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Energy efficiency in South African industry

by Howard Fawkes

Half-thesis for MSc (Mech Eng)

Department of Engineering and the Built Environment

University of Cape Town

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Supervisor: Prof. K Bennett

Abstract

The concept of energy efficiency is not new, but it has been largely ignored in SA industry due to the low cost of South Africa's electricity and a not too distant history of isolation (and lack of international competition) leading up to democratic elections in 1994. This study will show that strong incentives exist for energy efficiency improvement in SA industry. Reduction of GHG emissions, the need to maintain economic competitiveness and the need to delay the cost of a new peak-load electrical generation plant are three objectives that can be achieved through improved energy efficiency in SA and particularly in SA industry.

Results from energy projects in industry in the USA and UK show that there is significant opportunity for energy cost saving through energy efficiency improvements. Case study assessments of industry leaders in SA suggest that SA industry has equal, if not greater, potential.

Barriers to the implementation of energy efficiency projects are presented in this study. These barriers need to be anticipated, avoided and/or addressed by policy makers and energy efficiency practitioners. In particular, the lesson from the case study in this thesis showed how organisation structure, financial controls and culture, can be barriers to the implementation of energy projects. By ensuring the support of top management, and by the initiation of an energy management programme early on, these barriers can be avoided. If this can be achieved, then the results and recommendations from the energy assessment can feed into a receptive management system.

Declaration

I declare that *Energy efficiency in South African industry* is my own work, that it has not been submitted before for any degree or examination at any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Signed by candidate

Howard Fawkes

August 2003

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List of Acronyms and Abbreviations

AIC	Additional item considered
ARP	Air replacement plant
CAPEX	capital expenditure
CDM	Clean Development Mechanism
CFL	Compact fluorescent lamp
cfm	cubic feet per minute (1cfm = 28,317 l/min = 1,699 m ³ /hr)
CRI	colour rendering index
ECO	Energy conservation opportunity
ERI	Energy Research Institute (UCT)
GDP	Gross domestic product
GHG	Greenhouse gas
HFO	Heavy fuel oil
HID	high-intensity discharge
HPS	high-pressure sodium
KPI	key performance indicator
kVAR	kilo-volt amps reactive
LPG	Liquid petroleum gas
M&V	monitoring and verification
MH	metal halide
mo	month
MV	mercury vapour
OECD	Organisation for Economic Cooperation and Development
PFC	power factor correction
PPP	Purchasing power parity
RH	relative humidity
ROI	return on investment
SA	South African
TPES	Total primary energy supply
UK	United Kingdom
USA	United States of America
yr	year

1 Introduction

Energy efficiency is neither a new nor a complex concept, but it is usually only considered when there are reasonable incentives that are understood by the energy user. Energy efficiency has been largely ignored in South African (SA) industry due to the low cost of SA's electricity and a not too distant history of isolation (and lack of international competition) leading up to democratic elections in 1994. This study will show that strong incentives exist for energy efficiency improvement in SA industry, in particular, the need to reduce greenhouse gas (GHG) emissions, the need to maintain economic competitiveness and the need to delay the cost of new peak-load electricity generation facilities.

This study also provides evidence that energy efficiency projects can save a significant portion of energy costs (25% in this case study). Results from energy projects in industry in the USA and UK as well as other case study assessments of industry leaders in SA suggest that SA industry has the potential for significant savings.

Finding opportunities for energy cost saving is only the first step towards attaining a more efficient industry. For energy cost savings to be realised, these energy conservation opportunities (ECO's) need to be implemented. This thesis describes some of the barriers to implementation of energy efficiency projects in SA industry. These barriers need to be anticipated, avoided and/or addressed by policy makers and energy efficiency practitioners. The case study will highlight the importance of creating a receptive management system by ensuring the support and participation of top management in creating an energy management programme.

This thesis consists of a *literature survey* of energy efficiency in South African industry, and a *case study* of a motor vehicle manufacturing company in South Africa. The literature survey will provide the context from where the results of the case study will be discussed. The *research*

methodology for the energy assessment is contained within the case study.

The literature survey begins by describing the *current status* of energy use and energy efficiency in SA industry and comparing our consumption and performance with the rest of the world. The following section presents the *incentives* that are currently driving the move towards a more efficient industry in South Africa. The third section explores the *barriers* to implementation of energy efficiency projects that have been experienced by practitioners in South Africa and in other countries. These incentives and barriers will determine whether industries and government will spend money on, and allocate human resources to, energy efficiency programmes. Global warming, economic competitiveness and the capital cost of new electricity generation facilities are the main incentives for energy efficiency improvement, while the low cost of SA coal and electricity is one of the main barriers.

The literature survey also contains sections on proven *management techniques* as well as a summary of the *technologies and techniques* that can be used for energy efficiency improvement in industry. . These two sections provide the background that is needed when considering the results of the case study. These sections show that energy needs to be treated as a legitimate input to production, rather than an unavoidable overhead and that apart from efficient technology, the human element is a vital part of any energy management programme.

The case study begins with a brief background to the energy assessment (performed by the author) of a motor vehicle manufacturing company in South Africa. It then moves to the research methodology that was followed while preparing for and conducting the energy assessment.

The *results* of this assessment are presented (along with recommendations for each energy conservation opportunity) and this is followed by a *discussion of the results*. Finally *conclusions* are drawn from the experience of the energy assessment case study and from the findings of the literature survey.

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2. Literature survey

The following two quotes from the *White Paper on the Energy Policy of the Republic of South Africa - 1998* provide a good backdrop to this thesis.

"Past governments devoted little attention to energy efficiency in industry, mining and commerce. Greater efficiency will provide financial and environmental benefits, with industry becoming more internationally competitive. Government needs to tap this potential." (DME, 1998 pxi)

"It is estimated that greater energy efficiency could save between 10% and 20% of current consumption. Government needs to facilitate increased energy efficiency. Obstacles include: inappropriate economic signals; lack of awareness, information and skills; lack of efficient technologies; high economic return criteria; and high capital costs. Government commits itself-to facilitate greater energy efficiency." (DME, 1998 pxi)

This literature survey begins by showing the current situation of SA industry with respect to energy consumption and efficiency. It goes on to present the current incentives for energy efficiency improvement and the barriers as experienced by energy efficiency practitioners in the USA, UK and South Africa. The following section investigates the financial benefits from energy projects completed in the UK, the USA and South Africa. The final two sections provide some background theory to the case study - covering energy management and efficiency improvement through technology.

2.1 Energy use and energy efficiency in SA industry

This section will show where SA gets its energy, what it uses its energy for, and how efficiently it uses its energy.

South Africa has enormous reserves of easily accessible coal and has relied on coal as its main energy source. Because of its wealth of coal,

South Africa has been slow to develop its reserves of petroleum and natural gas. Recent exploration has revealed extensive gas reserves (13 trillion cubic feet) (Argus, 15 June 2003) in the Ibhubesi gas field off the west coast but development in this regard is still at the starting blocks. SA is a world leader in the production of synthetic fuels and a regional leader in petroleum refining. The project to pipe gas from Pande and Temane gas fields in Mozambique to Sasol (chemicals) and Secunda (synthetic fuels) in South Africa, is 70% complete (Argus, 15 June 2003). SA also has Africa's only nuclear power station. Energy sources for the total primary energy supply (TPES) of SA and the world in 2000 are compared in Figure 1 below.

Figure 1 - Energy shares of TPES for 2000 (excluding electricity trade)
(Data source: www.iea.org)

Final energy consumption in SA is split as shown in Figure 2.

Figure 2 – Final energy consumption by sector in SA – 1998 (Data source: Environmental Information Agency)

So where is South African industry currently positioned with respect to energy efficiency? Are we efficient, or are we sitting on a 'gold mine' of opportunities for energy cost savings?

The *energy intensity* of a country is an indicator that describes energy use against the value of production or per capita. However, energy intensity by itself, cannot be used as a comparative measure of energy efficiency unless the types of industries of the countries are similar. Developed countries have generally shifted from energy-intensive processes (mining and materials processing) with relatively low product value, to low-energy industries (computer chips, information technology) with relatively high value. Nonetheless, it is still interesting to compare SA's energy intensity with its neighbours and the rest of the world.

Table 1 below shows energy intensity of SA against that of Africa, Non-OECD countries, OECD countries and the World. Total primary energy supply (TPES) per capita is high in OECD countries and South Africa's TPES/capita is much higher than the African average. TPES per gross domestic product (TPES/GDP) shows that South Africa uses almost four times more energy than OECD countries to produce products of

equivalent financial value. When purchasing power parity (PPP) is taken into consideration, SA uses just over twice as much energy as OECD countries (and the world average). Electrical consumption per capita shows how South Africa uses ten times more electricity per capita than the African average, uses double the world average and uses about 60% of the OECD average.

	<i>TPES/capita</i>	<i>TPES/GDP</i>	<i>TPES/GDP</i>	<i>Elec. consumption per capita</i>
	<i>toe/capita</i>	<i>toe/000 1990 US\$</i>	<i>toe/ 000 PPP 1990 US\$</i>	<i>kWh/capita</i>
South Africa	2,68	0,88	0,57	4 509
Africa	0,64	0,87	0,39	490
Non-OECD	0,95	0,85	0,32	975
OECD	4,63	0,25	0,26	7 751
World	1,64	0,37	0,29	2 252

TPES = total primary energy supply, toe = tonnes of oil equivalent, PPP = purchasing power parity, GDP = Gross domestic product

Table 1 - Comparative energy intensity of SA in 1998 (Source:<http://www.helio-international.org>)

The high energy intensity that is evident from Table 1 is largely a result of the economy's structure, with large-scale, energy-intensive primary minerals extraction and processing industries dominating. In addition, there is a heavy reliance on coal for generating most of the electricity and for producing a significant proportion of the liquid fuels consumed in the country. Furthermore, South Africa's industry has not generally used the latest in energy-efficient technologies - mainly as a result of low energy costs.

The figures for energy intensity do not prove that SA industry is inefficient but they do show that large quantities of energy are used in our industrial

processes. For this reason we should expect significant energy cost savings through the implementation of energy efficiency projects.

2.2 Incentives for energy efficiency in South African Industry

The driving forces for energy efficiency are:

- profit
- the need to reduce greenhouse gas emissions
- the need to becoming more competitive by reducing energy costs and
- capital investment constraints.

Profit

Significant financial gain can be achieved through reducing energy costs. Implementing energy efficiency projects and an energy management programme will increase profits. Evidence of this is presented in Section 2.4 – “Energy cost savings – Experiences from energy programmes”.

Greenhouse gas emission reduction

Human activities have added 925 billion tons of CO₂ to the atmosphere as well as other greenhouse gasses (GHG's) such as methane and nitrous oxide (Flavin, 1998). These additional gasses intensify the greenhouse effect of Earth's atmosphere, and may cause predicted global warming of 1°C by 2025 and 3°C by 2100 (IIEC, 1996), more severe weather conditions and rising sea level (0,65m by 2100). In 1998, South Africa produced 1,7% of the world's carbon emissions (Grobler & Den Heijer, 2001). The whole of Africa produced approximately 4% and the USA approximately 24%. Contributions to CO₂ emissions by sector in South Africa for 1994 (Howells & Solomon, 2000) are shown below.

Figure 3 - %CO₂ emissions for South Africa by sector (1994)

From Figure 3, notably the three largest sources of CO₂ emissions are 'Energy - public electricity and heat production' (46.67%), 'Energy - fuels and other' (15.12%) and 'Manufacturing industries and construction' (14.42%). Together, these three sectors of South African industry contributed 76.21% of CO₂ emissions in 1994.

Also noteworthy is that 'public electricity and heat production' also produced 72% of CH₄, 100% of N₂O, 99% of NO₂, 82% of CO and 55% of SO₂ in 1994. Coal mining produced 21% of CH₄, road transport produced 13% of CO and 91% of non-methane volatile chemicals. 74% of all SO₂ was emitted by 'energy' industries (Howells & Solomon, 2000).

The problems of global warming and greenhouse gas emissions have necessitated an international, collective effort that has resulted in the Kyoto Protocol. Forged by 167 nations in December 1997, the Protocol marked the first international attempt to place legally binding limits on greenhouse gas emissions from developed countries. Countries that ratify the agreement (Annex B countries) must seek to achieve emission reduction targets and must develop a legal instrument through which greenhouse gas emissions can be monitored and reduced. On average, the Protocol requires a reduction of fossil fuel emissions of 5.2% below

1990 emission levels. South Africa ratified the Protocol on 13 March 2002, but has not yet negotiated an emission reduction target.

Mechanisms have been built into the Protocol to promote flexibility and cost-effectiveness for developed nations and to provide incentives for developing countries to participate in global emissions reductions without being compelled to do so (Cameron, 2000). These mechanisms are:

- Emission trading - where an Annex B country with excess emission credits may sell emission credits to another Annex B country.
- The Clean Development Mechanism (CDM) - allowing industrialised countries to meet their emission objectives through implementing emission reduction projects in developing countries
- Joint Implementation projects - where Annex B countries may work together to meet their emission targets
- The use of emission sinks - where CO₂ is removed from the atmosphere and stored in plants. Projects include forest preservation, forest enhancement through management and the creation of new carbon sinks (plant-rich areas).

These mechanisms, particularly the CDM are potentially valuable sources of funding for energy efficiency projects in South African industry. In the Journal of Energy in South Africa (May 2001), Grobler and Den Heijer state that: "The sector that holds the greatest potential for emission reductions and energy efficiency improvements is the industrial sector, ... (being) responsible for almost 63% of carbon emissions."

To enter into force, at least 55 nations representing 55 percent of the industrial world's 1990 emissions must ratify the Kyoto agreement. At this stage (August 2003), 111 countries have ratified, accepted, approved or acceded (59 have ratified) however these countries so far only represent 44,2% of GHG emissions. The USA (contributing 36% of GHG emissions) has refused to ratify the agreement. President George W Bush has

refused because he believes it would damage the USA economy, and also because it does not yet require developing countries to cut their pollution in the way developed countries must. At this point it is worth noting that: "Eleven Chinese people and twenty-three Indians have the same CO₂ impact as just one American." (Prospex Research Ltd, 2003). The Russian Federation (17,4%) has also so far refused to ratify.

The European Union is under pressure to either "persuade" the USA to reconsider, or to push forward for ratification of the agreement without the USA. If the USA chooses not to ratify, they will most likely face economic pressure (environmental sanctions) from the group of countries who have ratified the agreement and are not prepared to accept unfair competition.

The competitive edge

The opening up of world markets has provided new buyers for South African products but at the same time has introduced new international competition. Developed countries, such as those belonging to the Organisation for Economic Cooperation and Development (OECD), have been steadily improving the energy efficiency of their economies over the past 25 years. In contrast, developing and transitional economies have become less efficient - through rapid industrialisation and investment in inefficient technology.

In their report (IIEC, 1996 p4) for the U.S. Initiative on Joint Implementation, the IIEC point out that..."Developing country industries will not be able to compete when their outdated factories consume three times as much energy as more modern facilities" ...and ..."efforts to cut energy costs and remain competitive are creating lucrative (energy) markets."

The following graph (Figure 4) illustrates how energy intensities of undeveloped countries have been steadily increasing while intensities of developed countries have been declining between 1970 and 1992.

Figure 4 - Energy Intensities by region (1970 - 1992)(Source: IIEC, 1998)

Key: LAC Latin American countries

CEE Central & Eastern Europe

FSU Former Soviet Union

OECD Organisation for Economic Cooperation and Development

Capital investment constraints

The public electricity supply company, Eskom, expects that R100 billion of new investment will be required over the next 25 years (Chalmers, 2001).

At the same time, the government wishes to privatise Eskom by 2004. In response, Eskom has chosen to invest in energy efficiency projects and demand side management in order to delay the need for investment in more generating capacity.

It is predicted that current installed capacity will not meet the projected demand in 2007 and it is intended that demand-side management (negotiated load interruption, load management and reduction) will delay the 2007 deadline to somewhere between 2015 and 2025 (Bennett, 2001).

The Bonesa initiative is a load reduction project that is a joint venture between Eskom, Africon Engineering International and Umongi-Karebo. It aims to penetrate the South African lighting market with 31,5 million compact florescent light-bulbs (CFL's) that use 75% less energy and are said to last up to ten times longer than incandescent bulbs (Bennett, 2001).

On the side of managed load interruption, Eskom (in Johannesburg) currently controls 10 000 domestic electric water heaters in Cape Town. Eskom offers consumers the choice of 40 different control regimes, which determine the periods when the electrical supply to the water heaters is interrupted (Bennett, 2001).

Projects that receive financial support from Eskom need to be closely monitored and the energy savings verified in order that Eskom can be sure that the investment is worthwhile and so that repayment of capital costs from a portion of the company's energy savings can be calculated.

2.3 Barriers to energy efficiency in South African Industry

The potential for significant energy cost savings through improved energy efficiency has been shown in thousands of case studies conducted in the USA and UK and several in South Africa. Despite this record, industry often resists the adoption of energy efficiency.

Research by Kirsch, et al (1996) into the reasons for rejection of energy conservation opportunities by 3612 small and medium manufacturing plants in the USA from 1984 to 1993 showed the following reasons for rejection in 1993:

- 43% was due to *unacceptable financial risk* (unsuitable investment return, high initial cost and insufficient cash flow);

- 25% was due to *postponement* (still considering after two years);
- 11,5% was due to *unacceptable plant/person risk* (personnel safety, production rate or quality jeopardised, or unacceptable inconvenience);

No comparative study was found for South African industry, however, in a paper presented at the United Nations Educational Scientific and Cultural Organisation (UNESCO) 2001 workshop on "*Energy Efficiency in Africa for Sustainable Development*", Bennett describes five reasons for resistance to the implementation of energy efficiency opportunities in South Africa. Some of these reasons are quite possibly the 'reasons behind the reasons' stated by Kirsch et al. They are:

1. *Attitude: "I know my business best".* "No one can tell me how to run my business. No one outside the industry understands my energy problems like I do. I will appear incompetent if outsiders identify savings that I have not seen".
2. *Resistance to change.* "Everything is going along just fine. Why must we continually be changing and trying new things that will probably not work anyway?"
3. *Energy is too cheap.* Many users see energy as a minor input cost, relative to raw material and labour, and tend to concentrate on these. Very often, education and examples can provide the incentive for these users to take another look at energy.
4. *Lack of capital.* Some energy efficiency measures involve the installation of expensive capital equipment. Users are nervous that the promises made by zealous salespersons may not be realised. Once again, education and objective information can go a long way to overcoming these misgivings.
5. *Uncertainty regarding the future.* Investors are sometimes reluctant to commit resources to long-term projects, given the financial instability both internationally and within regions. Payback periods need to be measured in terms of months rather than years, and this

can exclude energy efficiency investment opportunities. The lack of long-term commitment has been an on-going problem in Africa with many investors seeing better business opportunities in other regions of the world.

The reasons for resistance to implementation of energy conservation opportunities (including energy management) could be addressed in the following ways:

- Provide education (training) around energy issues
- Create capacity for energy auditing, monitoring and management.
- Disseminate information regarding best practices.
- Use benchmarking, where the specific energy use of competitors is made known (anonymously) for compared within the industry (locally and internationally).
- Shift risk from the plant to the proposer/contractor of the project (capital cost being repaid from a portion of the realised energy cost saving).

2.4 Energy cost savings - Experiences from energy programmes

A number of energy efficiency programmes have shown that significant savings can be made.

In 1980, the UK Department of energy initiated a programme that aimed to install effective energy management systems at a quarter of all UK industrial sites that used more than 26 000 GJ/year. By the end of the programme in 1991, 700 energy information systems had been installed in 22 sectors. By 1987, overall annual savings of \$ 120 million had been achieved and were forecasted to rise to annual savings of \$ 640 million by 1995. Some of the *average* percentage energy cost savings for the

sectors were 9% (paper and board), 12% (non-ferrous metals), 13% (food) and 17% (textile finishing) (Caffall, 1995).

A programme in the USA provided technical assistance (energy assessments) from university engineering faculties to 3 612 small and medium sized industrial plants in the USA from 1984 to 1993. Implemented energy savings averaged \$19 250 to \$20 418 per plant per year over the ten-year period. The gross sales for these plants averaged \$16,4 million to \$31,0 million over the period. *Annual* recommended energy conservation as a percentage of consumption declined from 9,97% to 5,24% over the period. (Kirsch et al, 1996 p4) (Disappointingly, *implemented* savings averaged from 5,4% to 2,1%. The reasons for this resistance are discussed in Section 2.3).

Predictably, both the UK and US programmes showed a steady decline in energy savings as a percentage of consumption. As the industry became more efficient, the opportunities for efficiency improvements were reduced - which leads one to the question: "At what stage of 'efficiency development' is South Africa?"

A project to gather and package information on energy efficiency in SA, using three case studies in different industries, was undertaken by the Energy Research Institute (ERI) at UCT. The results show that leading players in SA industry have found room for efficiency improvement. Energy cost savings for South African Brewery's Prospecton plant were R1 370 000/annum (8% of annual energy costs) with a required investment of R1 180 000 giving a payback of ten months. Energy cost savings for Anglogold's Elandsrand gold mine were R1 990 000/annum with a required investment of R1 293 000 and a payback of eight months. Sappi's Mandini plant was able to save R5 550 000/annum in energy costs (5% of annual energy costs) from an investment of R3 220 000, giving a payback within seven months.

The case study in this thesis is of a motor vehicle manufacturing plant and another case study from the same sector shows impressive results. The Rover Group in the UK adopted a strategic approach to energy management and managed to reduce their energy consumption per vehicle by 26% during the 1990's. These cost-saving benefits have also reduced carbon dioxide emissions per vehicle by 30% (DETR, 1999 p8) Energy Efficiency Best Practice Programme)

There appear to be opportunities for significant energy savings through energy efficiency improvement in SA industry.

2.5 Energy management

Efficient energy management is essential for South African industry if we wish to make a success of energy efficiency projects. A successful energy management system should also remove some or all of the barriers (as discussed in Section 2.3).

This section provides a structured approach to the implementation of an energy management system. It shows that an energy assessment can be seen as an energy management tool. Conversely, experience from the case study will show that in the absence of an energy management system, an energy assessment is quite likely to initiate action towards the establishment of such a system.

Evaluating current energy management

An energy management matrix such as that shown in Figure 5 (next page) helps an organisation to identify the extent of their energy management practice, and gives them an opportunity to identify where they need to improve. A consistent score is desirable across all the criteria - the aim is to raise the score for each criterion up to the level of the highest scoring criterion.

Score	Energy Policy	Organising	Motivation	Information Systems	Marketing	Investment
4	Active commitment of top management	Fully Integrated into general management	All staff accept responsibility for saving energy	A comprehensive system with effective management reporting	Extensive marketing within and outside organisation	Positive discrimination in favour of energy efficiency
3	Formal Policy but no commitment from top management	Clear delegation and accountability	Most major users motivated to save energy	Monthly monitoring and targeting for individual sections	Regular publicity campaigns	Same appraisal criteria used as for all other investment
2	No policy Adopted	Delegation, but line management and authority unclear	Motivation patchy and sporadic	Monthly monitoring and targeting by fuel type	Some ad-hoc staff awareness training	Investment with short term payback only
1	Unwritten set of guidelines	Informal, part-time responsibility	Some awareness of importance of energy saving	Invoice checking	Informal contact used to promote energy efficiency	Only low cost measures taken
0	No explicit policy	No delegation of energy management	No awareness of the need to save energy	No information system or accounting for consumption	No marketing or promotion	No investment in energy efficiency

Fig. 5: Energy Management Matrix (Source: Good Practice Guide 84, 1993)

Critical factors for an effective energy management programme are:

- 1) Obtain top management commitment
- 2) Create an energy policy
- 3) Obtain commitment from all employees
- 4) Set up communication channels
- 5) Change or modify the organisation to give authority and responsibility for the conservation effort and develop an energy management programme.
- 6) Set up a means to monitor and control the programme.
- 7) Investment
- 8) Energy Assessments

Obtain top management commitment

The commitment of top management is essential for ensuring investment in energy efficiency projects and for providing a powerful source of leadership and motivation for the programme within the organisation. This commitment should be a formally communicated, financially supported dedication to improving energy efficiency while maintaining or improving the functioning of the facility. The commitment should be active and clearly communicated to all levels of the organisation. For this purpose, an energy policy is required.

Create an Energy Policy

An energy *policy* states what an organisation intends doing about energy management and the goals that they hope to achieve. An energy policy is not the same as an energy *strategy*. The *policy* defines *what* the institution intends doing regarding energy whereas the *strategy* determines *how* it will be accomplished. An energy policy should be a concise document (one page) and has three essential components:

- 1) *A Declaration of Commitment* - where top management declares that the management of energy will be sustained and supported as one of the many vital activities within the institution. For example:

"As an integrated part of its environmental policy, Total Refrigeration Limited is committed to responsible energy management and will seek to utilise energy efficiency throughout all its premises, processes, plant and equipment"

(www.totalrefrigeration.co.uk)

- 2) *A Mission Statement* - where the focus of the energy management programme is specifically defined. For example:

"Total Refrigeration Limited will seek to:

- *avoid unnecessary expenditure*
- *improve cost effectiveness, productivity and working conditions*
- *protect the environment*
- *prolong the useful life of fossil fuels"*

(www.totalrefrigeration.co.uk)

3) *Programme Goals* - where the specific objectives of the institution (in order to achieve the mission statement) are determined. The goals will eventually determine whether the energy management programme has been successful or not. For example:

"Our long term objectives are to:

- *buy fuels at the most economic cost*
- *burn and use them as efficiently as practicable*
- *reduce the amount of pollution, particularly CO₂ emissions, caused by our energy consumption*
- *reduce, wherever possible and practicable, our dependence on fossil fuels through the use of ambient and renewable energy"*

(www.totalrefrigeration.co.uk)

A quantifiable target may also be included in the goals. Once a set target has been reached, a new target can be set either along the same line or towards another objective of the energy management programme.

Obtain the commitment of employees

An energy management programme requires the participation and interest of people at all levels of the organisation. Energy saving ideas must be encouraged with rewards for significant contributions to the programme. Pride is generated in employees when they feel that they are partners in the planning and implementation of a programme that achieves positive results.

The formation of working teams to address specific energy issues can be highly successful. Once the problem is solved, the team is dissolved. For example, a four-person team at Land Rover encouraged paint shop staff to adopt attitudes of ownership and responsibility by rescheduling paint plant operations. As a result, savings of £6 000 per week were achieved, equating to more than £300 000 per year (DETR, 1999 p6). The importance of energy teams is also emphasised by Mashburn in his article *"Planning for an effective energy management programme"*. According to

Mashburn, energy teams are "the core of the programme" and teams should:

- be appointed for a specific time period, such as one year. Annual membership rotation can allow new people with new ideas to participate, provides a mechanism for tactfully removing non-performers, and involves greater numbers of people in the programme in a meaningful way.
- be selected to supplement skills the energy manager lacks. It is unrealistic to think one energy manager can have all the skills.
- have enough technical knowledge to understand the technology used by the organisation, or be trained in that technology
- have a knowledge of potential new energy-saving technologies
- have planning skills that will help establish the organisational structure, plan energy surveys, determine educational needs, and develop a strategic energy management plan
- Understand the economic evaluation system used by the organisation, particularly payback and life-cycle cost analysis
- have good communication and motivational, skills since energy management involves everyone within the organisation

Competition between sections can also generate enthusiasm.

Competitive programmes can be initiated and should be encouraged.

Acknowledgement of good ideas, positive reinforcement of good performance and encouragement of teamwork is essential. A clear, concise list of firm do's and don'ts to guide employees in their work can be helpful in improving energy conservation practices. These lists should be updated as often as necessary.

Employee participation can be increased by communicating examples of energy conservation ideas being implemented, photographs of employees who submitted the ideas, and information on the savings realised.

Effective communication channels are essential.

Set up communication channels

The purpose of these channels are to:

- report to the organisation the results of their efforts
- recognise high achievers and to identify reward recipients.
- advertise the programme and to encourage co-operation

The different *media* available that can be used as communication channels are:

- face to face discussion
- seminars and workshops
- distribution of informative and descriptive literature (newsletters, bulletin boards, email and intranets)
- industrial theatre
- the workplace (management leading by example)

Develop an organisational plan

An organisational plan should then be developed for both implementing and monitoring specific energy management programmes. This plan should address the criteria as identified in the energy management matrix. also, the plan must:

- define the responsibility of the energy management co-ordinator or committee;
- describe an effective communication system between co-ordinator, section managers and other employees;
- establish an energy accounting and monitoring system;
- provide the means for educating and motivating all employees (management training, energy team training and training for other employees)

Experience has shown that a 1-2% reduction in consumption can be achieved after meters are installed just by letting users know that they are being monitored. Up to a 5 % total reduction can occur when users then become proactive in better managing the use of their energy (Caffall 1995).

Investment

A result of the environmental concerns discussed in Section 2.2, is that there is growing pressure for corporate environmental responsibility to be demonstrated. Management will increasingly need to show a positive discrimination in favour of a “green investments” which would include energy efficiency.

At least, efficiency projects need to be appraised for their savings potential just as productivity improvement projects are appraised for their income - generating potential.

Energy Assessment

An energy assessment determines where and how energy is being used. It identifies measures to improve efficiency and provides a benchmark against which future efficiency can be compared. Conducting a successful energy assessment involves

- Following a methodical auditing procedure
- Determining a pattern of energy use:
 - by making use of effective instrumentation
 - from available records
 - by calculation and or estimation
- Identifying energy conservation opportunities (ECO's)
- Estimating and calculating energy and energy cost savings if the ECO's were implemented, as well as implementation cost and payback period.

The assessment can be split into two stages:

The *preliminary assessment* aims to :

- identify the types and overall quantities of energy used (from existing records)
- identify the main energy using equipment
- identify areas where significant savings could be made (ECO's) and which require detailed investigation
- provide an estimate of the savings, implementation cost and payback period that could be expected from implementing the identified efficiency improvements

The *detailed assessment* involves:

- collection of detailed information on chosen ECO's
- monitoring energy use over a suitable period if necessary
- analysing results (identify seasonal tendencies, unusual changes, base loads and peak loads)
- quantifying energy savings, energy cost savings, implementation cost and payback period
- presenting the results and providing recommendations for implementation of projects in an *assessment report*

Following the assessment report, a *monitoring and verification plan* will be necessary that describes:

- How energy consumption should be measured and recorded
- How the baseline energy consumption (if the project was not implemented) is determined (and adjusted)
- How the energy cost savings are calculated

If the company has an energy management system in place then the monitoring and verification process should slot into the existing system. If not, then this is the time to initiate *an energy management plan* for the company.

2.6 Efficiency improvement through technology

Much information is freely available (particularly from the internet) on methods of improving energy efficiency in industrial plants. For SA industry, a comprehensive set of handbooks (See Bibliography) titled *How to save energy and money* has been produced by the ERI at UCT.

This thesis will not include a detailed presentation of these methods (since they are readily available in print). However, the energy conservation opportunities that are presented in the case study do have detailed explanations of the methods used for each opportunity, as well as energy cost saving calculations. A summary of the main areas for energy saving in industry are listed below:

- Boilers and furnaces - optimising combustion efficiency, choosing the most economical fuel, boiler/furnace selection, flue gas heat recovery for combustion air or feed water, and insulation (3E Strategy Guidebook 2, ERI)
- Steam systems - 'blowdown' minimisation and blowdown heat recovery, steam pressure optimisation and pipe sizing, efficient condensate return and air removal by steam traps, design for efficient heat transfer, insulation of pipes, repairing steam leaks, heat exchangers and vessels and flash steam recovery (3E Strategy Guidebook 5, ERI)
- Thermic fluid heaters for transferring heat from combustion to a working fluid (like 'thermic oil') - similar to boilers and furnaces
- Electrical systems - power factor correction, reducing maximum demand costs by tariff analysis and load shifting, monitoring and targeting (3E Strategy Guidebook 1, ERI).
- Electric motors - motor starting methods to avoid or reduce the impact of high starting current, use of high efficiency motors, use of star windings for lightly loaded motors, using speed control (variable speed

drives or multiple speed motors) to control flow instead of throttling, better motor maintenance.

- Process heat confinement - installing/repairing/increasing insulation on equipment surfaces, covering heated tanks with floating insulation, adding covers or curtains at equipment openings (Clark & Birkmire, 1999).
- Lighting - reducing lighting time (switching off, occupancy sensors), optimising lighting levels, making use of natural light, using high efficiency luminaries, improving light utilisation, improving maintenance (3E Strategy Guidebook 1, ERI).
- Refrigeration - maintenance and design of insulation, monitoring performance, increase evaporator temperature to increase system coefficient of performance (COP), reduce condensing temperature to increase COP, high efficiency compressors, avoiding part-load operation of compressors and pumps (3E Strategy Guidebooks 4 and 6, ERI).
- Pumps - pump and impeller selection, pipeline design for lower resistance, flow rate control (3E Strategy Guidebook 1, ERI).
- Fans - selection, minimising duct restrictions (no dampers and sharp bends), not exceeding demand, minimising leaks, use of variable speed drive's where needed, minimising belt slippage.
- Compressed air systems - reducing demand (use, misuse and leaks), using outside (cool) air for compressor intake, efficient distribution, avoiding over-treating, compressor selection and sizing, heat recovery, siting compressor close to point of high demand or heat requirement, monitoring efficiency (3E Strategy Guidebook 3, ERI).

- The information obtained from the pre-assessment information form and from the discussions with engineers at the plant during the pre-assessment stage revealed a number of things. Most significantly:
- The plant was large (215 000m² of floor area - excluding administration buildings). Also, on a previous visit to the company, one of the ERI researchers identified significant potential for improving the energy efficiency of their lighting. It became clear that at least two people would be required to collect this (and other) information.
- Electricity, heavy fuel oil (HFO), liquid petroleum gas (LPG) and paraffin were the three main fuels that were consumed. The central ovens would need to be investigated, as these were the major consumers of HFO, LPG and paraffin. Equipment that consumed large amounts of electricity would need to be identified and investigated.
- Provision of compressed air was a problem. They were running at maximum capacity and consumption had been steadily increasing at a rate that did not tie in with production.

Measuring Equipment

In preparation for the on-site assessment, the following equipment was assembled:

- A three-phase electrical data-logger - for if sections of the plant or individual equipment needed to be investigated.
- A laptop computer to process data while on-site, and for setting up the electrical logger.
- An ultra-sonic leak detector for locating compressed air leaks (later found to be completely unnecessary because the leaks were large and easily audible). To obtain a reasonable estimate for leakage rates from individual leaks, a large plastic bag of known volume was placed over the leak and the time for complete inflation was measured. While this method was unsophisticated and in some instances provided much humour, it did also provide a reasonable estimate. It must be noted

that tables of air loss against hole-diameter are useful for creating awareness around air leaks but can seldom be used for estimating real air leaks (holes in pipes and fittings are seldom cylindrical).

- Thermometers for fluid temperature measurements were used in the investigation into the main water-cooling plant)
- A tachometer for measuring electric motor rotational speed for efficiency calculations (Not used because thermal, compressed air and lighting efficiencies took the lions share of time and focus.)

The On-site Assessment

The *on-site assessment* spanned a period of seven days. It was led by the author with assistance from another student from the ERI. The goals for this week were to:

1. establish good working relationships with the plant personnel
2. understand the production processes
3. identify opportunities for significant energy and energy cost savings
4. collect sufficient data so that these potential savings could be quantified

Good records of energy consumption and production were obtained from the plant and the only areas where data had to be recorded were for lighting (lux levels, numbers and location of lights and skylights), compressed air (estimates of individual leaks) and cooling-water (flowrates and temperatures).

The following short diary records the main activities over this period.

Day 1

- Introductions to the engineering manager, engineers in his department and to plant section managers.
- Walk-through of the entire plant and explanation of the production processes.

- Meeting with the engineering manager (Agenda: Known areas of energy wastage, focus areas for efficiency investigations, previous energy efficiency investigations, intended programme for investigations in the week ahead.)

Day 2

- Read reports on previous investigations into maximum electrical demand and the compressed air system. (The compressed air report was not entirely credible according to the plant engineer).
- Recorded light level readings (lux levels) and audited the position and number of lights) in the Engine Plant. Findings: Many skylights were very dirty, which reduced indoor natural light significantly. Indoor light levels varied between vastly insufficient and way too much light - mostly because of differing success in the use of natural light. Polycarbonate skylights degrade far slower than fibreglass and attract/retain far less surface dirt. Personnel in the Engine Plant said that they had complained about the dirty skylights several times but nothing has happened.
- Investigated compressed air leaks in the Press Shop. Found many large leaks above and below presses. Estimated that two continuously open blow-down hoses were together wasting about 400cfm.

Day 3

- Met with engineers (Agenda: Strategy for the rest of the week (in particular the measurement of compressed air into the press shop) Outcome: Engineers would set up their own logging equipment for days 4, 5 and 6.
- Met with the Process Department Manager. Topics of discussion: Thermal and chemical processes in the Paint Shop; water consumption and effluent generation.
- Went into main substations to confirm placement of recording devices and plant electrical layout.

- Measured light levels and audited lights at Final Assembly. Findings: Light levels were generally higher than necessary. Found several large compressed air leaks and several large fans running unnecessarily.

Day 4

- Engineers indicated that they would only be able to install the compressed air monitoring equipment in a few weeks time because they were struggling to get the instrument to work.
- Audited lights in the Body Shop and completed lighting audit at Final Assembly.
- Checked amp readings of the four main feeders and the incoming supply at the main substation.
- Investigated compressors at Main Compressor House and in the Engine Plant and also investigated water coolers outside the Main Compressor House.
- Measured light levels at the Body Shop and investigated reasons for different levels of light.
- Conducted a walk-through energy audit of the Press Shop, the Body Shop and the ground floor of the Paint Shop (looking for energy wastage of all types as well as high energy-using equipment - particularly compressed air leaks, excessive lighting, large compressors, fans, pumps and motors)

Day 5

- Investigated specifications of lighting used in the plant.
- Investigated Paint Shop Electro-coating bath heating.
- Continued the investigation into the water-cooling system at the Main Compressor House
- Investigated switching for all lights and personnel-cooling fans.
- Looked for air leaks at the Assembly Plant.

Day 6

- Measured light levels and audited lights inside the Container and Pressed Part
- Conducted a walk-through energy audit of the Assembly Plant.
- Measured light levels in the Press Shop
- Photocopied all necessary drawings and machinery specifications.

Day 7

- Located and quantified air leaks and air wastage in the Paint Shop.
- Measured transmission of light through clear polycarbonate, new translucent polycarbonate (steel store at end of press shop), clean fibreglass and dirty fibreglass

The analysis stage

After the seven-day on-site assessment the analysis stage began. Further information was obtained from the plant engineers via fax, telephone and e-mail, but the plant was a three-hour air flight away and effectively no longer accessible. The good working relationships established with the plant personnel during the on-site assessment proved to be invaluable.

Energy consumption and production data was processed in order to show and analyse the patterns of energy use and production in the plant.

Opportunities for significant energy and energy cost savings were identified, savings were calculated and recommendations were presented.

The contents of the document needed to be accessible to non-engineers (accountants, managers and directors with a non-technical background) so every effort was made to present energy conservation opportunities in an easily readable format. The layout was based on the *IIAC - Model report of an industrial assessment* (Clark, W., et al. 2000).

The assessment presentation to management

After sufficient time had elapsed for management to have had access to the report, a presentation was arranged. The purpose of the presentation was:

- to inform management of the issues (if they had not had the time to read, or had not had access to, the report).
- to get feedback from a wider group of managers, directors and engineers around these ECO's. (Only the engineering manager had provided feedback up to this point.)
- to decide on how to approach the implementation of the ECO's and the monitoring and verification of energy savings.
- to find out what sort of management systems (chain of authority, financing of projects, budgets, quality systems, training, communications and personnel) were in place and what could be done to improve energy management within the company.

The results of the presentation are shown in Section 3.2.3 - Outcomes of the assessment presentation to management.

3.2 Assessment Results

The company manufactures passenger cars and light commercial vehicles. Approximately 5 500 employees are involved in the production of about 80 000 vehicles per annum.

The average energy consumption and associated costs at the plant are summarised in Table 2 below.

Energy type	Usage (1 TJ = 1×10^{12} J)	Annual Cost
Electricity (kWh)	97 277 000 kWh per year 350,2 TJ per year	R 14 688 827
Electricity (kVA)	17 744 kVA per month energy value not applicable	R 6 218 157
HFO	4 536 893 litres per year 162,9 TJ per year	R 6 319 892
LPG	3 459 934 litres per year 96,1 TJ per year	R 8 393 800
Paraffin	847 484 litres per year 30,3 TJ per year	R 2 067 981
Totals	638,5 TJ per year	R 40 551 224

Table 2 – Average energy consumption and associated costs

A summary of the energy conservation opportunities and their associated savings, implementation costs and payback periods, is shown in Table 3 on the following page. The energy conservation opportunities recommended and described in this report represent a total value of approximately R 15 000 000 per year. The savings as listed for each opportunity are the savings achievable when implementing each opportunity independently. Some of the recommended measures overlap with respect to savings (also ECO 9a and 9b are mutually exclusive), therefore actual cost savings will be less than the total value of R15 000 000 (more likely in the region of R10 000 000).

Table 3 – Energy conservation opportunities - recommendations and results									
	Description	Electric energy conserved (kWh/year)	Electrical demand reduction (kVA)	HFO conserved (litres)	LPG conserved (litres)	Paraffin conserved (litres)	Potential savings (R/year)	Implementation cost (R)	Simple payback (years)
ECO 1	Repair compressed air leaks and faulty blow-down valves to achieve a 10% leakage target	8 001 500	1 080				1 262 000	60 000	0,04
ECO 2	Avoid and discourage misuse of compressed air (blowdown valves and paint-mix room)	1 292 043	174				263 189	30 000	0,1
ECO 3	Switch off ER compressors and main cooling towers during non-production time	1 699 908					268 075	zero	zero
ECO 4	Isolate areas of the plant or individual machines that do not require compressed air during non-production time	1 394 403					219 896	40 000	0,2
ECO 5	Install suitable power factor correction equipment		1 516				516 690	1 007 500	2,0
ECO 6	Use waste heat to heat phosphate bath			136 000			190 000	300 000	1,6
ECO 7	Install high efficiency lighting	2 110 783	3 072				179 803	628 198	3,4
ECO 8	Turn off bay lights during non-production hours	2 672 657					446 190	included	zero
ECO 9a	Install direct acting electric heaters to air replacement plants serving colour line 1.				tradeoff against electricity		4 355 536	4 000 000	0,9
ECO 9b	Extend existing thermic oil/HFO system to supply the ARP (HFO instead of gas)				tradeoff against HFO		4 656 666	19 000 000	4,1
ECO 10	Make use of heat pump heat recovery between ARP exhaust and supply air streams				1 313 843		3 187 385	2 750 000	0,9

3.2.1 Trends in Production and Energy Use

The following graphs show the trends in production and energy use.

Monthly production is compared to total energy costs in Fig 6 below. The dip in production for August 2001 resulted from a weeklong labour strike. The three-week shutdown over December and January also caused a predictable dip.

Fig 6 - Production and Total Energy Cost

From Fig 6 above, the ratio of Total energy cost / Production, ranges from R 680 / vehicle in August to R 351 / vehicle in November. This large difference is due to the impact of seasonal temperature differences on thermal heating requirements of the production process. The effect of seasonal temperatures can be seen in the consumption graphs for HFO and LPG later in this section. The relatively high energy cost /production ratios for December and January are due to two factors. Firstly, the three-week shutdown over December and January causes lower production during these months. The second factor is that energy is still used through the shutdown period for compressed air, air conditioning, ventilation and lighting

Monthly electrical energy consumption, maximum demand, and costs for the plant are shown in Figures 7 to 10.

Consumption of electrical energy (Fig 8) is relatively unaffected by seasonal change (temperature) – possibly because any extra electrical energy used directly or indirectly in heat generation in winter is offset by energy used for air conditioning and process chilling in summer. Also, cooling towers, that run permanently, draw the same amount of energy all the time (whether there is a cooling load or not) The December-January shutdown results in a predictable drop in electrical energy use during these months.

Fig 7 - Electrical Energy Use - Aug 00 to Jul 01

Maximum electrical demand is shown in Fig 8 (following page).

Fig 8 - Maximum Electrical Demand - Aug 00 to Jul 01

Maximum electrical demand is measured as the highest recorded kVA demand in any thirty minute period in a month. A portion of the demand should be related to the maximum intensity of production during that month and a second portion made up of non-production-intensity related kVA demand. There is little seasonal variation in the maximum demand figures.

Plant-wide intensity of production for any hour (or even day) of the month is difficult to quantify. Final production figures are based on vehicles leaving the Final Assembly section and these figures are not necessarily related to the intensity of production in the rest of the plant. Nevertheless there is a small measure of correlation when maximum daily final production is compared to maximum demand for that month (Fig 9 below).

Fig 9 - Maximum Demand vs. maximum daily production

One pattern that stands out fairly clearly is that maximum demand/production intensity ratio is comparatively greater in summer – probably due to a larger base load (air-conditioning and ventilation, refrigeration units and water cooling towers).

Electricity costs (Fig 10) echo the kVA and kWh consumption. Maximum demand (kVA) costs are clearly unrelated to electrical energy (kWh) costs – in the same way that intensity of production in a particular day is unrelated to the overall production figure for that month.

Fig 10 - Electricity Costs - Aug'00 to Jul'01

Figures 11 and 12 show LPG consumption and costs. The use of LPG (entirely for thermal heating) shows large seasonal fluctuation. This close relationship to seasonal temperature fluctuations suggests that there may be opportunities to reduce energy losses through insulation improvement or through conservation and re-use of waste heat. The condition of insulation in the HFO and LPG systems appeared to be acceptable which implies that attention should be given to opportunities for use of waste heat. On average, about 150 000 litres are used during the warm summer months and about 400 000 litres are used in winter. This means that an extra 250 000 litres per month are required in winter to make up for a seasonal temperature drop of about 15°C.

Fig 11 - LPG Consumption - Aug'00 to July'01

Costs have been calculated at a fixed price of R2,426 / litre.

Fig 12 - LPG Costs - Aug'00 to July'01

Figures 13 and 14 show HFO consumption and costs. Again, the seasonal change in the consumption of HFO suggests that there are opportunities for thermal energy conservation (ensuring sufficient insulation and the use of waste heat wherever possible).

Fig 13 - HFO Consumption - Aug'00 to July'01

Costs for HFO have been calculated at a fixed price of R1,393 / litre.

Fig 14 - HFO Costs - Aug'00 to July'01

Figures 15 and 16 show paraffin consumption and cost. Consumption figures for paraffin do not show any meaningful trends. It is likely that the consumption data refers to bulk quantities of paraffin transferred (from one tank to another) and not paraffin used in a particular month.

Fig 15 - Paraffin Consumption - Aug'00 to July'01

Costs for paraffin have been calculated at fixed prices of R2,675 and R2,262 / litre, for Fluiden 1520 and illuminating paraffin respectively.

Fig 16 - Paraffin Costs - Aug'00 to July'01

Figure 17 shows the total energy costs for Plant A. Electrical energy is the largest energy cost, closely followed by LPG in the winter months. Maximum electrical demand is consistent throughout the year. When taken together (as fuels for thermal heating) LPG and HFO are particularly significant during the winter months, as opposed to the summer months.

Fig 17 - Energy Costs by fuel type - Aug'00 to July'01

3.2.2 Energy Conservation Opportunities

The following energy conservation opportunities (ECO's) were identified.

The details of these ECO's are presented in this section. Separate recommendations have been prepared for each ECO.

ECO	Description
1	Repair compressed air leaks and faulty blow-down valves to achieve a 10% maximum leakage target
2	Avoid and discourage misuse of compressed air.
3	Switch off ER compressors and main cooling towers during non-production time.
4	Isolate areas of the plant or individual machines that do not require compressed air during non-production time.
5	Install suitable power factor correction equipment.
6	Use waste heat to heat phosphate bath.
7	Install high-efficiency lighting.
8	Turn off bay lights during non-production hours.
9a	Install direct acting electric heaters to air replacement plants serving colour line 1.
9b	Extend existing thermic oil/HFO system to supply the ARP (HFO instead of gas)
10	Make use of heat pump heat recovery between ARP exhaust and supply air streams

The following additional items have also received consideration and are presented from Section 3.2.2. Further investigation into these AIC's is recommended.

AIC	Description
1	Identify and switch off equipment that is not essential during non-production time.
2	Spread electrical demand to reduce peak kVA costs.
3	Make use of water from effluent plant to reduce water consumption and effluent costs.
4	Install skylights and photosensor light controls

ECO 1 - Repair compressed air leaks and faulty blow-down valves to achieve a 10% leakage target

Estimated electric energy conservation:	8 001 500 kWh / yr
Estimated electric energy cost savings:	R 1 261 836/ yr
Estimated electric demand reduction:	1 080 kVA / mo
Estimated electric demand cost savings:	R 368 064/ yr
Estimated total cost savings:	R1 262 000 / yr
Estimated implementation cost:	R 60 000
Simple payback:	2 weeks

Recommended Action

Repair leaks and faulty blow-down valves in compressed air lines on a regular basis with the aim of reaching a 10% leakage rate.

Background

Two previous investigations by 'Pascal Projects' have identified the base load (waste) of the main compressed air system as a major cause of wasted energy. During this investigation, base demand (outside production hours) was measured at 6 600 cfm¹ from the three ZR compressors (running at full load) and 625 cfm from one ER compressor (topping up) to give a total base demand (waste) of 7 225 cfm. This flow rate was required in order to maintain a pressure of 6,7 bar in the line. These investigations also identified the Press Shop (at 3 269 cfm) and the Paint Shop (at 2 182 cfm) as the areas that contributed the most to the high base demand. These investigations reported that the generating cost to meet the base demand was calculated to be greater than R 1 579 000 per year.

Evidence to support the findings of these two reports was readily available:

- During the assessment week of 6 to 12 August 2001 an extensive list of compressed air leaks (particularly in the press shop) was compiled.

This list is presented below.

1. The unit of cubic feet per minute (cfm) is not an ISO or SI unit, however its use is still widespread in South African industry and the world. It was the unit of choice of the engineers and consultants at VW and was therefore used for their report. Conversion: 1 cfm = 28,317 l/min or 1,699 m³/hr.

- On Thursday 9 August 2001 (a public holiday) when there was no production, the three ZR compressors ran continuously at full load (6 600 cfm). The cost implications of this will be re-examined.

Compressed air leaks

The table of 'Leakage in the Compressed Air System', in Appendix B, is intended as a guide for beginning the process of repairing the air leaks.. Additional leaks are probable and can be most easily detected and repaired by plant maintenance personnel during non-production periods when the hiss of the air leaks will be easier to detect. Huge and large leaks are **bold** printed in the table.

The cost of air leaks

Compressed air manuals set air leakage targets of below 5% for small engineering works and below 10% for heavy engineering in harsh conditions. As mentioned already, during a period of no production, three ZR compressors ran continuously at full load (6 600 cfm). Neither of the Centac compressors were running at that time. Owing to the disruption of the labour strikes during the week of the initial site visit it was difficult to be sure of what represented air demand during production time and non-production time. For this reason, the findings of the Pascal Projects report will be used as a basis for determining potential savings.

The September 2000 base load was measured at 7 225cfm. In order to obtain the amount of air escaping through leaks, the paint mix room requirement (693cfm average) must be subtracted from the base load. This leaves a leakage rate of 6 532cfm. The same report states that maximum demand during production is in the region of 13 000cfm. From these figures it can be seen that leakage accounts for 50% of maximum air demand and the amount of air required for useful production is in the region of 6 500 cfm.

If we wish to reduce leakage to 10% of the maximum demand, the 6 500 cfm used constructively in production would represent 90% of the total air demand and the leakage rate of 10% can then be calculated at 720 cfm. The aim then is to reduce leakage losses from 6530 cfm down to 720 cfm – a difference of 5 810cfm (see diagram below). The target demand would be 7 220 cfm (6 500 cfm plus leakage of 720 cfm).

A rough energy cost saving can be calculated from the cost that is incurred while running compressors necessary to produce 5 810cfm in the plant. The costs to run 2 × ER8 compressors at 2200 cfm each as well as approximately 2/3 of a Centac @ 1 333 cfm is the cost of a 5 810 cfm leak.

The financial implication of this shown in the table below:

Current air maximum demand and calculated cost (cooling excluded)						
units required	compressor (cfm/unit)	delivered capacity (cfm)	total rated power (kW)	kWh / year *	energy saving @ R0,1577 /kWh	demand saving @ R28,40 /kVA ***
2	ER8 (2200)	4 400	672	5 531 900	R 872 380	R 254 464
2/3	Centac 2000)	1 330	300 **	2 469 600	R 389 456	R 113 600
	Totals	5 700	972	8 001 500	R1 261 836	R 368 064

* @ 8232 hours per year (49 weeks/year, 7days/week, 24hours/day)

** 2/3 of 430kW is 286kW, which has been rounded up to 300 kW to include idling power requirements.

*** Total rated power is divided by the overall power factor (0,9), multiplied by 12 (months per year) and multiplied by the demand cost (R32,376/kVA).

The cost of running cooling towers for the above compressors has not been included because the cooling towers of the ER8 compressors are also used for welding tool cooling. Also, the Centac cooling tower would

need to be on because the Centac would be cycling on and off intermittently during production time. A calculated saving of roughly R1 630 000 per year can be expected if the leakage rate is reduced from 50% down to 10% (an amount of about 5 810 cfm).

Implementation Cost

The cost of fixing the leaks is extremely difficult to determine – mainly because it is difficult to be sure of exactly how many leaks there are. Also it must be pointed out that misuse (leaving drain hoses open) will severely hamper any progress towards a lower leakage target. The aspect of misuse is dealt with in the next section.

For the purposes of getting a feel for the advantage of fixing the leaks, if the table of 62 leaks was addressed at a price of R500 per leak the cost would R30 000. Even if double the amount of leaks must be fixed in order to reach the 10% target, the amount of R60 000 required to fix them is small compared to the R 1 630 000 saving. The simple payback period is 0,4 months (2 weeks).

A better way to look at the numbers is to consider what a saving of R1 800 000 would justify in terms of long term action. The calculated saving would appear to justify either regular contracted leak detection and repair services or the full-time employment of several people dedicated to monitoring, detecting and repairing compressed air leaks and preventing misuse.

ECO 2 – Avoid and discourage misuse of compressed air

	Blowdown valves	Paint mix room
Estimated electric energy conservation:	543 310 kWh/yr	748 733 kWh/yr
Estimated electric energy cost savings:	R 85 680 / yr	R 118 075 / yr
Estimated electric demand reduction:	73 kVA / mo	101kVA /mo
Estimated electric demand cost savings:	R 24 993/ yr	R34 441 /yr
Estimated total cost savings:	R110 673 / yr	R 152 516 / yr
Estimated implementation cost:	free	R 30 000
Simple payback:	immediate	0,20 years (2,4 months)

Background

Apart from extensive air leaks, misuse of the compressed air system was evident in some sections of the plant. It must be noted however that the week spent in the plant provided only a snapshot in terms of usual practice in the plant. The engineering and plant personnel are in a better position to determine the level of misuse of compressed air.

In the Press Shop, it was noticed that two blow-down valves were left open for the entire assessment week.

In the Assembly Hall (noticed late Friday night), a valve on a workstation hose (possibly used as a blow-down hose) had been left open. The lever shut-off valve could not be easily reached because it was located about 3m above the floor. The end of the hose had been loosely secured to a nearby column to prevent it from making a noise and flailing around.

It is possible that each of these cases were rectified immediately after the weekend – but it is also possible that the three hoses blow freely for most of each year, 24 hours per day. Evidence to support the latter scenario, is the recommendation, in the 'Pascal Projects' compressed air report, that "manual condensate drains should be closed".

The engineering personnel drew attention to two examples of compressed air misuse in the Paint Shop. Firstly, condensation on the paint mix motors was being removed by blowing the motors with jets of compressed air. We understand that an alternative, low-pressure cooling/drying system has been proposed.

A second example was of compressed air being bubbled into a process tank to agitate the liquid inside. In each case, the compressed air 'does the job' but much energy is wasted in the process.

The process of compressing air takes a large amount of energy because during compression of air, about 90% of the energy for compression is converted to heat. This heat is usually lost in the cooling towers (unless it can be used constructively, for example for space heating in a cold climate or to provide necessary heat to a production process). In both the cases described in the Paint Shop, compressed air is being used for blowing (a low pressure activity). Low-pressure air can be produced more economically from a fan because no heat of compression is generated and lost.

The cost of compressed air misuse

To get a feel for the magnitudes of wastage, it may be useful to approximate the cost of some of the examples of misuse mentioned above:

Blow-down valves

For the three manual blow-down valves left open the total cost is in the region of R 180 000 per annum. These three blow-down pipes have been included in the list of 62 leaks of the previous section.

Location		Description	Estimated loss for an 8mm hole (cfm)	Power loss (kW)	Energy cost *	Demand cost **
Press Shop ground level	Electrical cabinet (EC) 7849	10mm ID drain hose, permanently open (during entire week), 6 bar	150cfm	22	R 28 560	R 8 331
Press Shop ground level	Between EC's TAG-4628 and TAG-4888	10mm ID blowdown pipe permanently open (whole week), 6bar	150cfm	22	R 28 560	R 8 331
Assembly	station 54 alongside stairway in isle F	open 10mm IDhose (tied to column to prevent it from thrashing around), 6 bar	150cfm	22	R 28 560	R 8 331
			450cfm	66	R 85 680	R 24 993
			Total		R 110 673	

* kilowatts $\times$ 8 232 hours per year (49 weeks/year, 7 days/week, 24 hours/day) $\times$ 0,1577 R/kWh

** kilowatts divided by overall power factor $\times$ 12 months $\times$ 28,40 R/kVA

Anticipated savings

From the table above, savings, from ensuring that just three blowdown valves are closed after use, amount to R 110 673 per year (543 310 kWh; 73 kVA). There is no cost associated with closing valves.

Paint-mix room

On average, 693 cfm is used in the paint mix room. A small amount of compressed air is used for operating a small hoist and also for some small pneumatic equipment in the room. Most of the compressed air is used in the motor cooling/drying system that consists of:

- 9 motors each cooled by 8 jets of air from a 5mm hole in a 25mm pipe (72 $\times$ 5mm holes)
- 12 motors, each cooled by 3 jets from a 5mm hole in a 25mm pipe (36 $\times$ 5mm holes)

The 25mm pipes have shut off valves installed so air pressure at jet holes is unknown. For this reason, flow rate cannot be easily estimated. If it is

assumed that about 90% of air going to the paint mix room is used in the motor drying process, then this means that about 620cfm is being lost through the motor drying system.

The cost of using compressed air to dry mix motors is:

electrical energy cost = 620cfm × 0,1467kW/cfm × 8232hrs/yr ×
R0,1577/kWh

= R 118 075 / yr

electrical demand cost = 620cfm × 0,1467kW/cfm ÷ 0,9 × 12months/yr
× R28,40/kVA

= R34 441 / yr

Total cost of using compressed air to dry mix motors is **R 152 516** per year.

Implementation Costs

If replacement of the current motor drying system with suitable ducting and a 500W fan costs in the region of R30 000, with running costs in the region of R1 000 per year. The simple payback period for this installation is about two months.

ECO 3 - Switch off ER compressors and main cooling towers during non-production time.

Estimated Electric Energy Conservation	1 699 908 kWh / yr
Estimated Electric Energy Cost Savings	R 268 075 / yr
Estimated Electric Demand Reduction	none
Estimated Implementation Cost	none
Simple Payback	immediate

Recommended Action

Switch off the ER8 compressors and the three main cooling towers outside the main compressor house during non-production time.

Anticipated savings

The two ER8 compressors use cooled water from the three large packaged cooling towers (Universal Airbrand NCM 8600) outside the main compressor house. This cooled water is also used for welding tool cooling in the body shop during production time. The current base load in the plant is about 6600cfm. This base demand can be supplied by the three ZR compressors and one Centac (The Pascal Projects report recommends that the ER compressors be used as little as possible because they are introducing water and oil into the compressed air system). At the moment, the NCM 8600 cooling towers run continuously, (in case the ER8 compressors are required). Electrical energy savings (see table below) can be achieved if these cooling towers were turned off during non-production time (23:00, Friday to 05:00, Monday, and 23:00 to 05:00 of each weekday – a total of 84 hours / week). Maximum demand cost savings will not be achieved since maximum demand does not occur during non-production time.

Motor	Shaft power rating (kW)	Rated real power (kW)*	Utilized power (kW)**	Electrical energy (kWh/yr)***	Electrical energy cost saving (R/yr)****
pump	75	79	71	292 236	46 086
pump	250	263	237	975 492	153 835
fan	37	39	35	144 060	22 718
fan	37	39	35	144 060	22 718
fan	37	39	35	144 060	22 718
Total	436	459	413	1 699 908	268 075

* shaft power divided by 0,95 mechanical efficiency

** rated real power $\times$ 0,9 utilisation factor (assumed)

*** utilized power $\times$ 84 hours $\times$ 49 weeks/yr

**** electrical energy $\times$ R0,1577/kWh

An energy cost saving of R 268 075 per year can be achieved by switching off the three main packaged cooling towers and circulation pumps alongside the main compressor house for 84 hours per week. No expenditure is required.

ECO 4 - Isolate areas of the plant or individual machines that do not require compressed air during non-production time

Estimated Electric Energy Conservation	1 394 403 kWh / yr
Estimated Electric Energy Cost Savings	R219 896/ yr
Estimated Electric Demand Reduction	none
Estimated Implementation Cost	R40 000
Simple Payback	0,18 years (2 months)

Recommended Action

Isolate areas of the plant or individual machines that do not require compressed air during non-production time.

Background

Base demands (see table below) from the Pascal Projects report will be used to calculate possible savings in this regard.

Area	Base demand (during non- production) (cfm)	Isolation potential
Paint Shop	2182	will require action - see ECO 2
Engine Plant	181	easily isolated
Assembly Hall	161	easily isolated
Press Shop	3269	easily isolated
Toolroom	681	easily isolated
Body Shop	751	limited isolation

If there were no leaks in the plant, this action would be unnecessary., but owing to the magnitude of the current air losses it is worth consideration until the leaks are repaired. During non-production time, compressed air is essential to the Press Shop (for a limited preparation period) and the Paint Mix Room (693 cfm average – Pascal Projects report). If ECO 2 – is adopted, where the paint mix room is provided with a low-pressure motor drying system then the Paint Shop (base load 2 182 cfm (PP report) could, apparently be isolated. If compressed air is essential for any valid

processes in the paint shop during non-production time then leakage reduction should be the focus and not isolation.

Anticipated savings

Because the Press Shop draws air from the main line running through the Body Shop it may be difficult to isolate the Body Shop completely (individual feeder lines may need to be isolated).

Since the Paint Shop area will require some engineering work before it can be isolated, and because the impact of isolation will reduce as the leaks are repaired and air ceases to be misused in the Paint Shop, it has been excluded from the calculation of cost saving.

Isolation during weeknights (which should be considered) has not been included in the cost saving calculation in Table 4.

Area	Non-production demand (cfm)	Isolation	Non-production demand saved (cfm)	Power saved (kW)*	Hours isolated per week **	Electrical energy saved (kWh/yr) ***	Energy cost saving (R/yr)
Engine Plant	181	yes	181	30	54	78 512	12 381
Assembly Hall	161	yes	161	26	54	69 837	11 013
Press Shop	3 269	yes	3 269	536	30	787 775	124 232
Toolroom	681	yes	681	112	54	295 398	46 584
Body Shop	751	half	376	62	54	162 881	25 686
		Totals	4 668	765		1 394 403	219 896

* based on the assumption that 1kW is required for the compression of 6,1cfm to 6bar

** 11pm Friday to 5am Monday, (Press Shop less 24 hrs for preparation)

***power saved × isolated hours/week × 49weeks/yr

****electrical energy saved × R0,17978/kWh

Table 4 - Energy cost saving by compressed air isolation (Excluding Paint Shop)

Some engineering work may be required to make isolation of the various areas possible. A few valves may need to be installed or moved (to be more accessible) and some existing valves may need to be serviced.

Costs for this action may be in the region of R40 000, which gives a simple payback period of about two months.

If the Paint Shop can be isolated, a further saving of about R63 000 per year could be achieved (base on current demand) as shown below. It has been assumed that isolation could only be achieved for 20 hours on the weekend.

Area	Non-production demand (cfm)	Isolation	Non-production demand saved (cfm)	Power saved (kW)	Hours isolated per week	Electrical energy saved (kWh/yr)	Energy cost saving (R/yr)
Paint Shop	2 182	yes	2 182	358	20	350 840	55 327

Projected kvar required per incomer; Incomer 1: 3 490kVAR
Incomer2: 4 284kVAR

Total installed kvar recommended Q = 5 500kVAR

Estimated Implementation Cost = R1 007 500

Simple Payback = 24 months

Total installed kvar recommended $Q = 7\,700\text{kVAR}$

Estimated Implementation Cost = R1 194 500

Simple Payback = 26 months

Locate the source of the 5th and 7th voltage harmonics and filter these harmonics at the source. Potential voltage harmonic sources on site are dc and ac machine's drives and welding machines.

Install the optimum size of capacitor banks to correct for low power factor caused by the inductive loads of the motors and lamp ballasts at the two incoming lines, 11kV side. To ensure maximum savings, correct the power factor at the metering point, i.e., at the main substation (11kV side).

If there are plans for expansion in the near future then the maximum installation may be more suitable. Over-correction of the power factor is to be avoided.

Power factor is a way of quantifying the reaction of alternating current (AC) electricity to various types of electrical loads. Inductive loads, such as motors and fluorescent lamp ballasts, cause the voltage and current to shift

out of phase. The utility company must supply additional power, measured in kilovolt-amps (kVA), to make up for the phase shift. The total power requirement of the load is made up of two components, the resistive, or real, component and the reactive component. The resistive component, measured in kilowatts (kW) by a wattmeter, does the useful work. The reactive component, measured in reactive kilovolt-amps (kVAR), represents the current needed to produce the magnetic field for the operation of a motor or other inductive device. This component does no useful work, is not registered on a power meter, but contributes to the heating of generators, transformers and transmission lines, constituting a loss for the utility company.

Components of Electrical Power

The ratio of real, useable power (kW) to apparent power (kVA) is known as the power factor. To reduce reactive losses, the user should increase the power factor to a value as close to unity (1.0) as is practical for the entire manufacturing plant. For example, assume that a manufacturing plant has an average annual power factor of 0.78. Power factor of 0.78 means that for every 78 kW of usable power that the plant requires, the utility must supply 78 kW/PF or 100 kVA. If the plant's power factor is changed from 0.78 to 0.95, then for every 78 kW required by the plant, the utility need only supply 78 kW/0.95 or 82 kVA.

Capacitor banks can be installed to decrease the reactive power (kVAR) and thus the apparent power. Capacitors draw current, which leads the voltage, while inductive loads draw current, which lags the voltage. The net result is that the current in the supply line is brought more closely in phase with the supply voltage. A power factor of 1,0 indicates that the current and the voltage are exactly in phase. It is not always economical to install PFC equipment with an aim of unity power factor.

Capacitors can be installed at any point in the electrical system and will improve the power factor between the point of application and the power source. Capacitors can be added at each piece of equipment, ahead of groups of small motors, or at main services. The advantages and disadvantages of each type of installation are highlighted in Table 5 below.

Type of Capacitor Installation	Advantages	Disadvantages
1. Individual Equipment (e.g. individual induction motors)	Increased load capabilities of distribution system Better voltage regulation	Smaller capacitors cost more per kVAR than larger units Heavy on maintenance and monitoring Possible high failure rate
2. Grouped Equipment (32 substations)	Increased load capabilities of the service	Switching means may be required to control the amount of capacitance used Heavy on maintenance and monitoring
3. Main Service (Main substation, Incomer 1 and 2)	Low installation costs Low maintenance costs	Switching means will usually be required to control the amount of capacitance used Does not improve load capabilities of distribution system

Table 5 - Options for capacitor installation

The primary objective is to reduce the peak demand thereby saving on the electricity bill, although the energy component is not changed. Initial installation (3 in table 11), is very costly on the equipment side, but reduced maintenance, installation and monitoring offset this initial cost in the medium to long term.

Anticipated Savings

The cost for this analysis are based on the following breakdown:

PFC equipment:	R85 000 / MVAR
Capacitor bank breakers:	R90 000/ breaker
Reactors/ Filters:	R100 000/ MVAR

It is assumed that three capacitor banks will be required for each of the two incomers (six breakers in total).

Table 6 (following page) shows the effect that capacitance (kVAR) will have on this plant's power factor, for the maximum and optimum scenarios. The table shows the measured demand, power factor and the cost savings to be expected by adding correction equipment (kVAR).

Current conditions				Proposed power factor		
Month	Measured Demand [kVA]	Measured Power [kW]	Calculated Power Factor	Excess kVAR	Proposed kVAR Correction	
					5 500	7 700
January	17 568	15 990	0,910	7 276	0,994	1,000
February	18 076	16 298	0,902	7 817	0,990	1,000
March	18 323	16 482	0,900	8 004	0,989	1,000
April	21 632	19 964	0,923	8 329	0,990	1,000
May	17 063	15 526	0,910	7 077	0,995	0,999
June	19 672	17 926	0,911	8 102	0,990	1,000
July	18 098	16 312	0,901	7 839	0,990	1,000
August	17 694	15 908	0,899	7 746	0,990	1,000
September	17 591	15 682	0,891	7 969	0,988	1,000
October	17 212	15 380	0,894	7 727	0,990	1,000
November	16 662	14 891	0,894	7 474	0,991	1,000
December	17 764	16 019	0,902	7 677	0,991	1,000
Savings projected						
	Measured Demand [kVA]	Measured Power [kW]	Calculated Power Factor	Savings per month		Savings per month
				5 500		7 700
January	17 568	15 990	0,910	R 40 022	R 42 533	
February	18 076	16 298	0,902	R 43 659	R 48 083	
March	18 323	16 482	0,900	R 44 680	R 49 722	
April	21 632	19 964	0,923	R 39 722	R 44 850	
May	17 063	15 526	0,910	R 39 413	R 41 238	
June	19 672	17 926	0,911	R 42 146	R 47 107	
July	18 098	16 312	0,901	R 43 796	R 48 295	
August	17 694	15 908	0,899	R 44 040	R 48 309	
September	17 591	15 682	0,891	R 46 409	R 51 575	
October	17 212	15 380	0,894	R 45 216	R 49 554	
November	16 662	14 891	0,894	R 44 372	R 47 853	
December	17 764	16 019	0,902	R 43 211	R 47 195	
	Average savings/ month			R 43 057	R 47 193	
	Total savings/ year			R 516 691	R 566 320	

Table6: Maximum demand savings through power factor correction

Implementation Cost

As calculated in Table 12, the installation of capacitors rated at 5 500 and 7 700 kVAR would be required to correct for low power factor, optimally and to unity respectively. The installed cost for capacitors is estimated as R85 000/MVAR, which leads to an implementation cost of R1 007 500 and R1 194 500. Thus, the annual cost savings of R516 600/yr and R566 320/yr

would pay for the implementation cost in 24 and 26 months, respectively. The costs of filter banks that may be needed on sight are excluded in these calculations, because the sources is unknown, Therefore it is difficult to estimate how much filtering is needed. Furthermore, the cost of installation cannot be estimated at this stage, because, civil work and re-cabling may be required on the main substation to accommodate the capacitor banks.

Notes

1. The determination of the optimum power factor correction and the installation of the capacitors may require additional engineering. We recommend that additional professional advice be obtained from a capacitor supplier, electrical contractor, or an engineering firm.
2. Following a site visit, S Khumalo reported that the capacitor banks in 30 out of 32 substations, were not in good working condition. His impression was that many of the capacitor banks were inoperative - possibly damaged from harmonics in the supply voltage or increased load since installation.
3. There are additional benefits from improving power factor. Less total current flows in the plant wiring, motors, and other equipment. Less current means reduced power losses with resulting energy and demand savings. However, energy savings caused by these power losses are typically less than 1% of plant electricity use.
4. Other benefits from improved power factor are that motors run cooler and that system voltage is higher. Therefore, motor efficiency, capacity, and starting torque will also be slightly higher. Branch circuit capacity also is higher because more real work can be done with the same total current.
5. If automatic controllers are used, the response time is important for rapid power factor variations.

ECO 6 - Use waste heat to heat phosphate bath

Estimated electrical energy saving:	R 190 000 / year
Estimated installation cost:	R 300 000
Payback period:	1,58 years

Recommended Action

Install liquid-cooled condensers to Electrocoat chillers. The additional condensers are to be installed in parallel with the factory supplied air-cooled condensers such that the liquid-cooled units have priority.

Background

Two large Carrier air-cooled water chillers currently provide cooling to the Electrocoat bath. The energy removed is discarded to atmosphere via the air-cooled condensers. Liquid-cooled condensers can be installed in parallel to the air-cooled ones such that they provide "free heat" to the phosphate bath instead of the cost of the present thermic oil/HFO arrangement. The plate heat exchanger between the thermic oil and the water circuit used to heat the phosphate bath is rated at 1 000kW.

Anticipated Savings

The cost of heating using HFO on this site is about R0,14/kWh at 100% efficiency. If we assume that the maximum system efficiency to the point of delivery of heat into the phosphate tank is about 75%, then the cost of "useful" HFO produced energy is about R0,19/kWh.

The cooling requirement of the Electrocoat bath is 420kW, which makes each chiller capable of rejecting at least 500kW (420kW plus compressor power). Based on a coincident heating/cooling requirement of 3 hours per day for seven day week and 49 weeks in the year, the annual "free energy" would be about 500 000 kWh. This amounts to an avoided HFO heating cost of at least R 95 000 / year per chiller (68 000 litres HFO/year/chiller), provided the heating and cooling needs are coincident.

The total anticipated energy saving from installing two chillers is R190 000 per year.

Implementation Costs

The cost of the conversion would be about R 150 000 for each of the two chillers – giving a total cost for conversion of R300 000. With an anticipated saving of R190 000 this results in a payback period of 1,58 years (19 months).

It is recommended that further observation be carried out to determine whether the loads are sufficiently coincidental.

ECO 7 – Install High-Efficiency Lighting

Estimated Electric Energy Savings:	2 410 244 kWh/yr
Estimated Electric Energy Cost Savings:	R 433 314 /yr
Estimated Electric Demand Savings:	3 301 kW/yr
Estimated Electric Demand Cost Savings:	R 118 772 /yr
Estimated Total Cost Savings:	R 239 473 /yr
Estimated Implementation Cost:	R 726 936
Simple Payback Period:	3,0 years

Recommended Action

The existing mercury vapor (MV) lamps (400W) and a few high pressure sodium (HPS) lamps (400W) should be replaced with metal halide (MH) lamps (250W) including new ballasts and igniters. MH lamps (250W) use less energy than MV (400W) and HPS (400W) with a comparable light output to the 400W MV.

Background

The focus of this investigation is the bay lighting. The bay lighting mainly consists of MV lamps, however, there are also a few HPS lamps installed. Each lamp has 400W. The total number of fittings adds up to approximately 1728 (Machining Hall: 265, Assembly Hall: 506, Press Shop: 231, Body Shop: 201, Pressed Part Warehouse: 212 and Container Warehouse: 193, Steel and Heavy Tool Store: 120). Moreover many lights are burned out and have not been replaced.

In general the arrangement of the lights in the separate parts of the plant as well as the measured lux levels are not as recommended by the South Africa Bureau of Standards (SABS). According to the SABS the recommended lighting level of the Body Shop, Press Shop, Steel and Heavy Tool Store, Paint Shop and the Final Assembly is 400 lux and recommended lighting level of the Warehouses is 160 lux. The measured lighting levels are shown in Appendix C.

For calculation purposes, it has been assumed that current lighting levels are acceptable to VW. Thus the methodology was to keep the lux level constant while choosing lamps with the same lumen output and a preferably better Colour Rendering Index (CRI).

Higher efficiency lighting has been a focus for many lighting manufacturers in recent years. New technology has led to innovative lamps that have a longer rated life and require less wattage with a minimal reduction in overall lumen output. Most of these lamps were designed as direct replacements for the old inefficient lamps, so the existing fixtures can be used in most cases. However, this investigation came to the conclusion that the existing fixtures can only be used for the 400W MV and 400 W HPS and not for the proposed 250 W MH lamps. Hence the up front cost for a new fitting or the replacement of the existing ballast and the igniter had to be taken into account. Ideally the installed lamps should have been replaced with 400W MH lamps because of the increased lumen output and overall improvement of the lighting situation in the plant. However, this would have resulted in a completely new refurnishing including delamping and rewiring which unfortunately exceeds the scope of this ECO.

High Intensity Discharge Lighting (HID)

The appropriate use of HID lamps, which include metal halide (MH), mercury vapor (MV), and low and high-pressure sodium (HPS), is dependent on several factors. When choosing an HID replacement lamp the application of the lamp will ultimately determine its suitability. For example, in areas where color differentiation is important the use of a HPS lamp may not be feasible due to its low CRI value. In our study we assumed that the CRI is also of greater importance because for most production processes it is important to clearly differentiate colors. The efficacy values of the most common lamp types are shown in Table 7 (following page). The efficacy of a lamp is a measure of the lamp's ability to convert electrical power into visible light. The

quantity of light emitted (lumen output) is divided by the input power of the lamp to determine the lamp's efficacy and is a measure of energy efficiency expressed in Lumens per Watt or LPW. A listing of efficacies, CRIs, and lamp life for HID lighting is shown in the following table.

	Standard incandescent	Tungsten halogen	Flourescent	Compact flourescent	Mercury vapour	Metal halide	High-pressure sodium	Low-pressure sodium
Watts	3 - 1 500	10 - 1 500	4 - 215	4 - 55	40 - 1 250	32 - 2 000	35 - 1 000	18 - 180
Average system efficacy (lm/W)	4 - 24	8 - 33	49 - 89	24 - 68	19 - 43	53 - 115	53 - 147	50 - 150
Average rated life (hours)	750 - 2 000	2 000 - 4 000	7 500 - 24 000	7 000 - 20 000	16 000 - 24 000	6 000 - 20 000	16 000 - 24 000	12 000 - 18 000
CRI	100	100	49 - 92	82 - 86	15 - 50	65 - 92	21 - 85	0 ⁽¹⁾
Life cycle cost	high	high	low	mod	mod	mod	low	low
Fixture size	compact	compact	extended	compact	compact	compact	compact	extended
Start to full brightness	immed	immed	0 - 5 sec	0 - 1 min	3 - 9 min	3 - 5 min	3 - 4 min	7 - 9 min
Restrike time	immed	immed	immed	immed	10 - 20 min	4 - 20 min	1 min	immed
Lumen maintenance	good/excellent	excellent	fair / excellent	good / excellent	poor / fair	good	good / excellent	excellent

Table 7: Lamp Characteristics (Source: International Industrial Assessment Centre)

Because use of HID lamps is so common in industry, progress is constantly being made toward higher efficiency. This results in fewer fixtures needed, less energy consumed, and reduced maintenance costs.

Lighting fixture specifications, and costs are given in Table 8 (following page). The prices indicate the retail cost of lamps available in South Africa.

Lamp/Ballast/Igniter/ Fixture Description	Lamp Code	Cost of new equipment R (incl. VAT)	Lamp Type
Lamp	400W	88	Mercury Vapor
Ballast	400W	133	Mercury Vapor
Igniter	400W	98	Mercury Vapor
Fixture + Lamp	400W	444	Mercury Vapor
Lamp	250 W	99	High Pressure Sodium
Ballast	250 W	150	High Pressure Sodium
Igniter	250 W	98	High Pressure Sodium
Fixture + Lamp	250 W	747	High Pressure Sodium
Lamp	400W	114	High Pressure Sodium
Ballast	400W	184	High Pressure Sodium
Igniter	400W	98	High Pressure Sodium
Fixture + Lamp	400W	762	High Pressure Sodium
Lamp	250 W	244	Metal Halide
Ballast	250 W	126	Metal Halide
Igniter	250 W	98	Metal Halide
Fixture + Lamp	250 W	935	Metal Halide
Lamp	400W	249	Metal Halide
Ballast	400W	149	Metal Halide
Igniter	400W	98	Metal Halide
Fixture + Lamp	400W	941	Metal Halide

Table 8 - Lighting fixture specifications, and costs

Anticipated Savings

Tables 9, 10 and 11, supported by calculations in Appendix D, provide the existing and proposed lighting scenario as determined from the lighting survey conducted during the facility visit, and the energy conservation, demand reduction, and cost savings for lamp/ballast combinations in the other plant areas.

Building Area	Existing ballast /lamp Code	Avg. light level fc	Existing ballast /lamp Description	No. of fixtures	Fixture power W	Total power W	Annual average demand kW/yr	Usage time h/yr	Total Energy Usage kWh/yr
Machining Hall	73	20	400W MV	260	454	118 040	1 416,5	8 760	1 034 030
Machining Hall	85	20	400W HPS	5	457	2 285	27,4	8 760	20 017
Pressed Part Warehouse	73	30	400W MV	184	454	83 536	1 002,4	8 760	731 775
Pressed Part Warehouse	85	30	400W HPS	28	457	12 796	153,6	8 760	112 093
Container Warehouse	73	26	400W MV	134	454	60 836	730,0	8 760	532 923
Container Warehouse	85	26	400W HPS	59	457	26 963	323,6	8 760	236 196
Press Shop	73	69	400W MV	231	454	104 874	1 258,5	8 760	918 696
Body Shop	73	23	400W MV	190	454	86 260	1 035,1	8 760	755 638
Body Shop	85	23	400W HPS	11	457	5 027	60,3	8 760	44 037
Assembly Hall	73	27	400W MV	479	454	217 466	2 609,6	8 760	1 905 002
Assembly Hall	85	27	400W HPS	27	457	12 339	148,1	8 760	108 090
Steel and Heavy Tool Store	73	35	400W MV	120	454	54 480	653,8	8 760	477 245
Total				1 728		784 902	9 418,8		6 875 742

100% coincidence factor was used in this table

Table 9 - Existing Lamp Situation:

Building Area	Existng ballast /lamp code	Existing ballast/lamp description	Percent existing lumen output	No. of fixtures	Fixture power W	Total power W	Annual average demand kW/yr	Total energy usage kWh/yr
Machining Hall	93	250W MH	96	260	295	76 700	920,4	671 892
Machining Hall	93	250W MH	42	5	295	1 475	17,7	12 921
Pressed Part Warehouse	93	250W MH	96	184	295	54 280	651,4	475 493
Pressed Part Warehouse	93	250W MH	42	28	295	8 260	99,1	72 358
Container Warehouse	93	250W MH	96	134	295	39 530	474,4	346 283
Container Warehouse	93	250W MH	42	59	295	17 405	208,9	152 468
Press Shop	93	250W MH	96	231	295	68 145	817,7	596 950
Body Shop	93	250W MH	96	190	295	56 050	672,6	490 998
Body Shop	93	250W MH	42	11	295	3 245	38,9	28 426
Assembly Hall	93	250W MH	96	479	295	141 305	1695,7	1 237 832
Assembly Hall	93	250W MH	42	27	295	7 965	95,6	69 773
Steel and Heavy Tool Store	93	250W MH	96	120	295	35 400	424,8	310 104
TOTALS	93			1 728		509 760	6 117,1	4 465 498

Table 10 - Proposed lamp situation

Building Area	Energy Conservation kWh/yr	Demand Reduction kW/yr	Energy Cost Savings R/yr	Demand Cost Savings R/yr	Lamp Replacement Cost Savings R/yr	Total Cost Savings R/yr
Machining Hall	362 138	496,1	65 105	17 845	-47 222	35 728
Machining Hall	7 096	9,7	1 276	350	-861	765
Pressed Part Warehouse	256 283	351,1	46 074	12 629	-33 419	25 285
Pressed Part Warehouse	39 735	54,4	7 144	1 958	-4 820	4 282
Container Warehouse	186 641	255,7	33 554	9 197	-24 338	18 414
Container Warehouse	83 728	114,7	15 053	4 126	-10 156	9 023
Press Shop	321 746	440,7	57 844	15 855	-41 955	31 743
Body Shop	264 640	362,5	47 577	13 041	-34 509	26 109
Body Shop	15 610	21,4	2 806	769	-1 893	1 682
Assembly Hall	667 170	913,9	119 944	32 877	-86 998	65 823
Assembly Hall	38 316	52,5	6 888	1 888	-4 648	4 129
Steel and Heavy Tool Store	167 141	229,0	30 049	8 236	-21 795	16 490
TOTALS	2 410 244	3 301,7	433 314	118 772	-312 613	239 473

Table 11 - Annual Savings through high efficiency lighting

From the previous tables, the total estimated energy savings is 2 410 244 kWh/yr, and the estimated demand savings are 3 301 kW/yr. Total cost savings are R 239 473/yr.

Implementation Costs:

The implementation cost for this recommendation includes the equipment and labor costs required for the new lamps, ballasts and igniters. Labor costs are estimated as R 50 per fixture. Table 12 below, again supported by calculations in Appendix D, summarizes the total cost savings, estimated implementation cost, and simple payback period for each area of the facility.

Building Area	Total cost savings per year R	Total lamp costs R	Total ballast costs R	Total igniter costs R	Total labour costs R	Total implemen-tation costs R	Simple payback (years)
Machining Hall	35 728	63 440	32 760	98	13 000	109 298	3,1
Machining Hall	765	1 220	630	98	250	2 198	2,9
Pressed Part Warehouse	25 285	44 896	23 184	98	9 200	77 378	3,1
Pressed Part Warehouse	4 282	6 832	3 528	98	1 400	11 858	2,8
Container Warehouse	18 414	32 696	16 884	98	6 700	56 378	3,1
Container Warehouse	9 023	14 396	7 434	98	2 950	24 878	2,8
Press Shop	31 743	56 364	29 106	98	11 550	97 118	3,1
Body Shop	26 109	46 360	23 940	98	9 500	79 898	3,1
Body Shop	1 682	2 684	1 386	98	550	4 718	2,8
Assembly Hall	65 823	116 876	60 354	98	23 950	201 278	3,1
Assembly Hall	4 129	6 588	3 402	98	1 350	11 438	2,8
Steel and Heavy Tool Store	16 490	29 280	15 120	98	6 000	50 498	3,1
TOTALS	239 473	421 632	217 728	1 176	86 400	726 936	3,0

Table 12 – Costs and savings for high efficiency lighting

From the table, the total estimated implementation cost is R 726 936. The cost savings of R 239 473 / year would pay for the implementation cost in 3,0 years.

The energy savings, cost savings and implementation costs presented in this analysis are based upon total replacement of all applicable fixtures in the facility at once. This would be the case if a facility has sufficient capital, loans or other funding available for implementation. This method would result in a large and immediate energy savings, but would require a large initial investment. Several options are available to spread out this investment, including spot relamping and group re-lamping. An analysis of spot relamping and group relamping options with incremental costs and savings is in APPENDIX E.

University of Cape Town

ECO 8 - Turn off bay lights during non-production hours

Estimated Electric Energy Savings:	2 672 657 kWh/year
Estimated Electric Energy Cost Savings:	R 480 490 /year
Estimated Total Cost Savings:	R 446 190 / year
Payback Period:	No capital costs. Labour costs included in estimated
	total cost savings.

Recommended Action:

The bay lights can be turned off during non-production hours such as during the Christmas break and especially during the night.

Background:

The bay lighting mainly consists of Mercury Vapor (MV) lamps, however, there are also a few High Pressure Sodium (HPS) lamps installed. Each lamp is rated at 400W. The total number of fittings adds up to approximately 1728 (Machining Hall: 265, Assembly Hall: 506, Press Shop: 231, Body Shop: 201, Pressed Part Warehouse: 212, Container Warehouse: 193, and the Steel and Heavy Tool Store: 120). These lamps are unnecessarily left on during non-production hours including nighttime and during the Christmas break. The production hours are tabulated on the following page.

Building	Production time	Days/ week	Time the lights could potentially be turned off	Total hr/week
Press Shop, Steel Store and Heavy Tool Room	6:00-14:30 +14:00-22:30 + weekend preparation (6:00 – 14:00)	5 + 2	23:00 – 5:00 (during the week)+15:00-5:00 (during the weekend)	30+28 = 58
Body Shop	6:00-14:30 +14:00-22:30 + weekend (6:00-14:00)	5 + 2	23:00 – 5:00 (during the week)+15:00-5:00 (during the weekend)	30+28 = 58
Assembly Hall	6:00-14:30 +14:00-22:30	5	23:00 – 5:00 (during the week)+0:00-24:00 (during the weekend)	30+48 = 78
Pressed Part Warehouse	6:00-14:30 +14:00-22:30	5	23:00 – 5:00 (during the week)+0:00-24:00 (during the weekend)	30+48 = 78
Machining Hall	6:00-14:30 +14:00-22:30	5	23:00 – 5:00 (during the week)+0:00-24:00 (during the weekend)	30+48 = 78
Container and Receiving Warehouse	3 shifts (24hrs/day)	5	0	0

Table 13 - Production hours by area

Thus the total time the lights can be turned off adds up to the following:

Building	Weeks of production	Hour lights can be turned off	Weeks without production	Hours lights can be turned off	Total hours lights can be turned off hr/yr
Press Shop, Steel Store and Heavy Tool Room	53	58	3	24	3 146
Body Shop	53	58	3	24	3 146
Assembly Hall	53	78	3	24	4 206
Pressed Part Warehouse	53	78	3	24	4 206
Machining Hall	53	78	3	24	4 206
Container and Receiving Warehouse	53	0	3	24	72

Table 14 - Total time that lights can be turned off by area

Anticipated Savings:

The estimated energy conservation, EC , for replacing lamps in a specific area is given by the following relation:

$$EC = \frac{N \times CFW \times H}{C_1}$$

where,

N = number of fixtures in area, no units

CFW = power rating of current fixtures in area, W

H = non operating hours of lamp in area, h/yr

C_1 = conversion constant, 1,000 W/kW

The demand reduction, DR , associated in a specific area is given by the following relation:

$$DR = \frac{N \times CFW \times CF}{C_1}$$

where,

CF = coincidence factor - probability that the equipment contributes to the facility peak demand, per month

Therefore, the total annual cost savings, TCS, can be estimated as follows:

$$TCS = (EC \times \text{energy rate}) + (DR \times \text{demand rate}^1) \times 12 \text{ mo/yr}$$

Total annual cost savings for each area are shown in the table below:

Building Area	Existing Ballast/Lamp Description	Number of Fixtures	Fixture Power W	Total Power W	Usage Time h/yr	EC (Total Energy Saving) kWh/yr	TCS (Total Annual Cost Savings) R/yr
Machining Hall	400W MV	260	454	118 040	4 206	496 476	89 256
Machining Hall	400W HPS	5	457	2 285	4 206	9 610	1 727
Container	400W MV	134	454	60 836	72	4 380	787
Warehouse	400W HPS	59	457	26 963	72	1 941	349
Press Shop	400W MV	231	454	104 874	3 146	329 933	59 315
Steel and Heavy	400W MV	120	454	54 480	3 146	171 394	30 813
Tool Store	400W MV	184	454	83 536	4 206	351 352	63 166
Pressed Part	400W MV	28	457	12 796	4 206	53 819	9 675
Warehouse	400W HPS	190	454	86 260	3 146	271 374	48 787
Pressed Part	400W MV	11	457	5 027	3 146	15 814	2 843
Warehouse	400W HPS	479	454	217 466	4 206	914 662	164 437
Body Shop	400W MV	27	457	12 339	4 206	51 897	9 330
Body Shop	400W HPS						
Assembly Hall	400W MV						
Assembly Hall	400W HPS						
TOTALS		1 728		784 902		2 672 657	480 490

Table 15 - Total annual cost savings by area

Avoided Electric Cost: R 0,17978 /kWh (values in this table include VAT)

From the table above it can be seen that turning the bay lights off in each area during non-production time will result in an electrical energy saving of 2 672 657 kWh / year and a total cost saving of R 480 490 / year (including VAT). Maximum demand occurs during production time and will not be reduced by this action.

Anticipated Costs:

The easiest way this saving can be implemented is by somebody going around the whole plant and turn the lights off. Considering a labour cost of R 50/hour and a time consumption of 30 minutes to turn the lights off, the costs add up to the following:

Building	Production: days/ week	Production: weeks/year ⁽¹⁾	Total Days
Press Shop, Steel Store and Heavy Tool Room	5 + 2	49	7x49 = 343
Body Shop	5 + 2	49	7x49 = 343
Assembly Hall	5	49	5x49 = 245
Pressed Part Warehouse	5	49	5x49 = 245
Machining Hall	5	49	5x49 = 245
Container and Receiving Warehouse	5	49	5x49 = 245

Table 16 - Production days/year by area

Using the maximum of 343 days where lights are to be turned on and off, costs add up to:

$$343 \text{ days / year} \times R 100 / \text{day} = R 34\,300 / \text{year}$$

Hence the Total Annual Savings are:

$$R 480\,490 / \text{year} - R 34\,300 / \text{year} = R 446\,190 / \text{year}$$

⁽¹⁾ 52 weeks / year minus 3 weeks of vacation

ECO 9a – Install direct acting electric heaters to air replacement plants serving colour line 1

Estimated Electric Demand Increase:	8 925 kVA
Estimated Total Cost Savings:	R 4 355 536 / yr
Estimated Implementation Cost:	R 4 000 000
Simple Payback:	< 1 year

Recommended Action

Investigate the practicality of installing direct acting electric heater elements ahead of the gas burners, together with the necessary temperature controls and maximum demand control.

Background

The paint tunnel receives heated and humidified air from five Air Replacement Plants (ARPs). The total supply air volume is about 200 m³/s and all of it is exhausted to atmosphere. The supply air is heated by direct gas burners in the ARPs and humidified by water sprays. The exhaust air passes through a water bath before being discharged to atmosphere.

Eskom (Industrelek) have produced a report (for VW SA) showing that direct acting electric heating is cheaper to use than the presently installed Liquid Petroleum Gas (LPG) heating. We have verified their calculations and can agree with the basic figures leading up to total energy consumption and corresponding cost of gas fuel.

The average enthalpy for the year is 33,14 kJ/kg of dry air with the enthalpy of the air at the design condition around 58 kJ/kg of dry air [CSIR Research Report 300]. The specific mass of the air at this condition is approximately 0,825 m³/kg.

The energy consumption for an eleven-month year at 557 hours per month is then given by:

$$(200 / 0,825) * (58 - 33.14) * 557 * 11 = 36\,925\,387 \text{ kWh}$$

This is close to the Industrelek figure of 34 881 485 kWh for a relatively warm year. (Note that the supply air condition rather than the design air condition should be used in both calculations. However, the difference is not significant in the context of imprecise knowledge of operating hours)

In addition, their claim that electric heating at about 70% of the design (worst case) load will cover about 80% of the energy requirements is what one would normally expect.

Anticipated savings

Please see the Industrelek report for full details.

Note! These calculations are extremely sensitive to average annual weather loads and, more particularly, hours of operation. It can be seen from the invoices that the total annual bill for LPG during the year of investigation was only R8 393 800, about 25% lower than the calculated value.

ECO 9b - Extend existing thermic oil/HFO system to supply the ARP (HFO instead of gas)

Estimated energy cost saving:	R 4 656 666
Estimated installation cost:	R 19 000 000
Estimated payback:	4,1 years

Recommended action

Install an additional HFO heater to supply heated thermic oil to the ARP (to replace the gas fired system completely)

Background

The costs of the various fuel options on site are

Gas:	R0,32/kWh at 100% efficiency
HFO:	R0,14/kWh at 100% efficiency
Electricity:	R0,15771/kWh (or R0,21/kWh average including present demand charges)

The cost of HFO makes it attractive when compared with gas and electricity and an additional thermic oil heater should be considered to replace the gas-fired system completely. The heat recovery option (ECO 11) would still be valid.

Anticipated Savings

The cost of useful heat from the HFO/thermic oil system is about R0,187/kWh, assuming an overall system efficiency of 75%. The cost of the 34 881 485 kWh ARP energy consumption then becomes R6 511 210 (at 75% system efficiency), which represents a saving of R4 656 666 per year against the R11 167 877 gas bill.

Implementation Cost

The estimated cost of an extension to the HFO/thermic oil system is about R19 000 000, which gives a payback period of 4,1 years. (Cost estimate acquired from Mr Jorg Steinbach, Oilco Engineering, Port Elizabeth who

did the original HFO heater installation at the plant. They are also agents for Konus Kessel and have recently priced a similar conversion)

Note! These calculations are extremely sensitive to average annual weather loads and, more particularly, hours of operation. It can be seen from the invoices that the total annual bill for LPG during the year of investigation was only R8 393 800, about 25% lower than the calculated value.

University of Cape Town

ECO 10 - Make use of heat pump heat recovery between ARP exhaust and supply air streams

Estimated energy saving:	1 313 843 litres of gas
<i>Estimated energy cost saving:</i>	<i>R 3 187 385</i>
<i>Estimated installation cost:</i>	<i>R 2 750 000</i>
<i>Estimated payback:</i>	<i>0,87 years</i>

Recommended Action

Install a heat pump heat-recovery unit between the ARP exhaust and supply air streams.

Background

Air leaves the water baths below the paint tunnels at 23°C and 70% RH. A good deal of energy can be extracted from this air by cooling it to about 10°C and 90% RH. The actual potential rate of heat extraction is given by

$$200 \text{ m}^3/\text{s} \times 1/0,83 \text{ m}^3/\text{kg} \times (54-27) \text{ kJ/kg} = 6\,400 \text{ kW approximately}$$

Typically this would result in a heat pump heat output of 8 000kW, based on a cooling coefficient of performance of 4. That is, the compressor input power would be about 1 600 kW.

It is clear from the (Idustrelek) profile of monthly energy consumption that a machine delivering about 1 000 MWh heating per month would run throughout the year. This is because the month of smallest need is February at about 963 MWh. Bigger capacity and or additional machines would be increasingly less cost effective since the number of over-capacity hours increases as a proportion of the available hours.

Anticipated Savings

Using the nominal monthly run figure of 557 hours gives a machine requirement of about 1 700 kW heat output. Typically, such a machine would have a compressor input of about 360 kW, effectively reducing the cost of heating to about R0,04/kWh (including the increase in demand charges).

The cost of providing recovered heat all year round would then be
 $1\,700\text{ kW} \times 557\text{ hours/month} \times 12\text{ months} \times 0,04\text{ R/kWh} = \text{R } 454\,512$

The remaining energy (gas) cost would be
 $(34\,881\,485 - (1\,700 \times 557 \times 12))\text{ kWh} \times \text{R } 0,32/\text{kWh} = \text{R } 7\,525\,979$

where 34 881 485 kWh is the total annual energy consumed in a design year at a cost of R 11 167 877 and R 0,32/kWh is the cost of gas.

The annual fuel cost has been reduced to R 7 980 491, which results in a cost saving of R 3 187 385 (1 313 843 litres of gas)

The installed cost of the heat pump heat recovery system is estimated at R 2 750 000, based on an industry guideline of about R 2 000 per kW of cooling capacity: $(1\,700 - 360)\text{ kW} \times \text{R } 2\,000/\text{kW} = \text{R } 2\,680\,000$, rounded up to cover possible contingencies. This results in a payback period of 0,87 years (about 10 months).

Note: Mr Des Smith at Improvair, East London provided advice for estimates of cost and capacity of heat pumps. He knew of the plant situation and has done related work for Daimler-Chrysler.

3.2.2 Additional items considered

AIC 1 - Identify and switch off equipment that is not essential during non-production time.

Recommended action

Identify and visibly mark or signpost equipment that should be running during non-production time. Switch off all other equipment at the end of the production period.

Background

Electrical power demand during zero-production time is more than a third of the power demand during peak production time. It is likely that electrical energy wastage is occurring because of electrical equipment left running unnecessarily. There is a need to identify the essential equipment (which is presumably less than the non-essential equipment) and take steps to ensure that only that equipment is left running during non-production time.

Recorded graphs of kVA in July 2001 show the electrical demand for Plant A peaking at about 17 MVA. During zero-production time (the 20 hour period from Saturday 10:00 to Sunday 6:00) the total electrical demand was measured at 6 MVA (6 000kVA). Electrical demand is recorded at three of the four substations (Sub 12, Sub 17A and Sub 17B) that are fed directly from the Main Substation. Assuming that the fourth substation (13B) accounts for the remaining demand, then the demand is split in the following ways.

Main Incoming Substation Sub 1 (6 000kVA) [measured]	Ring main through: Sub 12 (1 600 kVA) [measured] and Sub 13B (1 200 kVA) [remainder] Total (2 800 kVA)	Sub	Area
		12	engine shop
		15	offices
		22	computer room and offices
		1	Intermediate store, sub-assembly, offices and workshops
		9	offices and warehouse
		4	press shop and body shop
		3	body shop
		26	body shop (roof)
		25	body shop (roof)
		24	body shop (roof)
		14	press shop
		10	press shop, general and body shop
		16	quality assurance offices
		11	warehousing (CKD)
		13B	-
	Supply through Sub 17A (1 600 kVA) [measured]	27	Engine Shop
		18	Paint Shop, General and Electro-coating Plant
		28	First Colour Line – Paint Shop
		19	Prime Paint Line – Paint Shop
		23	First Colour Line – Paint Shop
		20	Paint Shop, General and Electro-coating Plant
		21	Boiler House – Electro-coating Plant
	Supply through Sub 17B (1 600 kVA) [measured]	8	EC Plant, Power Rails – Paint Shop
		13A	350 kVA to Assembly Hall
		7	Paint Shop General
		6	Third Colour Line & General Paint Shop
		5	Offices & Paint Shop
		2	Compressor House, Pilot Hall, Ablutions & Fire Station

Table 17 - Electrical demand during zero-production time

Table 17 is the first step in identifying where the energy is going during zero-production. The next step will be to monitor the individual substations during the zero-production period. Once the essential processes have been identified, the proportion of the 6 000kVA that is justifiable will be known and can be targeted.

Anticipated Savings

Savings can only be known once further investigation has been completed. An indicator of the extent of possible savings is the cost of the

current 6 000kVA load. Over a year of weekly 20 hour periods, 6 000kW (ignoring power factor) will cost:

$6\,000\text{kW} \times 20\text{hr/week} \times 49\text{weeks/year} \times R0,17978 / \text{kWh} = R\,1\,057\,106 / \text{year}$

If demand can be reduced by just a quarter during this 20 hour period (1 500kVA – a couple of air conditioners and chiller units) a saving of about R 250 000 /year will be achieved.

AIC 2 - Spread electrical demand to reduce peak kVA costs

Recommended Action

Turn off non-essential electrical equipment at times that correspond to peaks of maximum electrical demand. Run processes that could be operated at off-peak times only, only at off-peak times.

Background

Savings through spreading electrical demand will not be easy to achieve.

The maximum demand curve (see over the page) is relatively flat each side of lunchtime. There is a fairly regular morning undulation from peak to trough of between 500 and 1 000 kVA, peaking at about 08:30 and 11:30. If this undulation were perfectly flattened out, peak reduction of 250 to 500 kVA would be achieved representing a saving of R8 000 to R16 000 per month (@R32,38/kVA).

Turning off equipment like air-conditioners is not feasible because the maximum load occurs over an extended period during the day. The most headway will be made by identifying which processes can be run at off-peak times.

AIC 3 - Make use of water from effluent plant to reduce water consumption and effluent costs.

Recommended Action

If economically beneficial, install equipment and pipe work to further treat effluent so that it can be re-used in place of freshwater for certain processes in the plant.

Anticipated savings

To determine the economic effectiveness of this action, the quantity of water that could be re-used will need to be established. For each kilolitre of fresh water saved, the cost of effluent corresponding to that kilolitre of fresh water will also be saved.

On the negative side would be the cost of treatment per kilolitre.

Engineering personnel have indicated that an investigation into effluent treatment and re-use has already been performed, and a detailed report has been produced but was not available during the time of the assessment.

AIC 4 - Install Skylights and photosensor light controls

Estimated Electric Energy Savings: 804 776 kWh/yr
Estimated Electric Energy Cost Savings: R 303 314/yr
Estimated Total Cost Savings: R 303 314/yr
Estimated Implementation Cost: R 2 844 900
Simple Payback = 9 years

Recommended Action

Install skylights and use photo sensors to control artificial (electrical) lighting. Photo sensor devices allow control of lighting during periods when natural sunlight from exterior windows and skylights is adequate. Savings are due to reduced operating hours from the photosensor controlled light fixtures.

Background

The reasoning behind this ECO was that clean skylights transmit enough sunlight in a building for ambient light purposes during a clear day hence the bay lights could be turned off. Energy savings would accrue from reduced electrical costs. Dirty/old skylights need to be replaced.

Skylights

The use of skylights will result in energy savings by reducing the number of lights that have to be turned on during the day. The table below shows how clean polycarbonate skylights transmit sunlight as opposed to dirty fiberglass skylights. All values are measured at ground level during a partly cloudy day.

Assembly Hall		Container Warehouse	
Clean Skylights	Dirty Skylights	Clean Skylights	Dirty Skylights
751 lux	98 lux	595 lux	158 lux

The methodology of the measured values is as follows: In the Assembly Hall and the Container Warehouse, two measurements of luminous intensity

were taken below clean and dirty skylights in turn. The first measurement was taken during the day with lights on and the second measurement was taken during the night with the lights on. The difference between the two measurements (the contribution from the skylights) is shown in the table above. The impact of skylight cleanliness is clearly shown.

The lowest measured clean skylight value is 595 lux and highest measured dirty skylight value is 158 lux. The difference of those values, 437 lux, gives an idea of how much the lighting level in the plant increases if all dirty skylights are replaced with clean skylights. It moreover indicates that if the bay lights are turned off it is easily compensated by the increase of lux from clean polycarbonate skylights.

Photosensor (Photocell) Controls

Photocells are light-sensitive switches that are available in various sensitivities. During daylight hours the lamp is off and it turns on when the light level drops below the light level set-point of the control. It is best to use controls that are designed to turn the light on when the control fails; this is particularly important for security lights.

The installation of skylights will allow natural light to illuminate the plant during days without heavy fog or thunderstorms. A mixture of 400 watt high pressure sodium and 400 watt mercury vapor lamps provides the existing lighting in the area. The area of the pertaining rooms was estimated to be 59 000 m². The ceiling height is approximately eight to eleven metres (except for the steel store and the press shop with an approximate ceiling height of 17 metres). It was assumed for the calculations that the skylights could provide sufficient lighting 7,8 hours per day each of days the area is used. The number of days when the skylights would not provide sufficient light due to thunderstorms or heavy fog was also be taken into account when calculating the hours per year the lights will be left off.

Area of investigation

The comparison of present lighting levels during daytimes with the condition of skylights makes it possible to get a clear impression where the replacement of the skylights and at the same time turning off bay lights is feasible. In the Machining Hall, the Press Shop, the Steel Store and the Container Warehouse sufficient correlations are found. Those parts of the plant are the focus of the calculations involved in this ECO. However, the Assembly Hall, the Body Shop and the Pressed Part Warehouse appeared to be a more complex issue. In the Assembly Hall conveyor belts and production lines obscure the light transmitted through the skylights especially in the middle of the building. Inside the Body Shop highly positioned conveyor belt and production lines as well as high rooms also decrease the amount of light from the skylights. Furthermore the skylights in the Body Shop are mainly glass skylights which transmit sunlight much better than polycarbonate and are easier to clean. Therefore the skylights in the Body Shop are not considered as a possible replacement. In the Pressed Part Warehouse highly stockpiled boxes obscure the lighting level, too. Thus further investigation for the ideal solution is necessary in those parts of the plant.

Number of skylights needed:

The number of skylights needed depends on the condition of the skylights. Fiberglass deteriorates with age, exposing fibres that collect dust and render them almost opaque. Some of the fiberglass skylights have been replaced by polycarbonate, a smooth (therefore does not attract dust), long-lasting polymer. From an inspection of the plant, the skylights have been subdivided into clean (mostly polycarbonate), fairly clean (mostly fiberglass) and dirty (all fiberglass) as indicated in the Figures below. Cleaning of the skylights is a temporary option to increase the amount of light penetrating the skylight but this is labour intensive and would require ongoing attention. However, because of the long lasting (about 10 to 15 years) clean condition of the

polycarbonate the cleaning cost is not included in the cost calculations. In calculations in this section, fairly clean skylights (generally old fiberglass) have been grouped with dirty (fiberglass) skylights because they need to be replaced by polycarbonate. Drawings showing the condition of skylights are presented in APPENDIX F

Anticipated savings

The cost savings are due to switching off lights during daytime when sufficient light is transmitted through the skylights. The estimated energy conservation, EC , for replacing lamps in a specific area is given by the following relation:

$$EC = \frac{N \times CFW \times H}{C_1}$$

- N = number of fixtures in area that could be turned off, no units
 CFW = power rating of current fixtures in area, W
 H = non operating hours of lamp in area, h/yr
 C_1 = conversion constant, 1 000 W/kW

The demand reduction, DR , associated in a specific area is given by the following relation:

$$DR = \frac{N \times CFW \times CF}{C_1}$$

- CF = coincidence factor - probability that the equipment contributes to the facility peak demand, per month

Therefore, the total annual cost savings, TCS , can be estimated as follows:

$$TCS = (EC \times \text{energy rate}) + (DR \times \text{demand rate}^1) \times 12 \text{ mo/yr}$$

The following table is a summary of the anticipated savings from switching off lights during the day, and shows the anticipated savings per year for each area of the plant.

Building Area	Existing Ballast /Lamp Description	No. of Fixtrs	Fixture Power W	Total Power W	Coinc. Factor per month	Usage time h/yr ⁽¹⁾	EC (Total Energy Saving) kWhr/yr	DR (Monthly Average Demand Reduction) kW/mo	TCS (Total Annual Cost Savings) R/yr
Machining Hall	400W MV	260	454	118 040	1	2 190	258 507	118	97 430
Machining Hall	400W HPS	5	457	2 285	1	2 190	5 004	2	1 886
Container Warehouse	400W MV	134	454	60 836	1	2 190	133 230	61	50 213
Container Warehouse	400W HPS	59	457	26 963	1	2 190	59 048	26	22 255
Press Shop	400W MV	231	454	104 874	1	2 190	229 674	105	86 562
Steel and Heavy Tool Store	400W MV	120	454	54 480	1	2 190	119 311	54	44 967
TOTALS		809		367 478			804 776	366	303 314

Average Power Factor October 1999 – July 2000 assumed to be 0,9

Avoided Electric Cost: R 0,17978 /kWh

Avoided Demand Cost: R 35,973 /kW

⁽¹⁾ South African Weather Service: Thunderstorms 14 days per year, Fog 24 days per year, Average of 7,8 hours of sunshine per day

Table 18 – Anticipated savings from switching off bay lights during the day

Total Costs of Skylights

Estimates for replacement of the dirty skylights were obtained from two independent roofing contractors.

Estimate 1:

One 24 m section was quoted to cost R 20 000. A total of 61 sections are required for the machining hall, see APENDIX F, hence the total price is R 1 220 000.

Estimate 2:

The cost for the whole recommended replacements was estimated at R 2 832 900.

Cost of photo sensors:

Costs are shown in the table below.

Building Area	Number of Photo sensors needed	Total Installation Cost ⁽¹⁾	Total Implementation Costs
Machining Hall	4	R1 000	R4 000
Container Warehouse	4	R1 000	R4 000
Press Shop	4	R1 000	R4 000
Steel and Heavy Tool Store	4	R1 000	R4 000
TOTALS	16		R16 000

Table 19 - Cost of photo sensors

Payback period:

The calculation of payback period is shown below.

	Total annual cost saving (R/yr)	Total cost of skylights (R)	Total cost of photo sensors (R)	Pay back period (yr)
Estimation 1 (Only Machining hall)	97 430	1 220 000	4 000	13
Estimation 2 (Total replacements considered)	303 314	2 832 900	12 000	9

Table 20 - Calculation of payback period

The payback period of at least 9 years is very high. Moreover, after this period, the maintenance of the skylights also has to be considered. Based on the two quotes obtained (which varied significantly), returns from energy cost savings through skylights and photo sensors do not justify implementation. It is recommended that more quotes for skylight replacement be obtained – which may prove to be low enough to make this action economically viable.

⁽¹⁾ Number of circuits is unknown. Nominal allowance is estimated to be four sensors per hall under the assumption that it will be practical to install the sensors. The installation cost includes sensors, wiring, labour, and conduit (Rewiring may be needed).

3.2.3 Outcomes of the assessment presentation to management

Top management (directors) did not attend the presentation. The Engineering Manager had arranged that managers from the Finance, Human Resources and Procurement departments were present, along with several engineers from his Engineering department. Before the meeting began, the Engineering Manager informed the group that compressed air consumption had already been reduced by 40%.

The following staff ratios were recorded:

- Total managers = ± 120
- Manager/staff level (1 / 200)
- Supervisor/staff level (1 / 35)

The following points on the importance of energy efficiency were made:

- The Plant Finance Manager confirmed that expenditure on energy is roughly 5% of total overheads (excluding manpower) and represents approximately 10% of controllable costs. Agreed potential energy cost savings (as shown in the assessment report) are in the region of R 11 000 000 per annum.
- If energy is included as a key performance indicator for personnel evaluation (Section Managers) then energy consumption for each section would need to be monitored.

The following issues arose when the suggestion was made to create separate departmental energy budgets:

- This would be a sound policy if and only if monitoring of each department is achieved. Measurement and records of energy used by each department would be required.
- There was concern that agreement over energy budget allocations might not be achievable.

- There was a concern that the administrative burden might impact negatively on the flexibility of the plant.
- The cost estimate for all necessary monitoring equipment is approximately R300 000 (estimate from the 'Monitoring and Verification' document produced by D Van Es and Siboniso Khumalo, ERI, UCT)
- It was pointed out that different products would use different amounts of energy and that energy reticulation systems (electrical circuits, compressed air ...) overlap geographical section boundaries
- A suggestion was made to include a particular utility (compressed air, electricity ...) within a particular manager's area of responsibility (create a 'compressed air manager' and an 'electricity manager'). It was put forward that this would generate a higher level of awareness of the different utilities.

The last point led on to the concept of appointing an Energy Manager. The Engineering Manager currently dealt with energy issues within his portfolio. Discussion produced the following responses:

- The energy manager may become the scapegoat for all energy issues and possibly would not promote the culture that energy is everyone's responsibility.
- The Engineering Manager emphasised that the job description would need to include time and resources for investigating ideas for energy saving - not just for ensuring energy delivery.
- The point was made that VW is an international company with the goal of reducing headcount to a set target headcount. The Human Resources department would need to determine whether an energy manager could be appointed within the target headcount.

Two issues were identified as crucial to successful energy management.

- Firstly, the culture of irresponsibility towards energy use needs to be changed, but this is difficult to quantify.
- Secondly, energy-saving projects need to be prioritised and then require action.

When the obstacles to successful energy management were considered, all were related to financial systems and budgets. The following points arose.

- A budget for project investigation (a salary) would be required for successful energy management.
- Current budgets limit capital expenditure (CAPEX) and expenditure on overheads.
- Current budgets are based on expected return on investment (ROI) for the following year.
- CAPEX approval is focussed on car sales predictions - not energy cost savings. (Producing more cars is seen to be more worthwhile than saving costs.)
- Highest priority projects are those that will ensure uninterrupted production (Again, protection of the top line).
- Funding for energy related projects would currently come out of the planning budget. The planning budget is approximately 45% of the total budget.
- To create a separate budget for energy management, the General Manager of Planning (who was not present at the presentation) would need to approach the Board of Directors and motivate for an energy budget to be created (which would necessitate reductions in other budgets).

The following responses relate to the question of what suitable forum could be used for conveying information about energy efficiency.

- Awareness campaigns could be run.

- Energy efficiency could be included within the existing 'Ideas Management' system - which encourages employees to contribute ideas for technical and system improvements.
- Energy efficiency could be introduced as a feature in quarterly general staff meetings.

The possibility of including energy efficiency within the existing Quality Assurance (QA) system produced the following responses.

- The duties of the existing 'Process Quality Engineers' (PQE's) can be adjusted/changed. Current duties are based on the core functions of accountability, responsibility and knowledge.
- A concern was raised that adding additional duties to PQE's would interfere with their core functions.

Money is apparently not available for plant-wide improvement projects (such as energy efficiency projects) even if they can be shown to produce a reasonable return on investment. Comments related to this were:

- A change in mindset is needed, starting at Board level.
- Segregation of budgets shifts the focus away from corporate performance. The result is a narrow focus on departmental performance (individual budgets being carefully guarded without any vision of overall corporate performance).
- The change process needs to be elevated. Projects (such as energy efficiency projects) that have a reasonable ROI need to be presented at Board level to receive acceptance, support and funding.
- Resistance is expected from other budget holders because expenditure on plant-wide projects would reduce the size of departmental budgets.
- In order to get acceptance as a corporate project, integrity of information must be unquestionable.
- Projects that need to be dealt with on a corporate level will need to be identified.

The financing of energy projects was discussed:

- The benefit of ESKOM's possible involvement (using demand-side-management (DSM) funding) needs to be considered against self-funding.
- A link between cost savings and future CAPEX budgets does not currently exist. (The concept of a CAPEX 'reward' for energy projects, because of increased profits from energy cost savings, would not be entertained within the present system).

Education and training:

- The training centre has the capacity to present functional and leadership courses and can develop courses if there is an accepted need/demand.
- Energy would need to be part of the KPI's in order for energy training to be important or necessary.
- The decision to include energy efficiency as part of a training programme would need approval from the Board of Directors.

The following comments were made on the subject of changing the culture or attitude towards energy:

- Energy-related KPI's must be set up and cascaded downwards.
- An incentive system is already established in 'Ideas Management'.
- The use of an incentive system to encourage better housekeeping is not a good idea because it would be rewarding people for doing what they should be doing in the first place. People need to rather be held accountable for housekeeping.
- Awareness needs to be raised (possibly as a campaign). Previous success in environmental control was mentioned. Some possible routes for this are:
- A competition through 'Ideas Management'.

- Raise awareness through the house newsletter and electronic notice board.
- Include energy within the quarterly union feedback meeting.
- Use industrial theatre to get messages concerning energy efficiency across.
- A reward system for supervisors has recently been initiated. The aim of the system is to achieve a higher level of ownership and engagement. The reward is two tiered – being based on KPI's as well as corporate profits.
- Energy could be included in the KPI tier but performance would need to be measurable (monitoring required). Current KPI's are based on productivity, quality and throughput.

3.2.4 Monitoring and Verification Plan

Based on the findings of the energy assessment, a monitoring and verification document was produced by S Khumalo and D Van Es of the ERI, UCT. The document covered:

- Data requirements
- Monitoring periods (pre and post-implementation of ECO's)
- Monitoring equipment
- Energy consumption baseline characterisation and adjustment
- Savings (energy, costs and emissions) calculation methodology

The report estimates the total cost of monitoring at R270 000, including a R10 000 allowance for commissioning and training. The estimated total cost of all the energy cost saving measures is R12 825 098 which makes the M & V approximately 2% of this value. In addition, an Energy Manager would cost the company a further R150 000 per year.

The M&V report presented the following recommendations:

- Appoint a Project Manager with the sole responsibility of setting up and delivering all the requirements up to and including post-intervention monitoring and data collection
- Make a preliminary inspection of the plant under consideration, taking spot measurements and performing rough calculations to identify the most likely (feasible) opportunities for energy conservation.
- Note that non-electrical loads do not present an opportunity for Demand Side Management and that fuel substitution, while reducing energy costs, may not reduce the energy requirement to a process.
- Decide which energy (cost) saving opportunities are worth pursuing and consider how the existing (pre-intervention) and post-intervention energy consumption and costs can be simply, yet, reliably, assessed and monitored.

Note! Do not implement energy conservation measures before the existing energy consumption and costs have been accepted and agreed by all intended parties to the energy cost reduction programme. This is extremely important where Contract Energy Management companies may be involved.

- A (pre-intervention) baseline must be agreed between all involved parties, noting any possibilities for variations in production due to operational requirements.
- Determine and allow for the impact of changes in one variable on another, e.g., reduction in lighting power reduces the air conditioning load.
- Install measurement devices and connect to data loggers for those loads whose baseline values cannot be agreed in any other way.

- Loads may be cyclic in nature (e.g. seasonal) and it is necessary to analyse the collected data over a period long enough to establish reasonable repeatability.
- Energy conservation measures are introduced once all involved parties reach agreement on the baseline data.
- Ensure that additional metering and data-logging equipment is introduced as may be required by implementation of the conservation measure.
- Appoint an Energy Manager whose sole function is the analysis and interpretation of the data. The Energy manager must be part of the Finance Department.

3.2.5 Implementation

At the time of final editing of this thesis (October 2003) there had been an encouraging turnaround in the status of energy efficiency. The German VW head office was now including requiring energy and environment as a performance indicator. A manager with the portfolio of energy and environment had been appointed. An energy management system was starting to be put in place with the formation of "work circles" and "technical teams" for dealing with energy issues. Progress was reported in the monthly plant magazine and reported to the German head office quarterly. Monitoring of 90% of electrical substations was in place. Plant-wide monitoring of compressed air consumption was to be completed within two months.

ECO 1 (fixing air leaks) was beginning to be addressed. An air-leak tagging system was in place and the plant had reduced its compressed air consumption by 16%. ECO 3 (switching off compressors) had been implemented. ECO 4 (isolating compressed air lines during non-production hours) was being made possible by the installation of a ring-main compressed air line. ECO 5 (install power factor correction equipment) would be completed by the end of October. ECO 6 (using

waste heat to heat phosphate bath) was put on hold after consultants found the payback period would be too long (4 years as opposed to the initial 1,6 years predicted by this assessment). ECO 7 (install high efficiency lighting) was being addressed. Sixteen automatic voltage reduction devices had been installed on all major lighting circuits and 4000 lamps (2,4m magnetic ballast) had been replaced with 1,5m electronic ballasts). ECO 8 (turning off high bay lights) had been addressed by the installation of automatic time switches and the replacement of many of the high-bay lights with low level lighting. ECO 9 (using electricity or HFO for additional air heating in the ARP) was being investigated further, with the HFO option looking promising (after ESKOM increased electricity prices significantly). ECO 10 (heat recovery in ARP) was going to be implemented but suffered a setback when the heat pump acquisition fell through. An additional item that had received attention was the replacement of old skylights (the exact number of replacements was not available at the time of writing).

4. Discussion of Results

The findings of the literature survey and the results of the case study have revealed the following:

Strong incentives exist for energy efficiency improvement in SA industry.

South Africa, with its economic dependence on coal for electrical generation, produces significant quantities of GHG's - SA is the worst GHG offender in Africa. SA's GHG's are produced mainly through electricity generation from coal. In the near future, SA will be required to achieve greenhouse gas emissions targets.

SA uses roughly twice as much energy as the world average in its production. Our inefficient production is currently offset by our cheap and abundant coal. If we are forced to install cleaner coal-burning technology or reduce our coal combustion (or even pay for the externalities of coal combustion), the price of electricity will rise.

At the same time, Eskom is attempting to delay the capital cost required for more electrical peak-load generation capacity. Energy efficiency improvement, particularly in SA industry, is an effective way of achieving these three objectives.

Evidence suggests that there is much opportunity for energy cost saving through energy efficiency improvement in SA industry

The subject of the case study in this thesis is a leader in motor vehicle manufacturing in SA. Their attention to the manufacturing of an extremely high quality product did not extend to using energy efficiently.

The annual energy bill for this company was R40 000 000. Energy conservation opportunities worth R11 192 000 were identified (overlapping ECO's 2 & 4 and optional ECO 10b not included). If the nine main ECO's were implemented, energy savings of at least R10 000 000 would be

realised (a reduction of the annual energy bill by 25%). Seven of the nine ECO's have a payback within two years.

The results from three other energy assessments by the ERI at UCT have shown that other leaders in SA industry have also found room for improvement. Energy cost savings for South African Brewery's Prospecton plant were R1 370 000 per year (8% of annual energy costs) with a required investment of R1 180 000 and giving a payback of ten months. Energy cost savings for Anglogold's Elandsrand gold mine were R1 990 000 per year with a required investment of R1 293 000 and a payback of eight months. Sappi's Mandini plant was able to save R5 550 000 per year in energy costs (5% of annual energy costs) from an investment of R3 220 000, giving an overall payback of seven months.

These case studies strongly suggest that there is significant potential for energy cost saving through efficiency improvement in SA industry.

Barriers to the implementation of energy efficiency projects exist and need to be identified, anticipated, avoided and/or addressed by policy makers and energy efficiency practitioners.

The case study revealed a number of barriers to the implementation of the ECO's.

An ECO that fell within an existing budget would be implemented if the budget holder was aware of the opportunity and felt that it was part of their responsibility anyway. For example, the air leaks were fixed immediately because a budget existed that was supposed to be used for fixing air leaks. However, financing for 'improvement' projects (which is what many ECO's are) required an application for funds at a higher management level than the Engineering Manager had personal access to. Representation on this 'board' would be required.

The Engineering Manager was the initiator of the energy assessment. The meeting after the assessment revealed that his having the answers was only the first small step towards implementing the ECO's. Also, energy in this company was being treated as an overhead. Section managers had not been held accountable for energy consumption. An energy management system was not in place (although overall energy inputs were recorded).

Most of the obstacles to implementation that were being identified in the feedback meeting were the requirements for an energy management programme. If the interest and support of top management could have been obtained early on in the project, (as is emphasised in the energy management principles in Section 2.5) the budgetary and organisational obstacles that were identified in the feedback meeting might have been easily by-passed.

A high level of trust (and creative diplomacy) is necessary between energy consultant and management in order to dispel concerns that the assessment results may show middle management to be 'at fault'.

The turnaround that occurred after the German head office became involved was exciting and encouraging and reinforced the fact that informed leadership by top management is essential for the successful implementation of energy efficiency projects in SA industry.

5. Conclusions

Strong incentives exist for energy efficiency improvement in SA industry. Reduction of GHG emissions, the need to maintain economic competitiveness and the need to delay the cost of a new peak-load electrical generation plant are three objectives that can be achieved through improved energy efficiency in SA and particularly in SA industry.

Results from energy projects in industry in the USA and UK show that there is significant opportunity for energy cost saving through energy efficiency improvements. Case study assessments of industry leaders in SA suggest that SA industry is no different.

Organisation structure, financial controls and culture can be barriers to the implementation of energy projects. This can be avoided by ensuring the support of top management, and by the initiation of an energy management programme early on. The results and recommendations from the first energy assessment can then feed into an existing receptive energy management system.

Further investigation into the extent of energy management in SA industry may help in estimating the impact of energy efficiency programmes on energy consumption and energy intensity in South African industry.

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Websites

www.eia.doe.gov

www.iea.org

www.helio-international.org

www.energyusernews.com

University of Cape Town

Appendix A - Pre-assessment data form

Primary Contact: _____ Phone: _____

Other Contact: _____ Phone: _____

Address (street and mailing): _____

Directions: _____

Principal Products: _____ *Passenger cars and light commercials*

Product Distribution Area: _____ *Local + abroad*

Annual Production (units, lbs, etc): _____ ± 80000

Annual Sales: ± 80000 No of Employees: ± 6000

In-house Energy Management Engineer: _____

BUILDING LOCATION INFORMATION

Number of buildings to be considered: _____ *Refer attached document*

Major Areas (i.e. processing, warehouse, office, etc.):

<u>Area</u>	<u>Size</u>	<u>Notes</u>
<i>Refer attached document</i>		

Building leased or owned: _____ *owned*

Building Construction Date: _____ *refer attached*

Wall Construction (insulation, construction materials, etc): _____

Refer attached

Ceilings (insulation, height, construction): _____

Operating Schedules (office, production, major equipment, lights):

Production: Have hard copy available on Monday

Warehouse:

Offices:

HVAC EQUIPMENT

Heating (type, size, areas served): *Hard copy on Monday*

Air Conditioning (type, size, areas served):

Controls (setbacks, EMS, etc.): *Energy Management System –
obsolete / non functional*

Water Heaters (size, use, fuel): *± 101 geysers (2kW) not incl. Engine plant
and paintshop)*

Urns – not controlled

Kettles – not controlled

PROCESS EQUIPMENT

Boilers (size, type, purpose):

Electric – 2 x 36 kW

Showers B/S & Ass.

Thermic Oil x 2 Paintshop

Air Compressors (size, type, purpose): _____

2 x Ingersoll Rand Centac 2 x Atlas Copco ER 8 reciprocating

3 x Atlas Copco oilfree Rotary Screw Various smaller compressors throughout
plant - total: 2835 kW power consumption approx

Ovens/Kilns: Central ovens are heated through Parafin, Thermic Oil and LPG

Refrigeration/Process Coolers and Equipment: Cooling at Electrocoat,
compressed air paintshop, lasers and colour 1 oven exit

Chillers at colour 1 prep deck, touch up deck

Painting/Plating: 1100 kW Air Replacement Plant at colour 1 line, 2 and 3

Other Process Equipment: Resistance welding, laser welding, machining,
phosphating and electrocoating

Rollerbeds – 0.37 kW each Water test area

Lighting (types, size, controls, etc.): 5ft flurescent

8ft magnetic/elec balast

4ft flurescent

400W highbay mercury vapour

400W canopy mercury vapour

Flurescent – prep decks + touch-up decks (±41kW per deck)

DATA & SITE REQUESTS

Yes No

☒ ☐ Is a conference/meeting room available?
☐ ☒ Is safety equipment required? (Please list...) _____

☐ ☐ Are demand plots available?
☒ ☐ Are facility diagrams available?

- ☐ x Is an equipment list available (with motor size and heating ratings)?
- x ☐ Have copies of the site's utility bills for the last 12 months been assembled? (electric, gas, sewer & water, as applicable)

ENERGY CONSERVATION OPPORTUNITIES

Previous Energy Conservation Assessments (state, consulting, utility, etc.): _____

consulting

Existing Energy Conservation Measures (lighting, motors, etc.): _____

Energy Management System – non functional

Current Areas of Concern (Energy or otherwise...): _____

General

Potential Assessment Recommendation Opportunities:

Thank you for taking the time to complete this form.

APPENDIX B – Leakage in the compressed air system

The following air leaks were found during the assessment week. Leaks have been roughly classified into small (0 –29cfm), medium (30-100cfm), large (100 –300cfm) and huge (>300cfm). Where leaks could be measured (msrd), they were. Where the hole size and pressure were known, leaks were calculated (calcd). In some cases a rough comparative estimate (estd) could be made. Unfortunately the huge leaks were indeterminable because the extreme air velocities and volume flowrates.

This table is intended as a guide for beginning the process of repairing the air leaks.. Additional leaks are probable and can be most easily detected and repaired by plant maintenance personnel during non-production periods when the hiss of the air leaks will be easier to detect. Huge and large leaks are **bold printed**.

No.	Location: Press Shop, Upper level, Presses	Description	Size category	Waste estimate (cfm)
1	F3 7848	leak above beam of press	medium	
2	F3 7848	9mm ID hose blowing freely. No end connector.	medium	30cfm, msrd
3	B1 5696	pressed part lifter mechanism	large	
4	B1 5697	central connector	medium	
5	A2 4659	piston area, both sides	medium	
6	A1 4628	4 - way valve	large	
7	D2 4890	above press beam	medium	
8	D2 4890	leaks at pressure control valves	small	
9	D5 4893	leak at die	small	
10	D5 4893	table cushion control valve 7bar through 4,2mm hole	medium	50cfm, calcd
11	E6 7851	connector for hose on die	large	
12	E6 7851	hole in orange hose	large	
13	E6 7851	connector to blue hose on south side of press	small	
14	E5 5483	leaking T (blue pipe on wall side)	small	
15	E5 5483	connector to blue hose on south side of press	medium	40cfm, estd
16	E5 5483	inside post (side) of press	indet.	
17	C4 8604	above press beam	small	
18	F5 6262	above press beam	small	
19	B3 5697	upper press	large	
20	B2 5698	press sides	small	
21	C3 8603	flexible hose to tool car (C5)	small	
22	C5 10292	connector of tool car flexible hose	small	
23	F1 7850	die manifold fed by green hose	large	130cfm, msrd
24	F2 5486	connector to blue hose on south side of press	medium	30cfm, estd
25	E3 5485	above press beam	medium	80cfm, estd
26	D3 4891	leaks at pressure control valves	small	

27	D1 4894	black hoses above press beam	medium	
No.	Location: Press Shop, Lower level below presses, South side	Description	Size	Waste estimate (cfm)
28	Electrical cabinet (EC) 7849	10mm ID drain hose, permanently open (during entire week), (8mm @ 6 bar)	large	220cfm, calcd
29	opposite EC no.4 (14/800/115)	leaking valve	small	30cfm estd
No.	Location: Press Shop, Lower level below presses, North side	Description	Size	Waste estimate (cfm)
30	Between EC's TAG- 4628 and TAG-4888	10mm ID blowdown pipe permanently open (whole week), (8m @ 6bar)	large	220cfm, calcd
31	opposite EC TAG- 48888	leaking oil separator	small	
32	6th receiver from East end	leaking union	small	40cfm, estd
33	3rd receiver from East end	hole in valve (2mm), 6 bar	small	16cfm, calcd
34	green cylinder closest to EC TAG 5698	air leak	small	
35	4th receiver from East end	leak in pipework	medium	
36	above EC 7851	leaking coupling on 12mm pipe	small	
No.	Location: Paint Shop, Ground floor	Description	Size category	Waste estimate (cfm)
37	Station 26	air leak on hose coupling	small	
38	Group 8	air leak on hose coupling	small	
39	Station 10, Graco spray machine	air leak on hose coupling	medium	
40	Station 5, Graco spray machine	leak	small	
41	directly above EC marked "Main switch"	leak at hose feeder	medium	
42	stations 1 to 10 directly after 'blowing' oven	a number of leaks	small	
43	self etching spray booth	leak in hose	small	
44	primer bay stn 7 and 8	leak in hose coupling	medium	
45	wet on wet and blackout booth	leak in hose	small	
46	paint mix room	leaking crane	small	
47	paint mix room	open ended 5,5mm hose @6,6 bar	medium	60cfm calcd
No.	Location: Assembly Hall	Description	Size category	Waste estimate (cfm)
48	vehicle lift crane, citi- golf line	airleak on Haden vehicle lift	medium	
49	at main road entrance, AR45	auto-blowdown valve stuck open	huge	
50	where cars cross isle J overhead	air leak	medium	

51	station 56, opposite BH54	leaking air filter	small	
52	between stations 39 and 40	leaking hose on air filter	small	
53	just below roof, above sign "B5 Audi Fine Finishing Line"	air leak	medium	
54	column next to AV58	leaking air filter	small	
55	station 54 alongside stairway in isle F	open 10mm hose (tied to column to prevent it from thrashing around), (8mm @ 6 bar)	large	150cfm, calcd
56	1st level, station 8 above isle E	greasing tool, 4mm hole, 6 bar	medium	50cfm calcd
57	station 16 zone 4 on Golf line	leak in hose	small	
58	on roof, 2x8mm copper pneumatic tubing	tubing not closed off properly	medium	
No.	Location: Body Shop	Description	Size category	Waste estimate (cfm)
59	right-hand side of main road entrance, AL44	auto-blowdown stuck open, outlet feeds into NE downpipe, very noisy	huge	Indet.
60	North side of two Atlas Copco LT compressors	leaking main line flange or blowdown stuck open	large	indet
No.	Location: Pressed Part Warehouse	Description	Size category	Waste estimate (cfm)
61	Blue oiler plant	leak in hose	small	
62	halfway between Eng. Workshop and West wall	leak in main 5" airline	medium	

APPENDIX C – Lighting levels in the plant

The following colours have been used to indicate light levels (in lux) in each part of the plant: Building outlines are not to scale.

light level (lux)	0-40	40-120	120-240	240-280	280-600	600-2 000	>2 000
colour							

Machining Hall: Date: 07.08.2001 Time: 15:00-16:00

Assembly Hall: Date: 08.08.2001 Time: 16:00-17:00

Body Shop: Date: 09.08.2001 Time: 13:00-15:00 and
Press Shop: Date: 11.08.2001 Time: 14:45-15:30 and
Steel and Heavy Tool Store: Date: 22/10/2001 Time: 13:30 – 14:00

Pressed Part Warehouse: Date: 11/08/2001 Time: 14:00 – 14:45

Container Warehouse: Date: 11/08/2001 Time: 10:00 -11:00

APPENDIX D – Lamp replacement calculations

The estimated energy conservation, EC , for replacing lamps in a specific area is given by:

$$EC = [N \times (CFW - PFW) \times H] / C_1$$

where,

- N = number of fixtures in area, no units
- CFW = power rating of current fixtures in area, W
- PFW = power rating of proposed fixtures in area, W
- H = operating hours of lamp in area, h/yr
- C_1 = conversion constant, 1,000 W/kW

The demand reduction (DR) associated with replacing lamps in a specific area is given by:

$$DR = [N \times (CFW - PFW) \times CF] / C_1$$

where

- CF = coincidence factor - probability that the equipment contributes to the facility peak demand, per month

The change in annual lamp replacement cost (LRC - which may be positive or negative) for a specific area is given by:

$$LRC = [(NEL \times ELC / ELL) - (NPL \times PLC / PLL)] \times H$$

where

- NEL = number of existing lamps
- ELC = existing lamp cost, ZAR
- ELL = existing average lamp life, hours
- NPL = number of proposed lamps
- PLC = proposed lamp cost, ZAR
- PLL = proposed average lamp life, hours

Therefore, the total annual cost savings, TCS , can be estimated as follows:

$$TCS = (EC \times \text{energy rate}) + (DR \times \text{demand rate}^{(1)} \times 12 \text{ mo/yr}) + LRC$$

⁽¹⁾ Assumption: Maximum chargeable demand

Avoided Electric Cost: R 0,17978 /kWh
Avoided Demand Cost: R 35,973 /kW

The total implementation cost is:

$$\text{TIC} = \text{R } 63\,440 + \text{R } 32\,760 + \text{R } 98 + \text{R } 13\,000 = \text{R } 109\,298$$

The simple payback period is:

$$\text{Simple payback} = 109\,298 / 35\,728 = 3,1 \text{ years}$$

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APPENDIX E - Incremental relamping (spot and group relamping)

A common practice for many facilities is to relamp on a spot basis as the lamps burn out or group relamp a fraction of the fixtures in an area of the plant at periodic time intervals depending upon the rated life of the lamps and the annual usage hours of the lamps. These methods of relamping spread the total implementation cost over several years, as lamps are replaced only as the existing lamps burn out. The purpose of this section is to present estimates of the annual cost savings and implementation costs that are expected for the first two years if these methods of relamping are followed.

The annual savings due to replacing burned out conventional lamps with energy efficient lamps will depend on the life of the old lamps. Assuming an even distribution of lamp life throughout the areas considered, the current annual lamp replacement fraction, f , is estimated as follows:

$$f = H / CLL$$

where H is the number of hours that the lamp operates per year and CLL is current lamp life in hours. As an example, the lamp replacement fraction (f) for the Machining Hall, where lamps are turned on for 8 760 h/yr with lamps that have an average life of 24 000 hours (only looking at 400W MV), is calculated as follows:

$$f = 8\,760 / 24\,000 = 0,365$$

This value can be used to estimate the number of lamps of a specific type that will burn out each year. All lamps in a fixture are assumed to be of equal age, thus the lamp replacement fraction also represents the fixture replacement fraction for each area of the facility. The energy savings for an area after the first year would be the fraction of fixtures that burn out in that area in a given year multiplied by the difference in the total projected and total current electrical energy usage for all fixtures in that area. Each succeeding year more of the original lamps, ballasts and igniters are replaced with energy efficient lamps, ballasts and igniters. Thus, the incremental energy conservation in the n^{th} year, IES_n , can be estimated as follows:

$$IES_n = n \times f \times ES$$

The incremental savings cannot be greater than the total savings when all the lamps, ballasts and igniters have been replaced (i.e., if $f \times n > 1$, then $f \times$

$n = 1$). As an example, the incremental energy conservation that can be realized in the first year ($n = 1$) for the Machining Hall, IES_1 , is as follows:

$$IES_1 = (1)(0,365)(362,14) = 132,18 \text{ kWh/yr}$$

Similarly, the incremental cost savings after the n^{th} year, ICS_n , can be estimated as follows:

$$ICS_n = n \times f \times CS$$

As an example, the incremental cost savings that can be realized in the first year for the Machining Hall are, ICS_1 , are calculated as follows:

$$ICS_1 = (1)(0,365)(29\ 649) = R10\ 822$$

The incremental implementation cost for an area is equal to the fraction of fixtures in that area requiring replacement in a given year multiplied by the sum of the differential lamp costs, ballast and igniter costs for that area and labor costs (because ballasts and igniters are being installed). Except for the final year of lamp and ballast and igniter replacement, each year will have the same fraction of fixture replacement and thus equal incremental implementation costs. Each successive year will also have increasing cost savings. The final year will usually have a smaller fraction of fixtures to replace and thus a lower incremental implementation cost. The annual incremental implementation cost, IIC , can be calculated as follows:

For years 1 to $(n - 1)$:

$$IIC_n = f \times [\text{differential lamp cost} + \text{ballast cost} + \text{igniter cost} + \text{labour cost}]$$

For year n :

$$IIC_n = [1 - ((n - 1) \times f)] \times [\text{differential lamp cost} + \text{ballast cost} + \text{igniter cost} + \text{labour cost}]$$

The incremental cost savings and implementation costs for the remaining lamps in the facility are listed in the following tables.

Building Area	Annual Usage Time h/yr	Rated Lamp Life hours	Annual Replacement Fraction	1st Year Energy Savings kWh	1st Year Demand Savings kW	1st Year Energy Cost Savings	1st Year Demand Cost Savings	1st Year Cost Savings	2nd Year Energy Savings kWh	2nd Year Demand Savings kW	2nd Year Energy Cost Savings	2nd Year Demand Cost Savings	2nd Year Cost Savings
Machining Hall	8 760	24 000	36,5%	132 181	181,1	23 763	6 514	30 277	264 361	362,1	47 527	13 027	60 554
Machining Hall	8 760	24 000	36,5%	2 590	3,5	466	128	593	5 180	7,1	931	255	1 186
Pressed Part Warehouse	8 760	24 000	36,5%	93 543	128,1	16 817	4 610	21 427	187 086	256,3	33 634	9 219	42 854
Pressed Part Warehouse	8 760	24 000	36,5%	14 503	19,9	2 607	715	3 322	29 007	39,7	5 215	1 429	6 644
Container Warehouse	8 760	24 000	36,5%	68 124	93,3	12 247	3 357	15 604	136 248	186,6	24 495	6 714	31 209
Container Warehouse	8 760	24 000	36,5%	30 561	41,9	5 494	1 506	7 000	61 121	83,7	10 988	3 012	14 000
Press Shop	8 760	24 000	36,5%	117 437	160,9	21 113	5 787	26 900	234 875	321,7	42 226	11 574	53 800
Body Shop	8 760	24 000	36,5%	96 593	132,3	17 366	4 760	22 126	193 187	264,6	34 731	9 520	44 251
Body Shop	8 760	24 000	36,5%	5 698	7,8	1 024	281	1 305	11 396	15,6	2 049	562	2 610
Assembly Hall	8 760	24 000	36,5%	243 517	333,6	43 780	12 000	55 780	487 034	667,2	87 559	24 000	111 559
Assembly Hall	8 760	24 000	36,5%	13 985	19,2	2 514	689	3 203	27 971	38,3	5 029	1 378	6 407
Steel and Heavy Tool Store	8 760	24 000	36,5%	61 006	83,6	10 968	3 006	13 974	122 013	167,1	21 935	6 013	27 948
TOTALS				879 739	1 205,1	158 159	43 352	201 511	1 759 478	2 410,2	316 319	86 704	403 023

Incremental Saving:

Building Area	Annual Usage Time h/yr	Rated Lamp Life hours	Annual Replacement Fraction	1st Year Lamp Cost R	1st Year Ballast Cost R	1st Year Igniter Cost R	1st Year Labor cost R	1st Year Implement. Cost R	2nd Year Lamp Cost R	2nd Year Ballast Cost R	2nd Year Igniter Cost R	2nd Year Labor cost R	2nd Year Implement. Cost R
Machining Hall	8 760	24 000	36,5%	23 156	11 957	36	4 745	39 894	46 311	23 915	72	9 490	79 788
Machining Hall	8 760	24 000	36,5%	445	230	36	91	802	891	460	72	183	1 605
Pressed Part Warehouse	8 760	24 000	36,5%	16 387	8 462	36	3 358	28 243	32 774	16 924	72	6 716	56 486
Pressed Part Warehouse	8 760	24 000	36,5%	2 494	1 288	36	511	4 328	4 987	2 575	72	1 022	8 656
Container Warehouse	8 760	24 000	36,5%	11 934	6 163	36	2 446	20 578	23 868	12 325	72	4 891	41 156
Container Warehouse	8 760	24 000	36,5%	5 255	2 713	36	1 077	9 080	10 509	5 427	72	2 154	18 161
Press Shop	8 760	24 000	36,5%	20 573	10 624	36	4 216	35 448	41 146	21 247	72	8 432	70 896
Body Shop	8 760	24 000	36,5%	16 921	8 738	36	3 468	29 163	33 843	17 476	72	6 935	58 326
Body Shop	8 760	24 000	36,5%	980	506	36	201	1 722	1 959	1 012	72	402	3 444
Assembly Hall	8 760	24 000	36,5%	42 660	22 029	36	8 742	73 466	85 319	44 058	72	17 484	146 933
Assembly Hall	8 760	24 000	36,5%	2 405	1 242	36	493	4 175	4 809	2 483	72	986	8 350
Steel and Heavy Tool Store	8 760	24 000	36,5%	10 687	5 519	36	2 190	18 432	21 374	11 038	72	4 380	36 864
TOTALS				153 896	79 471	429	31 536	265 332	307 791	158 941	858	63 072	530 663

Incremental Costs

APPENDIX F – Condition of skylights in main workplaces

Key

Clean	Yellow
Fairly Clean	Red
Dirty	Dark Red

Machining Hall:

Length of one bay: 24 metres.

Number of bays to be replaced: 61

Total length of skylights to be replaced: $24 \times 61 = 1\,464$ metres

one bay

Body Shop, Press Shop, Steel and Heavy Tool Store:

(The rest of the skylights are plate-glass skylights and are therefore not marked in the drawing)

The following data was measured, but positions not recorded:

Steel Store & Heavy Tool :

Length of one bay: 24 metres

Number of bays to be replaced: 25

Total length of skylights to be replaced: $24 \times 25 = 600$ metres

Press Shop:

Length of one bay: 36 metres.

Number of bays to be replaced: 18

Total length of skylights to be replaced: $36 \times 18 = 648$ metres

Container Warehouse:

Length of one bay: 24 metres.

Number of bays to be replaced: 29

Total length of skylights to be replaced: $24 \times 29 = 696$ metres

Appendix G - Plant layout diagram