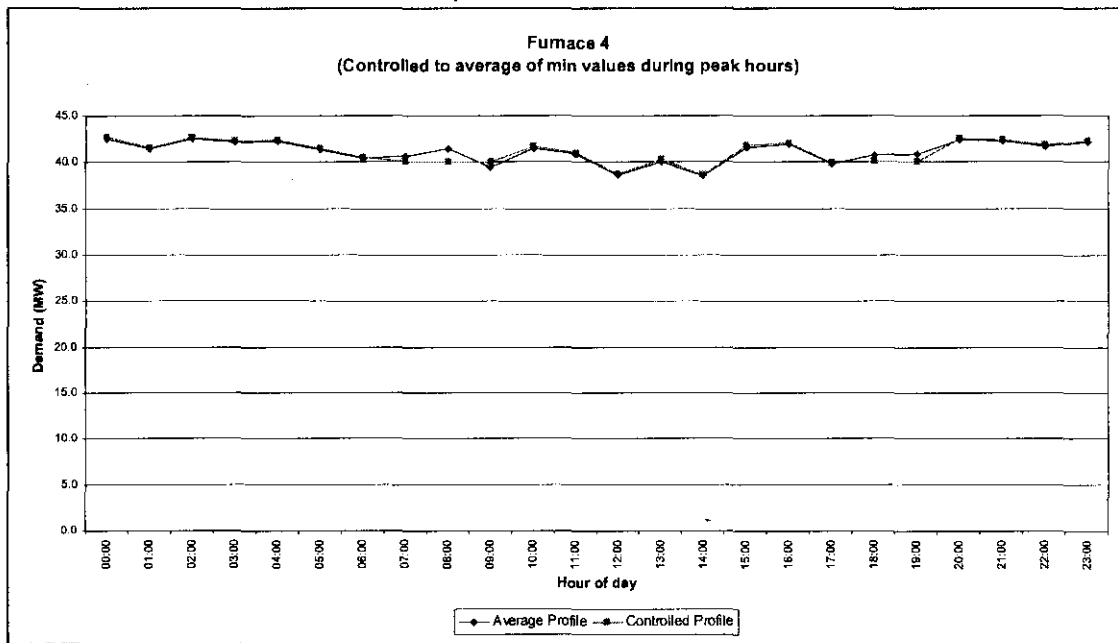


Figure B30: Furnace 4, load management to average of minimum demand during peak hours.



### B.5. Furnace 5

The average daily availability of Furnace 5 was determined as 94% whilst the average daily utilisation was 88%. The average specific energy consumption was calculated as 3,1 MWh per tonne saleable product.

Table B7: Summary of Furnace 5 KPIs.

Furnace description	Average MWh per month (MWh/month)	Average tonnes per month (Tonnes/month)	Average daily availability (%)	Average daily utilisation (%)	Average MWh per tap (MWh/tap)	Average tonne per tap (Tonne/tap)	Average MWh per tonne (MWh/tonne)
Furnace 5	25,800	8,400	94	88	109	36	3.1

Figure B31 shows the relationship between the daily energy consumption for Furnace 5 and its daily saleable production.

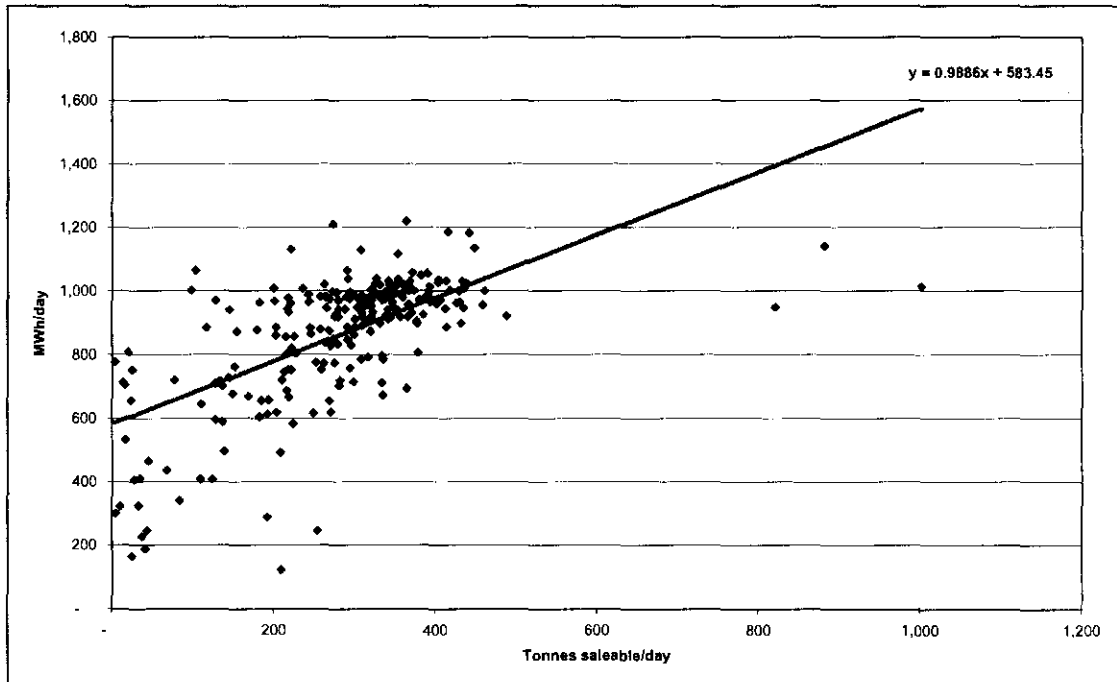


Figure B31: Furnace 5, daily applied energy vs. tonnes saleable (with regression).

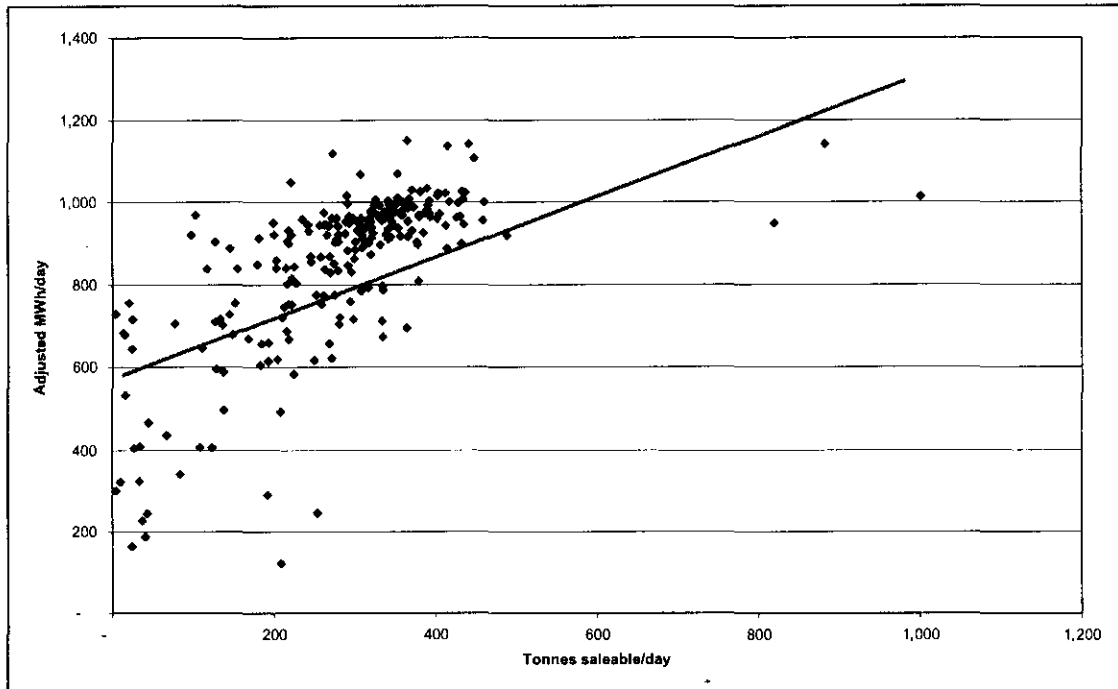


Figure B32: Furnace 5, daily applied energy vs. tonnes saleable reduced with 50% towards the average.

Figure B32 shows the impact of a potential 50% reduction in the specific energy consumption for all the values above the average (regression line). The cost saving impacts can be seen in Table B8 for a 50% and a 25% reduction above average.

Table B8: Furnace 5 potential annual cost saving summary.

Description	50%	25%
Single day data (R/year)	R 1,297,500	R 648,800
2-day average (R/year)	R 1,098,200	R 549,100
3-day average (R/year)	R 999,400	R 499,700

Figure B33 shows the relationship between the specific energy consumption (MWh/tonne) and the tonnes per tap. All the values above the average value are identified and these data sets are shown on Figure B34 that shows the daily energy consumption against the daily production.

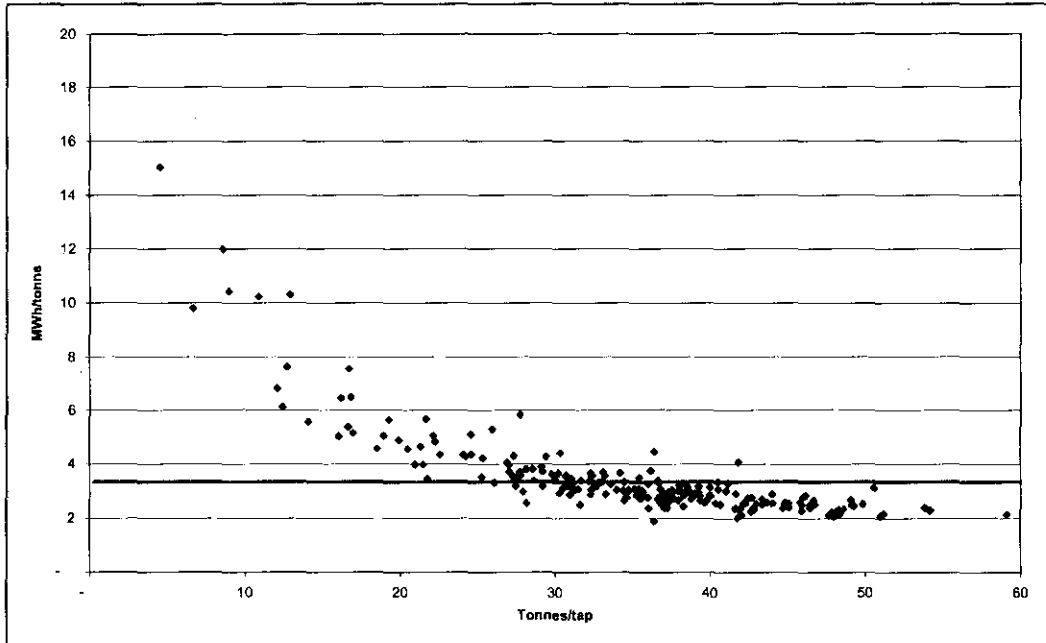


Figure B33: Furnace 5, energy consumption per tonne product versus tonnes saleable per tap (average indicated).

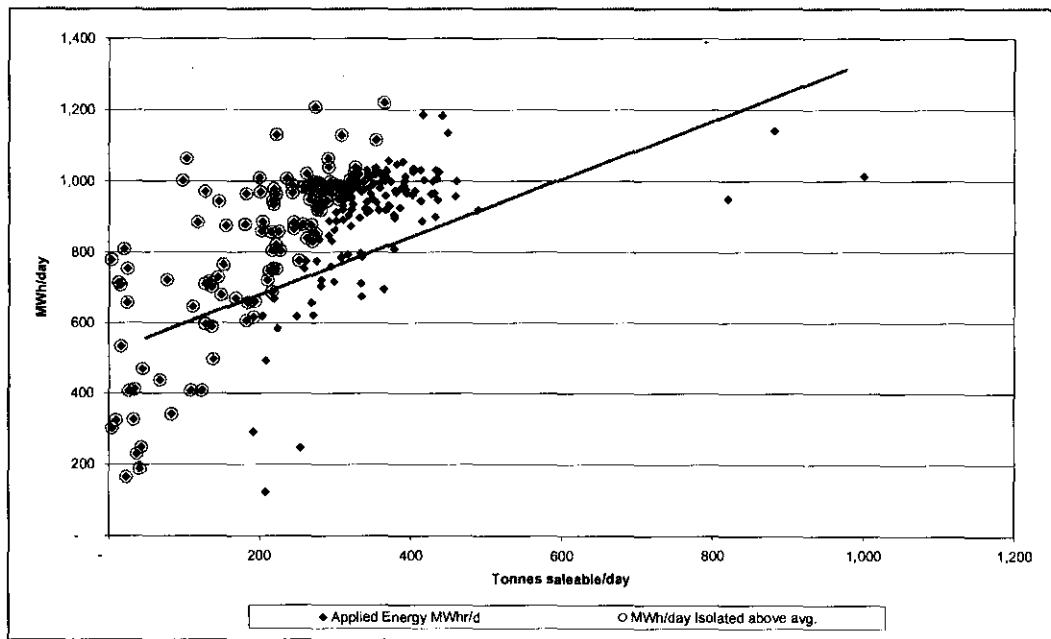


Figure B34: Furnace 5 energy consumption versus tonnes saleable production per day with isolated MWh/day above average.

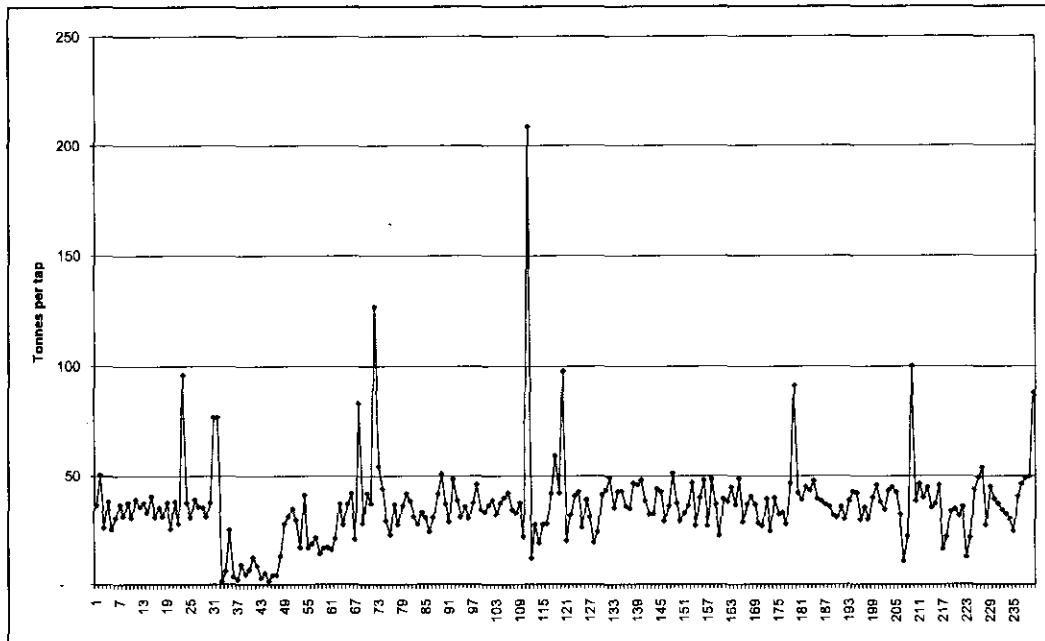


Figure B35: Furnace 5, tonnes product per tap.

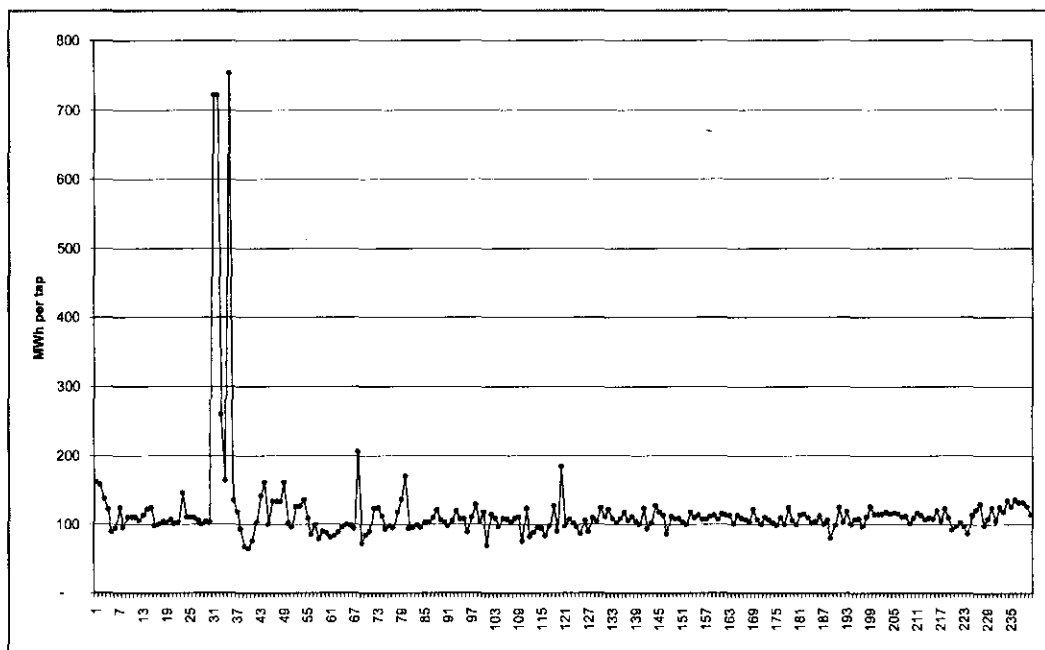


Figure B36: Furnace 5, energy consumption (MWh) per tap.

In Figure B35 it can be seen that the tonnes per tap ranged between 1 and 209 tonnes per tap. This is however not accurate. The more conservative operational bandwidth is between 14 tonnes per tap and 54 tonnes per tap. The energy consumption per tap ranged between 65 MWh/tap to 753 MWh/tap (Figure B36). This could also however be due to inaccurate data. The more conservative bandwidth is between 65 and 184 MWh per tap.

The Cusum analysis was repeated for Furnace 5. The periods of “good performance” or efficient performance in terms of energy use against production was identified. These periods of “good performance” were then used to determine a baseline of “good performance” which could then be compared to the actual performance to provide the savings that could potentially be achieved if Furnace 5 were operated in this efficient manner throughout the year. It is important to note that the level of efficiency is not estimated, but obtained from actual data over a certain period of time. This means that the level of efficiency used in the saving calculations has actually been achieved on previous occasions and sustained over a period of time. From the data that was used (1 September 2003 to 28 June 2003), Furnace 5 operated at this level of efficiency for approximately 20% of the time.

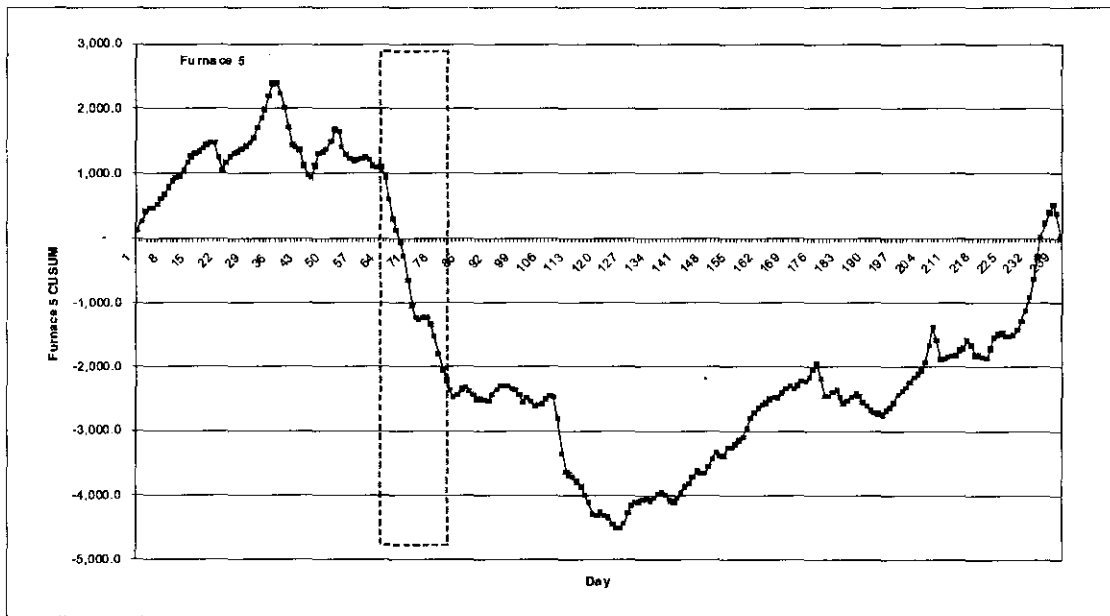


Figure B37: Furnace 5, Cusum analysis graph indicating a single period of “good performance”.

One of the longest periods of “good performance” is indicated in Figure B37. Through an adjustment of the Cusum graph one can determine what the impact would be if the furnace was operated throughout the period as it was operated during the “good performance” period. This impact is shown in Figure B38. The impact for the period from 1 September 2002 to 28 June 2003 would have resulted in a reduction in electricity consumption of 31,800 MWh. This would have been equivalent to a financial saving of R3,975,000 over the period for the same production, but at reduced electricity consumption. This can be extrapolated to an annual electricity cost saving of approximately R6,044,800 (48,400 MWh).

Furnace 5 had a key performance indicator of 3,1 MWh/tonne over the total period. Over the “good performance” periods Furnace 5 however operated at a value of 2,6 MWh/tonne saleable for 20% of the period. The above financial savings are therefore possible under a KPI of 2,6 MWh/tonne saleable.

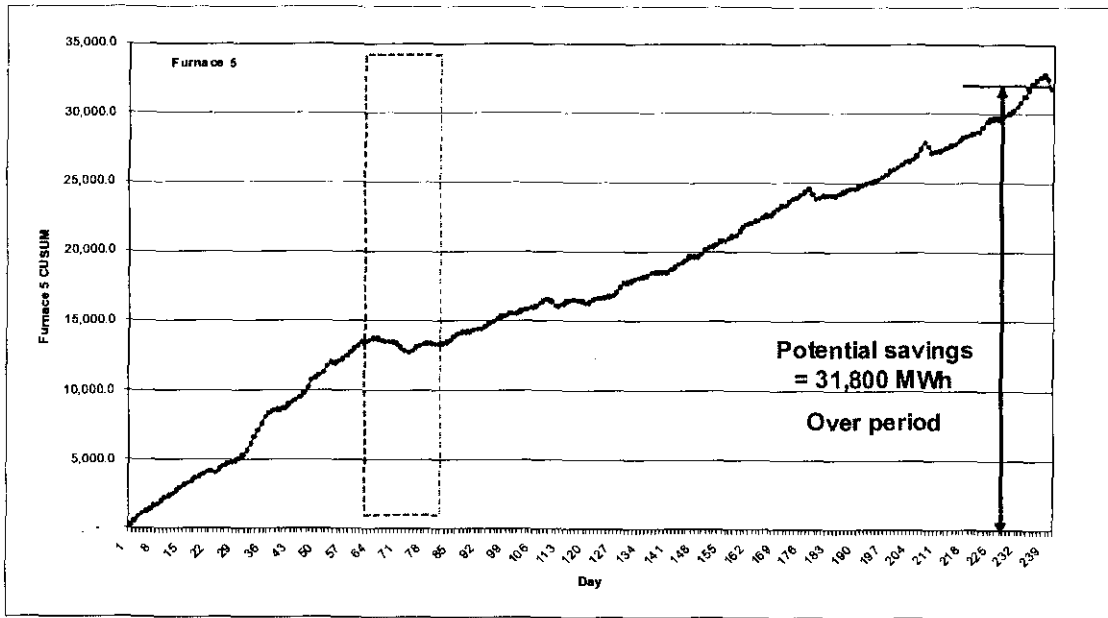


Figure B38: Furnace 5, Potential electricity consumption savings over period (1 Sep 2002 – 28 Jun 2003).

The analysis was however expanded to include the potential impact if electricity consumption remained unchanged to increase production under the “good performance” KPI of 2,6 MWh/tonne. The potential impact was an annual increase in production of 18,700 tonnes saleable. This could be converted to an additional annual income from increased production of R28,085,000.

Load management holds another opportunity for Furnace 5 to reduce its annual electricity accounts. If Furnace 5 is controlled to the “minimum of minimum” demand during the peak hours, savings of R1,111,300 can be achieved each year. On average, 1,40 MW needs to be added to the hours outside of peak to ensure that the overall electricity consumption and production remain constant. The control graph is shown in Figure B39.

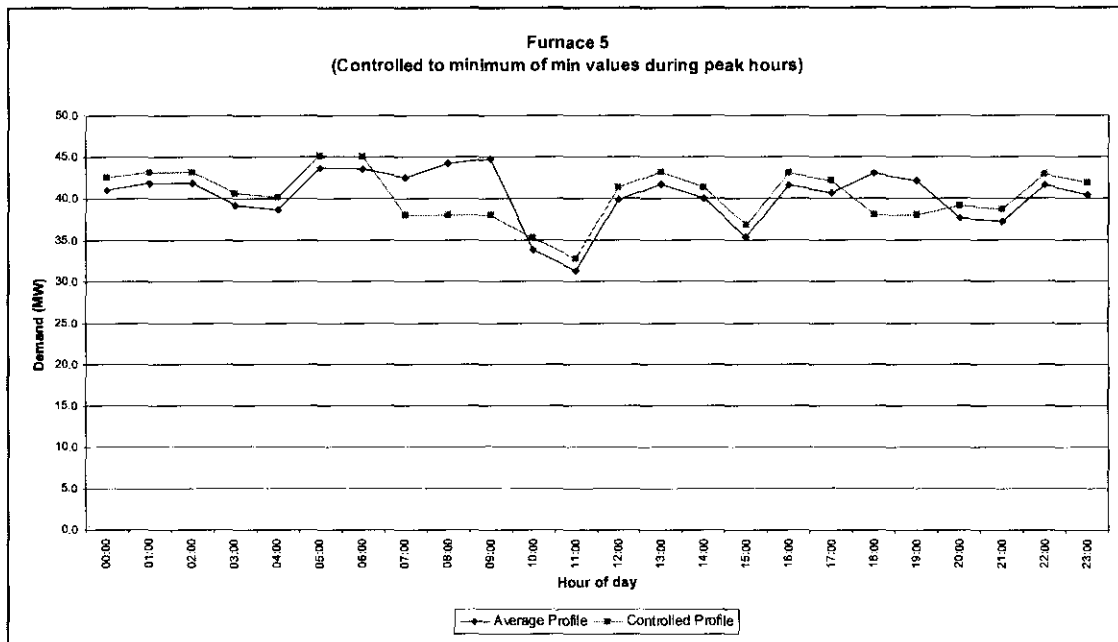


Figure B39: Furnace 5, load management to minimum of minimum demand during peak hours.

If control is applied to the “average minimum” demand during peak, Furnace 5 could realise an annual cost saving of R539,500. In this case only 0,68 MW need to be added during the hours outside peak. The control graph is shown in Figure B40 for the above load management mode.

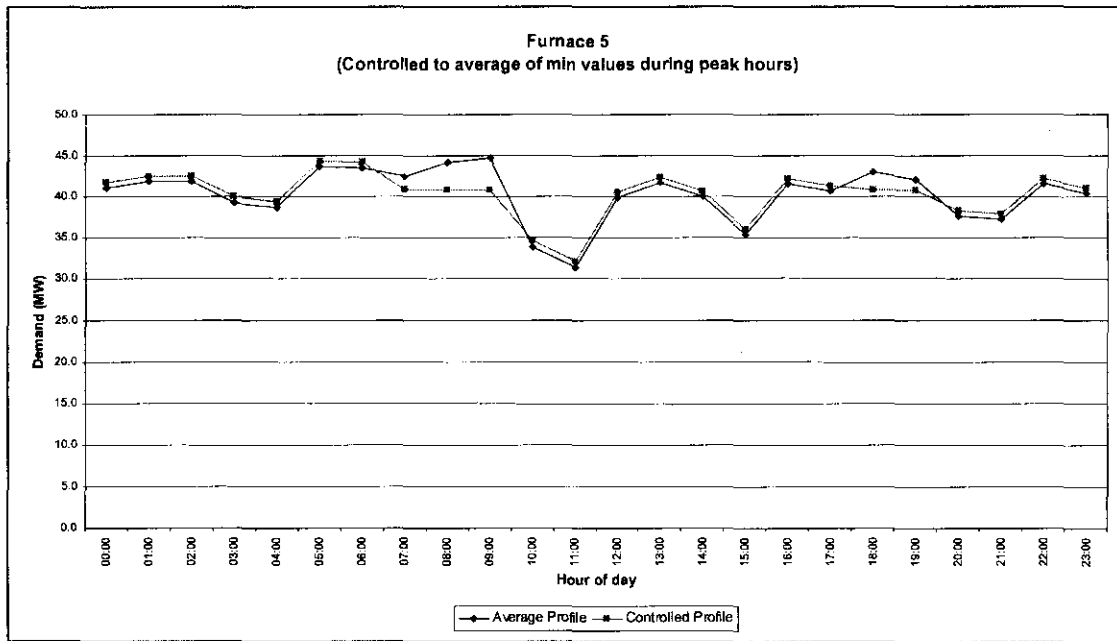


Figure B40: Furnace 5, load management to average of minimum demand during peak hours.



**B.6. FURNACE 4 AND 5 (COMBINED)**

The average specific energy consumption when Furnaces 4 and 5 are combined is calculated as 3,2 MWh per tonne product.

Table B9: Summary of Furnace 4 and Furnace 5 combined KPIs.

Furnace description	Average MWh per month	Average tonnes per month	Average daily availability	Average daily utilisation	Average MWh per tap	Average tonne per tap	Average MWh per tonne
	(MWh/month)	(Tonne/month)	(%)	(%)	(MWh/tap)	(Tonne/tap)	(MWh/tonne)
Furnace 4+5	52,300	16,300	96	88	107	33	3.2

Figure B41 shows the relationship between the daily energy consumption for Furnace 4+5 and its daily saleable production.

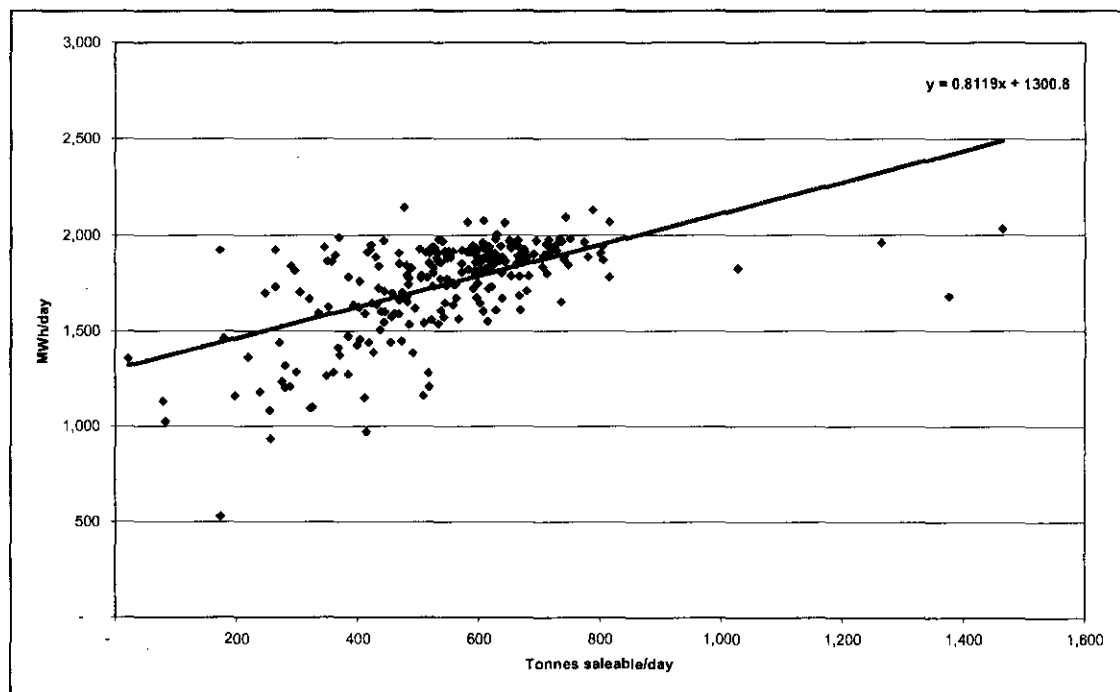


Figure B41: Furnace 4+5, daily applied energy vs. tonnes saleable (with regression).

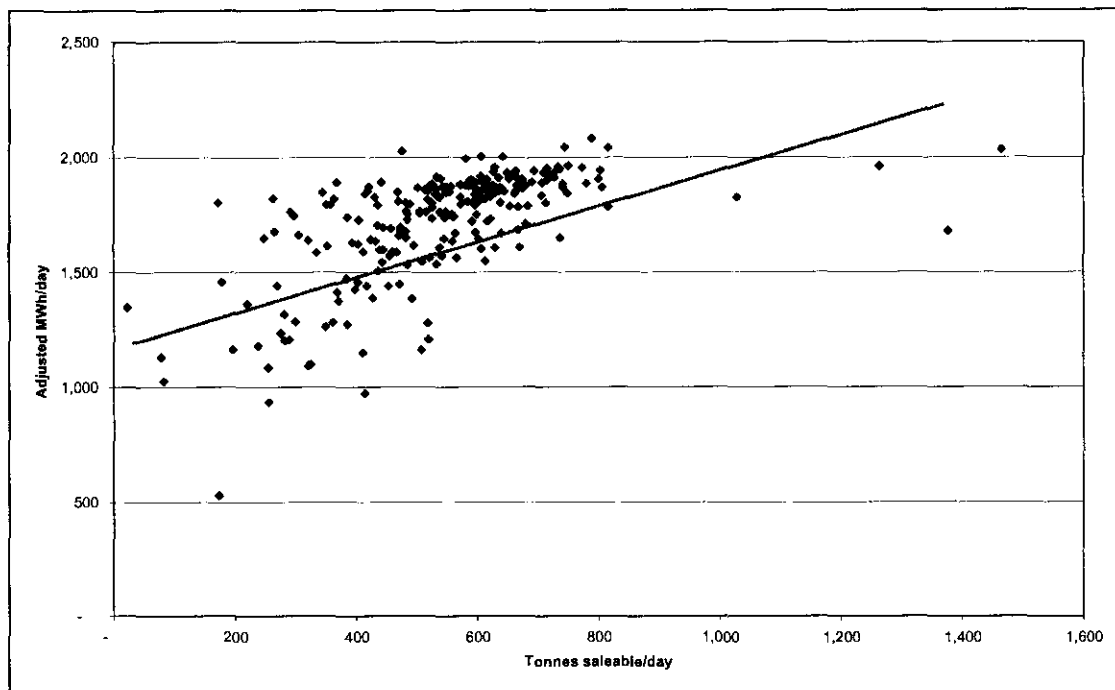


Figure B42: Furnace 4+5, daily applied energy vs. tonnes saleable reduced with 50% towards the average.

Figure B42 shows the impact of a potential 50% reduction in the specific energy consumption for all the values above the average (regression line). The cost saving impacts can be seen in Table B10 for a 50% and a 25% reduction above average.

Table B10: Furnace 4+5 potential annual cost saving summary.

Description	50%	25%
Single day data (R/year)	R 1,757,000	R 878,500
2-day average (R/year)	R 1,428,000	R 714,000
3-day average (R/year)	R 1,269,500	R 634,700

Figure B43 shows the relationship between the specific energy consumption (MWh/tonne) and the tonnes per tap. All the values above the average value of are identified and these data sets are shown on Figure B44 which shows the daily energy consumption against the daily production.

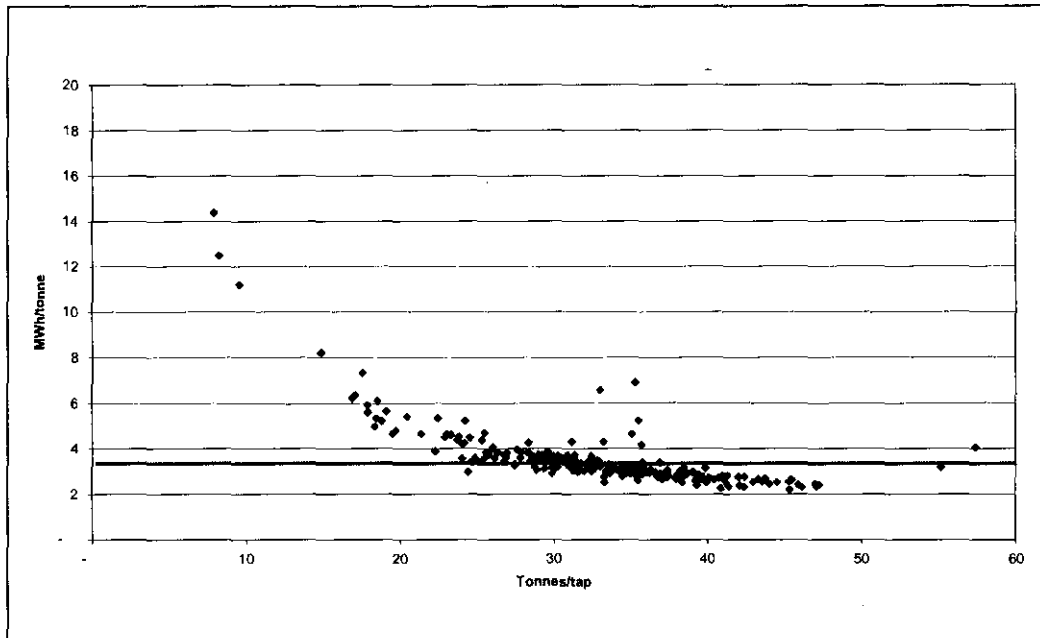


Figure B43: Furnace 4+5, energy consumption per tonne product versus tonnes saleable per tap (average indicated).

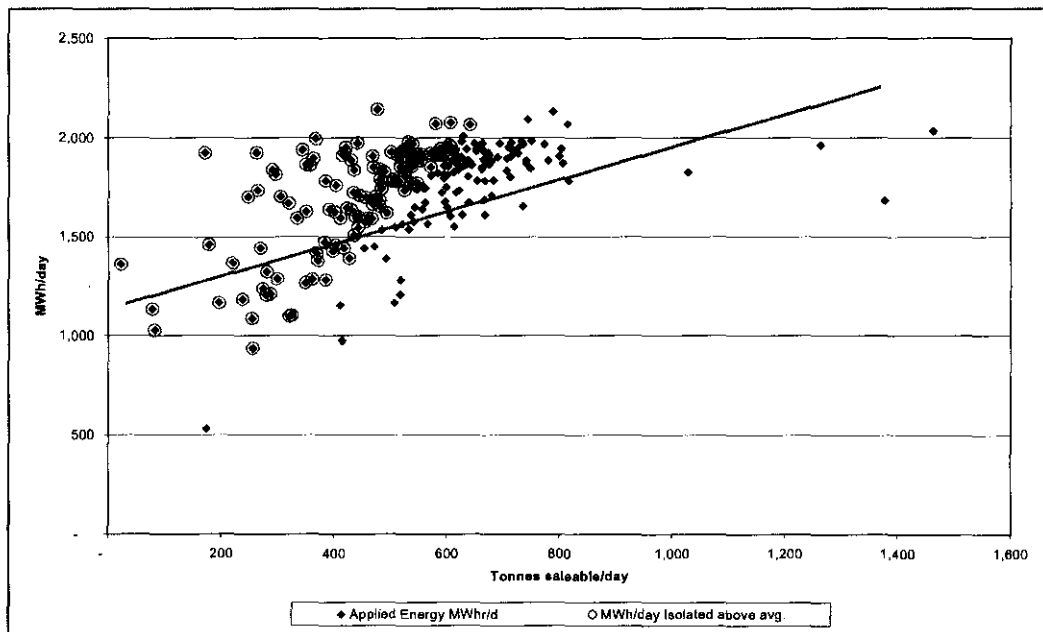


Figure B44: Furnace 4+5 energy consumption versus tonnes saleable production per day with isolated MWh/day above average.

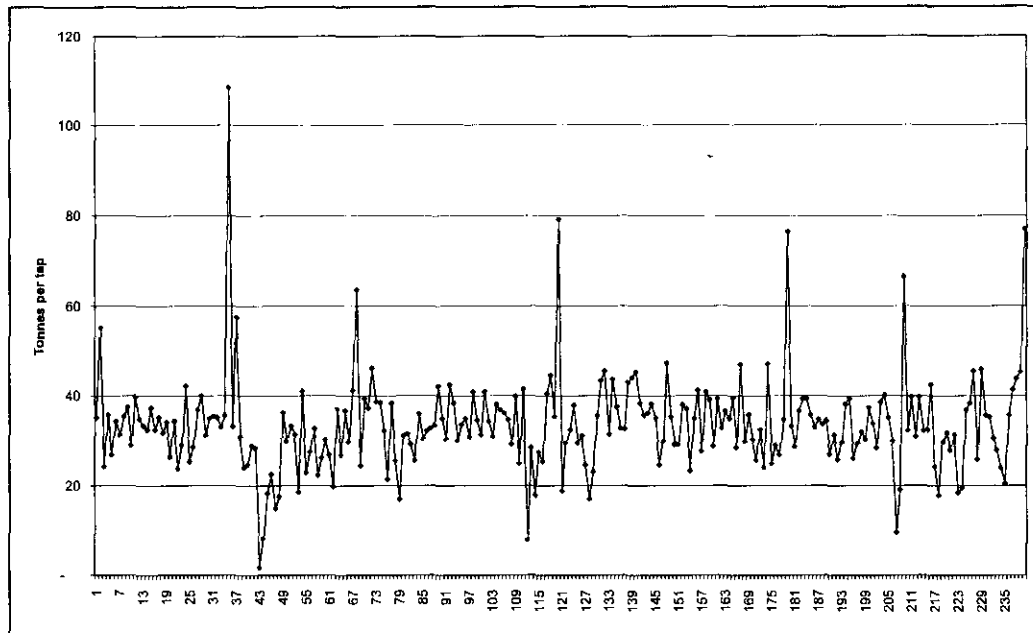


Figure B45: Furnace 4+5, tonnes product per tap.

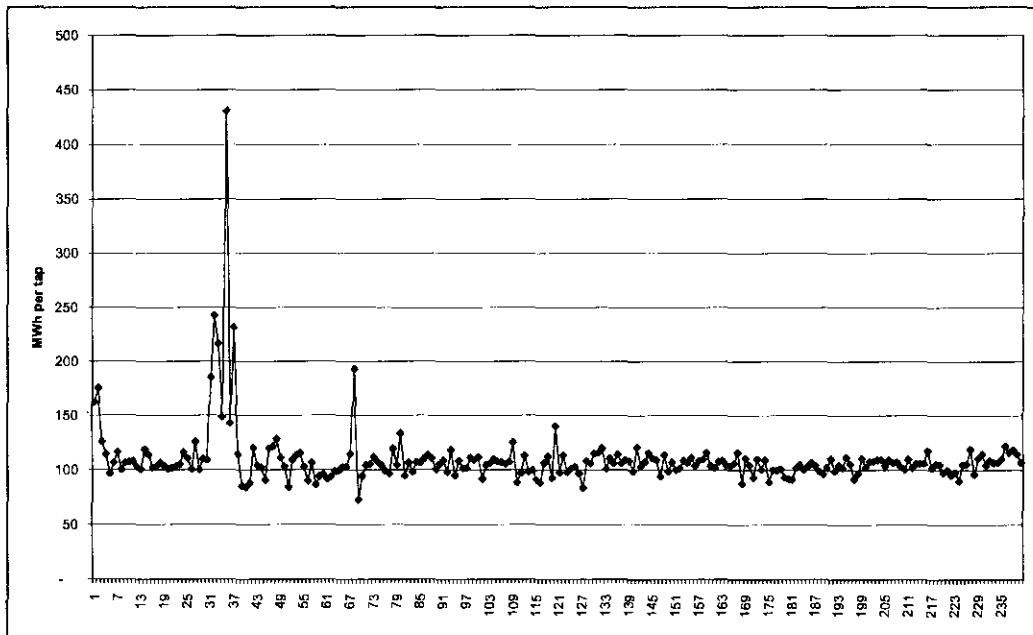


Figure B46: Furnace 4+5, energy consumption (MWh) per tap.

In Figure B45 it can be seen that the tonnes per tap ranged between 2 and 109 tonnes per tap. This is however not accurate. The more conservative operational bandwidth is between 17 tonnes per tap and 46 tonnes per tap. The energy consumption per tap ranged between 73 MWh/tap to 431 MWh/tap (Figure B46). This could also be due to inaccurate data. The more conservative bandwidth is between 73 and 141 MWh per tap.

### B.7. FURNACE 6

The average daily availability of Furnace 6 was determined as 94% whilst the average daily utilisation was 83%. The average specific energy consumption was calculated as 3,6 MWh per tonne saleable product.

Table B11: Summary of Furnace 6 KPIs.

Furnace Description	Average MWh per month (MWh/month)	Average tonnes per month (Tonnes/month)	Average daily availability (%)	Average daily utilisation (%)	Average MWh per tap (MWh/tap)	Average tonne per tap (Tonne/tap)	Average MWh per tonne (MWh/tonne)
Furnace 6	24,200	6,700	94	83	98	27	3.6

Figure B47 shows the relationship between the daily energy consumption for Furnace 6 and its daily saleable production.

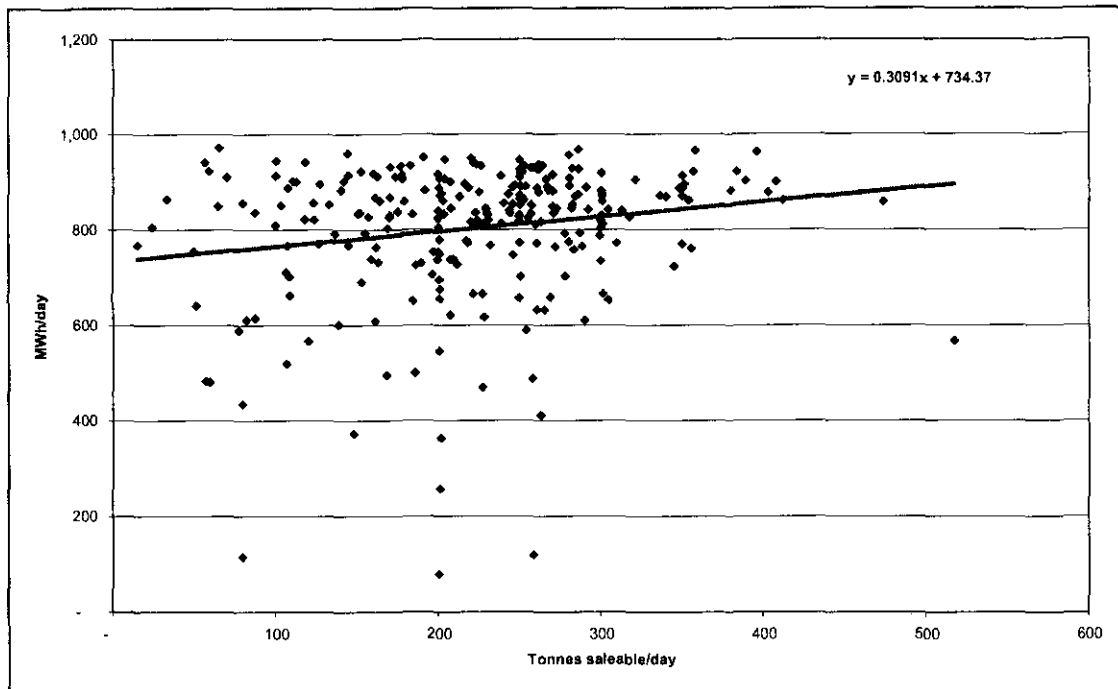
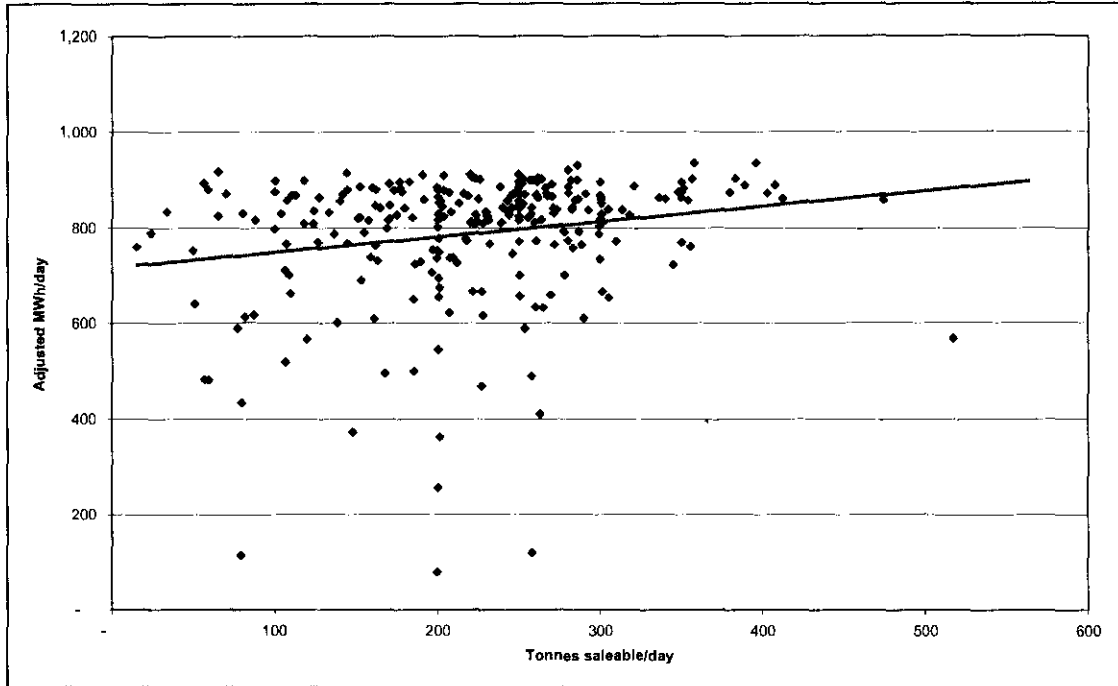


Figure B47: Furnace 6, daily applied energy vs. tonnes saleable (with regression).



**Figure B48:** Furnace 6, daily applied energy vs. tonnes saleable reduced with 50% towards the average.

Figure B48 shows the impact of a potential 50% reduction in the specific energy consumption for all the values above the average (regression line). The cost saving impacts can be seen in Table B12 for a 50% and a 25% reduction above average.

**Table B12:** Furnace 6 potential annual cost saving summary.

Description	50%	25%
Single day data (R/year)	R 1,114,200	R 557,100
2-day average (R/year)	R 904,900	R 452,400
3-day average (R/year)	R 784,700	R 392,400

Figure B49 show the relationship between the specific energy consumption (MWh/tonne) and the tonnes per tap. All the values above the average value are identified and these data sets are shown on Figure B50 that shows the daily energy consumption against the daily production.

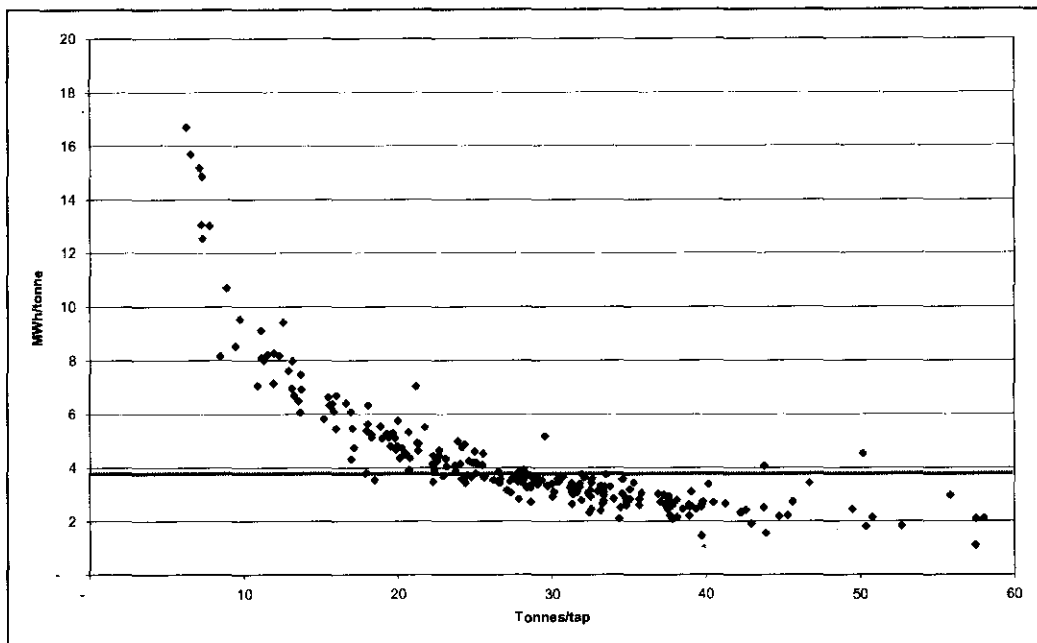


Figure B49: Furnace 6, energy consumption per tonne product versus tonnes saleable per tap (average indicated).

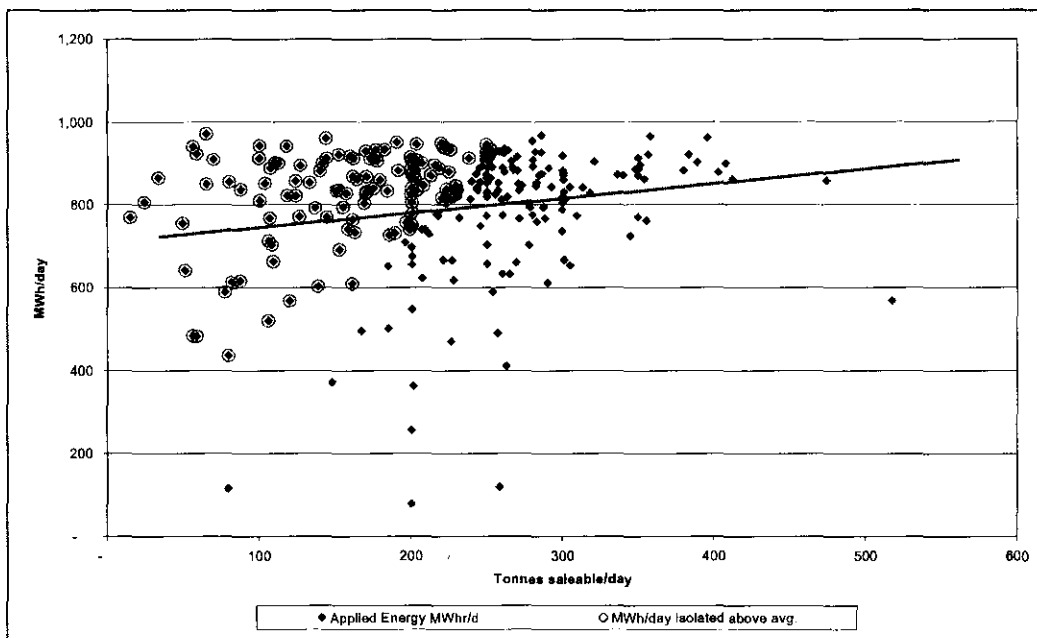


Figure B50: Furnace 6 energy consumption versus tonnes saleable production per day with isolated MWh/day above average.



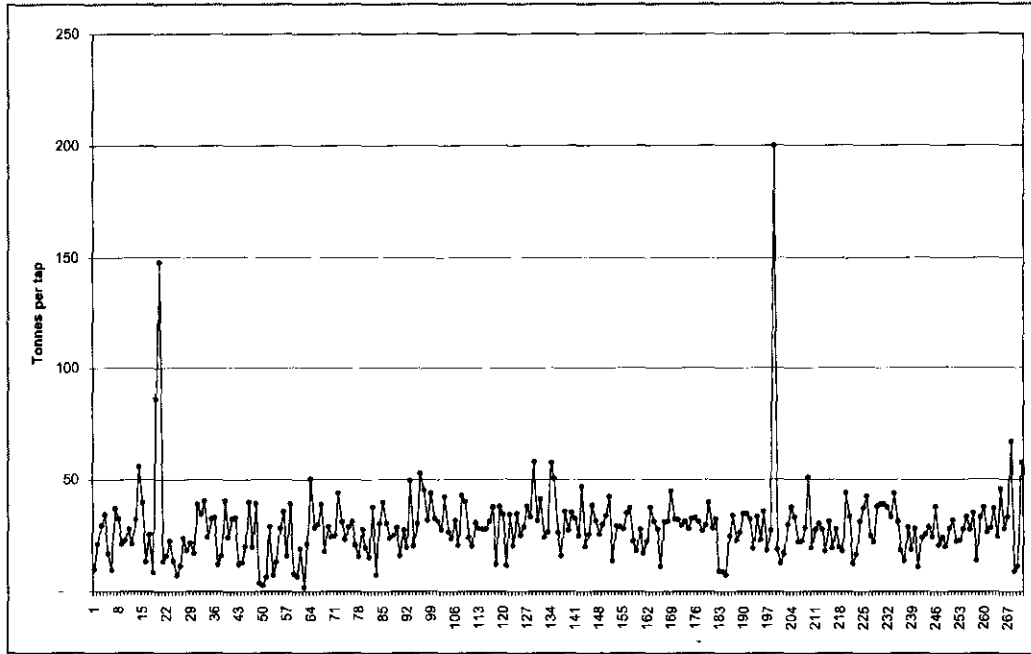


Figure B51: Furnace 6, tonnes product per tap.

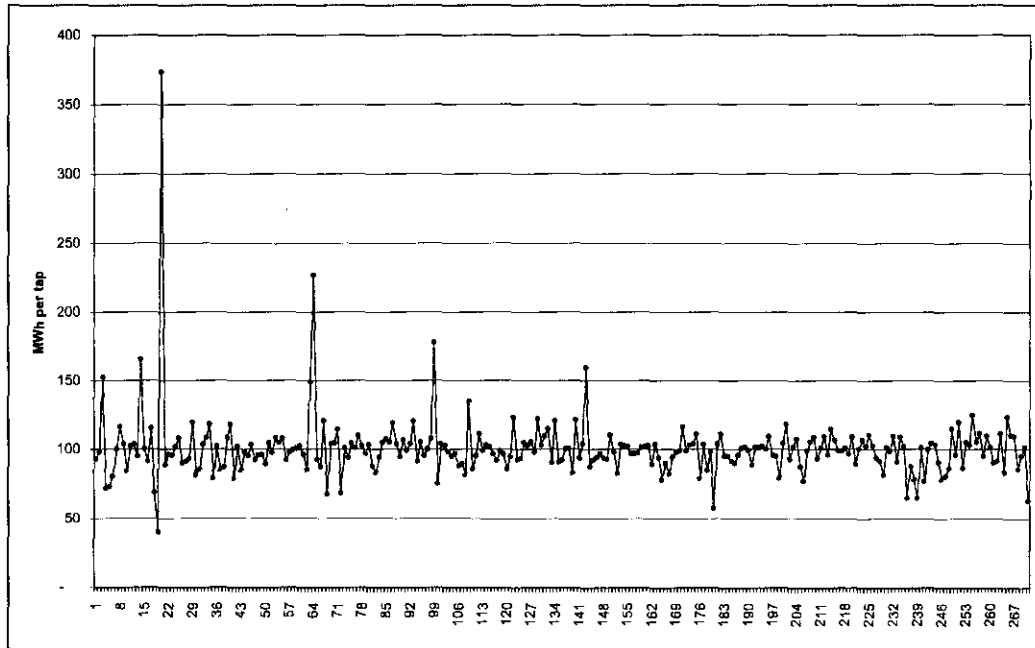


Figure B52: Furnace 6, energy consumption (MWh) per tap.

In Figure B51 it can be seen that the tonnes per tap ranged between 2 and 200 tonnes per tap. This is however not accurate. The more conservative operational bandwidth is between 7 tonnes per tap and 586 tonnes per tap. The energy consumption per tap ranged between 40 MWh/tap to 374 MWh/tap (Figure B52). This could also be due to inaccurate data. The more conservative bandwidth is between 68 and 135 MWh per tap.

The periods of “good performance” or efficient performance in terms of energy use against production was again identified for Furnace 6. These periods of “good performance” were then used to determine a baseline of “good performance” which could then be compared to the actual performance to provide the savings that could potentially be achieved if Furnace 6 were operated in this efficient manner throughout the year. It is important to note that the level of efficiency is not estimated, but obtained from actual data over a certain period of time. This means that the level of efficiency used in the saving calculations has actually been achieved on previous occasions and sustained over a period of time. From the data that was used (1 September 2002 to 28 June 2003), Furnace 6 operated at this level of efficiency for approximately 35% of the time.

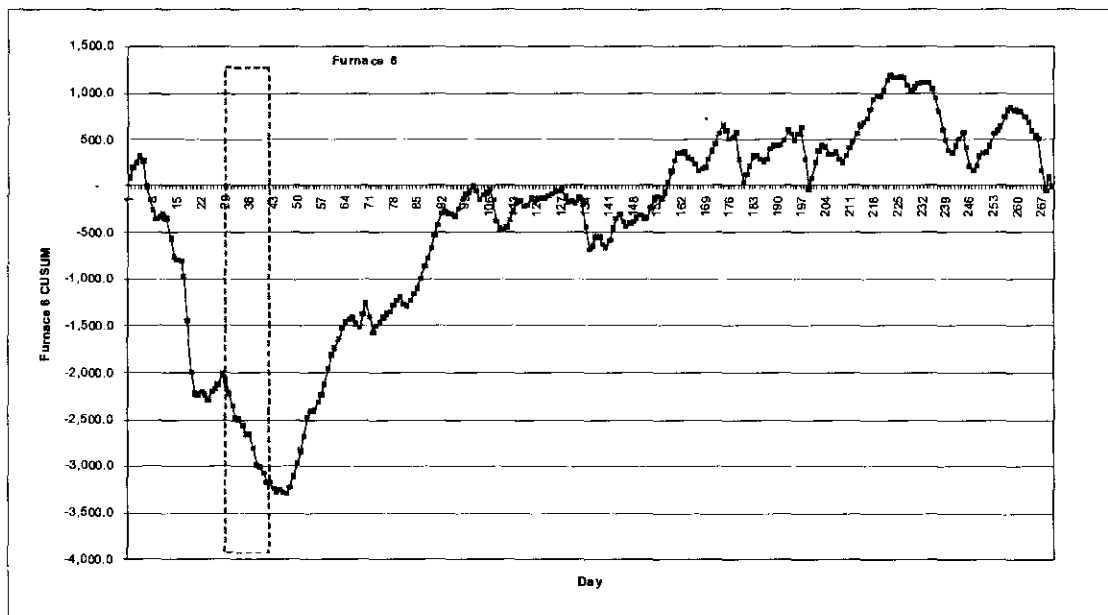


Figure B53: Furnace 6, Cusum analysis graph indicating a single period of “good performance”.

One of the longest periods of “good performance” is indicated in Figure B53. Through an adjustment of the Cusum graph one can determine what the impact would be if the furnace was operated throughout the period as it was operated during the good performance period. This impact is shown in Figure B54. The impact for the period from 1 September 2002 to 28 June 2003 would have resulted in a reduction in electricity consumption of 22,200 MWh. This would have been equivalent to a financial saving of R2,776,000 over the period for the same production, but at reduced electricity consumption. This can be extrapolated to an annual electricity cost saving of approximately R3,753,000 (30,000 MWh).

Furnace 6 had a key performance indicator of 3,6 MWh/tonne over the total period which concurred with the previous findings of this section. Over the “good performance” periods Furnace 6 however operated at a value of 3,3 MWh/tonne saleable for 35% of the period. The above financial savings are therefore possible under a KPI of 3,3 MWh/tonne saleable.

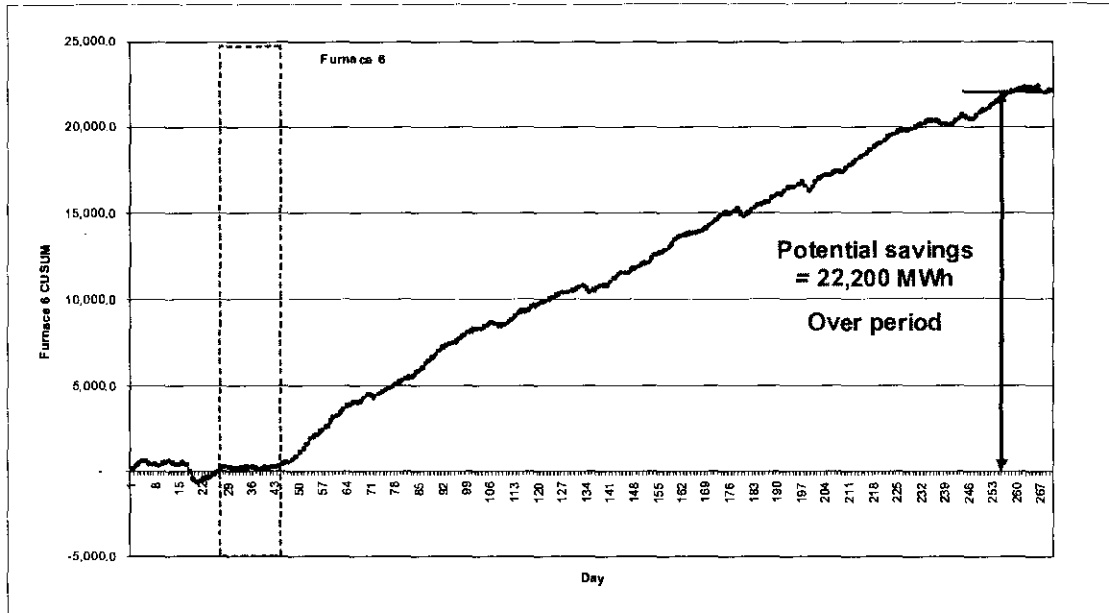


Figure B54: Furnace 6, Potential electricity consumption savings over period (1 Sep 2002 – 28 Jun 2003).

The analysis was expanded to include the impact if electricity consumption remained unchanged to increase production under the good performance KPI of 3,3 MWh/tonne. The potential impact was an annual increase in production of 9,200 tonnes saleable. This could be converted to an additional annual income from increased production of R13,830,000.

Load management holds another opportunity for Furnace 6 to reduce its annual electricity accounts. If Furnace 6 is controlled to the “minimum of minimum” demand during the peak hours, savings of R214,800 can be achieved each year. On average, 0,27 MW needs to be added to the hours outside of peak to ensure that the overall electricity consumption and production remain constant. The control graph is shown in Figure B55.

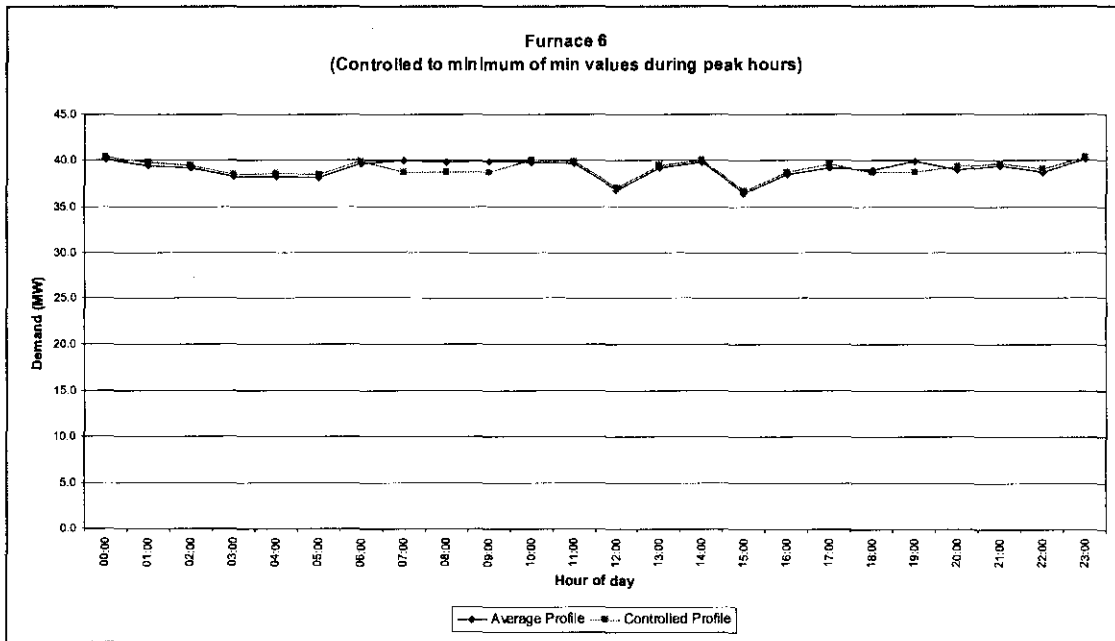


Figure B55: Furnace 6, load management to minimum of minimum demand during peak hours.

If control is applied to the “average minimum” demand during peak, Furnace 6 could realise an annual cost saving of R101,100. In this case only 0,13 MW need to be added during the hours outside peak. The control graph is shown in Figure B56 for the above load management mode.

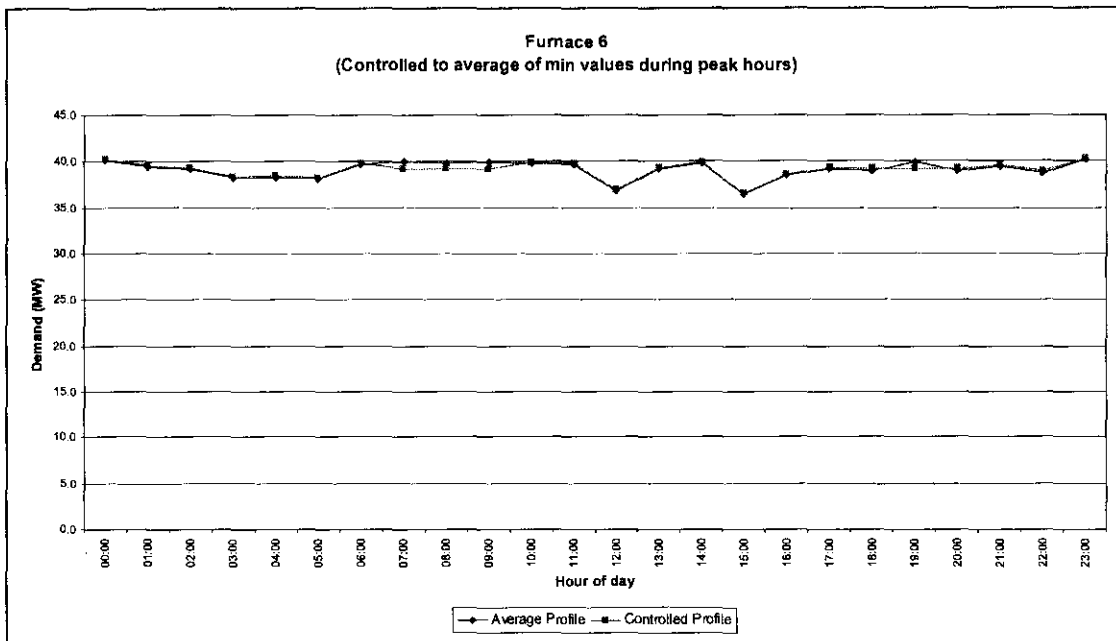


Figure B56: Furnace 6, load management to average of minimum demand during peak hours.