

**RESEARCH ON REDUCING COSTS OF
UNDERGROUND VENTILATION NETWORKS IN
SOUTH AFRICAN MINES**

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ABSTRACT

Title:	Research on reducing costs of underground ventilation networks in South African mines
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South Africa is currently facing a major electricity crisis due to the continuous growth in electricity demand. Eskom, the largest electricity supplier in South Africa, have enabled numerous methods to support energy reduction in both the residential and industrial sectors.

Programs developed by Eskom to help the different major electricity consuming industries with the development of energy efficient and load shift strategies, have already been put into practice. These programs solely focus on the potential savings in megawatts each production sector might consist of. The key features of the Eskom electricity reduction initiative are driven by the energy efficiency concept and the peak demand load shift capability.

Both the load shift and energy efficient initiatives are mostly active in the mining industry, because of the high electricity consumption levels of a standard mining operation. One of the most inefficient systems currently active within a mining operation is the ventilation control system.

This dissertation describes the energy efficient and load shift research on the current underground ventilation system by means of certain design methodologies that might improve the inefficient operational features on both the standard underground auxiliary fans and the main surface fans.

The operational features of a standard 2-pole 45 kW issued auxiliary fan were tested, by using a fan-testing column to compare the performance criteria to that of an improved auxiliary fan design.

An energy saving potential on a single 45 kW unit of 11 kW was evident during the testing analysis. This amounted to an estimated annual energy saving potential of R 370,000.00 with a total saving of 561 kW on all the installed 45 kW units at Kopanang goldmine, by means of an investment in the replacement of the current installed units with that of the improved units.

A secondary study was to gather information on the main surface fan operational features at Kopanang and Mponeng goldmines. The gathered information showed an estimated possibility for load shift and efficiency initiatives, which will result in fan operating life expansion and electricity savings capabilities.

Annual electricity savings of up to R 1,500,000.00 were calculated on efficiency and load shift strategies and gave an indication on how costly inefficient operations are. The calculated 10% increase in main fan efficiency resulted in an annual saving of nearly R 1,100,000.00 with a reduction of 1,05 MW at Mponeng goldmine and an annual saving of nearly R 721,000.00 with a reduction of 675 kW at Kopanang goldmine. The load shift potential at Mponeng and Kopanang goldmines were nearly 3,5 MW and 2,25 MW respectively.

Capital investments from either Eskom or alternative investors will definitely play a crucial part in the realization of energy efficiency and load shift measures. It may include, improved fan installations, variable speed drives for the main fans and real time management systems.

If the mine should decide to invest in these efficient strategies, the proposed Eskom DSM program might result in a net energy savings potential for any mining operation.

SAMEVATTING

Titel:	Research on reducing costs of underground ventilation networks in South African mines
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Die toenemende aanvraag vir elektrisiteit in Suid-Afrika het 'n probleem kwessie geword vir die energie verskaffer. Eskom, die grootste verskaffer van elektrisiteit in Suid Afrika, het weens die toenemende aanvraag verskeie metodes geïnisieer wat as ondersteunings middel dien om energie verbruik te verminder tot voordeel van beide die publieke en industriële sektore in Suid-Afrika.

Programme om verskeie super elektrisiteits verbruikers te help met die ontwikkeling van energie effektiewe en lasskuif strategieë het alreeds in werking getree.

Hierdie programme fokus slegs op die potensiële besparing in megawatts wat elke produksie sektor besit. Die sleutel aspekte van die Eskom elektrisiteits vermindering initiatief word gedryf deur die energie effektiewe inisiërings konsep asook deur middel van die piek lasskuif proses. Beide lasskuif asook energie effektiewe programme is grootendeels operationeel in die mynbedryf weens die hoë elektrisiteits verbruik in die algemene Suid Afrikaanse myn. Een van die oneffektiewe sisteme wat tans operasioneel is in die mynbedryf is die ventilasie sisteem.

Hierdie studie beskryf die potensiele energie vermindering van die huidige ondergrondse ventilasie sisteem met die hulp van sekere ontwerps metodes om die oneffektiewe operationele karakteristieke van die verskeie waaiers te optimaliseer.

'n Standaard 2-pool 45 kW waaier is getoets om die resultate te vergelyk met die van 'n geoptimaliseerde waaier. 'n Energie besparing van 11 kW op 'n enkele 45 kW waaier eenheid was sigbaar tydens die waaier toets periode. Dit dra by tot 'n moontlike jaarlikse koste besparing van ongeveer R 370,000.00, asook 'n totale energie besparing van 561 kW as die 45 kW eenhede op Kopanang goudmyn vervang sou word met die geoptimaliseerde waaier ontwerp.

Die sekondêre studie is gebaseer op die oneffektiewe operationele karakteristieke en lasskuif potensiaal van die bogrondse oorhoofse waaiers by Kopanang en Mponeng goudmyne. Die navorsing het getoon dat daar moontlike geleenthede vir las verskuiwing en energie effektiewe ontwerpe bestaan wat wel 'n impak op die operationele lewensduur van die waaier sal hê tesame met elektrisiteits besparingsmoontlikhede.

'n Jaarlikse elektrisiteits besparing van byna R 1,500,000.00 is bereken volgens die energie effektiewe en las verskuiwing metodes wat 'n duidelike aanduiding gee van watter impak oneffektiwiteit op die oorhoofse waaiers het.

Die berekende 10% toename in oorhoofse waaier effektiwiteit het 'n jaarlikse besparing van byna R 1,100,000.00 opgelewer met 'n koste besparing van 1,05 MW by Mponeng goudmyn asook 'n jaarlikse koste besparing van ongeveer R 720,000.00 met 'n energie besparing van 675 kW by Kopanang goudmyn. Die moontlike lasskuif potensiaal was ongeveer 3,5 MW en 2,25 MW onderskeidelik by Mponeng en Kopanang goudmyne.

Kapitale beleggings van beide Eskom en alternatiewe beleggers sal definitief 'n dominerende rol speel in die inisiëring van die energie effektiewe en lasskuif maatstawwe. Die beleggings kan dalk die volgende insluit; geoptimaliseerde waaier tegnologie, verstelbare snelheids toestelle vir die bogrondse waaiers en 'n moontlike ware energie tydsbestuur sisteem.

As die myn mag besluit om te belê in die energie effektiewe of lasskuif strategieë, sou die voorgestelde Eskom DSM inisiatief die oplossing wees vir 'n netto besparingspotensiaal.

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NOMENCLATURE

BAC	Bulk Air Cooling
c/kWh	Cent per kilowatt hour
CR	Cost Ratio
DME	Department of Minerals and Energy
DSM	Demand Side Management
EE	Energy Efficiency
EEDSM	Energy Efficiency and Demand Side Management
ERC	Energy Research Centre
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Gigawatt
GWh	Gigawatt hour
kW	kilowatt
LCC	Life Cycle Cost
MW	Megawatt
NERSA	National Energy Regulator of South Africa
Pa	Pascal
VRT	Virgin Rock Temperature
pf	Power Factor
P_{fan}	Fan Output Power
P_t	Fan Total Pressure
P_{input}	Electric Input Power
P_{shaft}	Shaft Power
P_{air}	Air Power
$\eta_{impeller}$	Impeller Efficiency
η_{motor}	Motor Efficiency

NOMENCLATURE

η_{fan}	Fan Efficiency
U_{line}	Line Voltage
I_{line}	Line Current
α	Solid Angle of Cone

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Chapter 1

INTRODUCTION – ENERGY MANAGEMENT

This chapter describes the role of energy efficiency and load shift in the South African energy sector. It looks at a variety of energy consumers but mainly focuses on the mining sector. The large energy consumption of the mining industry draws the attention towards inefficient production methods. The chapter concludes with a discussion on the effect of inefficient energy practice in the mining industry.

1.1 OVERVIEW OF THIS CHAPTER

The ongoing research and development of optimised energy efficient and load shift management strategies are currently playing an integral part in the South African industrial sector. Due to the continuous augment in electricity demand, inefficient operations are gradually replaced by improved management methods, which contribute to major energy savings by means of energy efficient or load shift executions to the benefit of both the energy supplier and the consumer.

With the mining industry being a large electricity consumer in South Africa, load shift and energy efficient strategies might play a crucial part in the reduction of annual electricity costs of this industry in the near future.

This chapter looks at the current status of the South African electricity sector, the possibilities of load shift and energy efficient strategies and it gives a short description on the highly inefficient ventilation system of the standard mining operation in South Africa.

1.2 ELECTRICITY DEMAND IN SOUTH AFRICA

1.2.1 Brief history on South African electricity supply

The energy sector of South Africa has been and continues to be the dominant force behind the country's economical growth. With the continuous requirement for a better and easier lifestyle throughout the world, energy became a necessity rather than a daily requirement.

The high increase in electricity demand was a major concern for the government in the 1960s and 1970s, which initiated the construction of numerous power stations and other energy sources in the country [1]. During the 1980s and 1990s, the national utility was left with a large excess capacity, where the capacity is shown as the difference between Eskom's total licensed capacity and the peak demand in Figure 1.1 [2].

This energy surplus ensured the lowest electricity costs in the world, but with the steadily exhaustion of the capacity throughout recent decades, the electricity peak demand has increased through this period in time.

Within the next three to five years [3], South Africa's excess capacity will no longer be the bargaining factor for low electricity costs [4]. With most of the capacity already been paid off, the need for new investments were pointless in the past, but it will become a necessity in the very near future with a direct impact on electricity pricing [1].

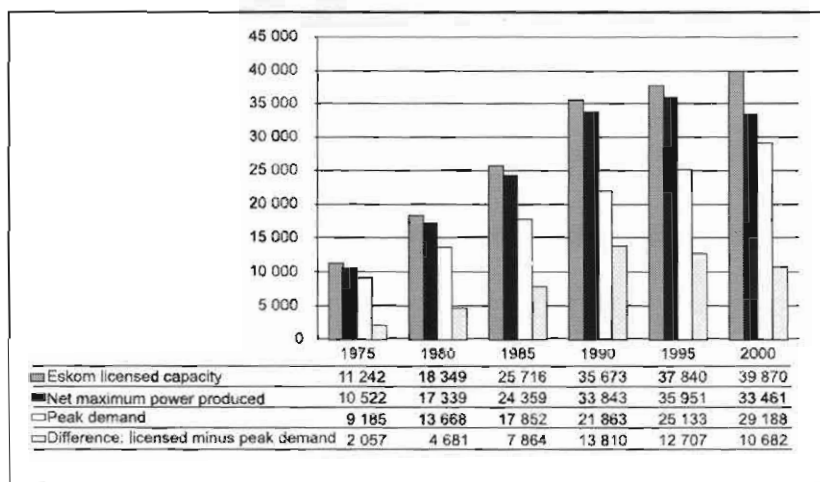


Figure 1.1: Eskom licensed capacity and peak demand (MW) [2]

1.2.2 Coal-fired electricity generation

South Africa has very large coal reserves, with an approximate 5.6% [6] of the total reserves in the world. Looking at the primary energy supply of South Africa, coal contributes to nearly 79.8% [7] of the total supply as shown in figure 1.2. The utilisation of this coal largely focuses on export, liquefaction and most importantly electricity generation.

Approximately 90% [6] of South Africa's electricity comes from coal-fired power stations, which is mostly owned and operated by Eskom. The low cost in coal has encouraged the growth for an energy-intensive industry, especially in the smelting and mining sectors [4].

Future predictions show that the dominance of coal generated operations will continue for at least two decades, but the supply capacity from 2007 onwards will be affected by daily high demand (peak) periods [8]. The use of South Africa's low cost coal is currently very inefficient, but it leaves room for significant opportunities in energy efficient sustainability [9].

Energy efficient measures on the other hand will not change the energy intensive structure of South Africa, but it will provide a short term solution before the demand for new power stations become essential.

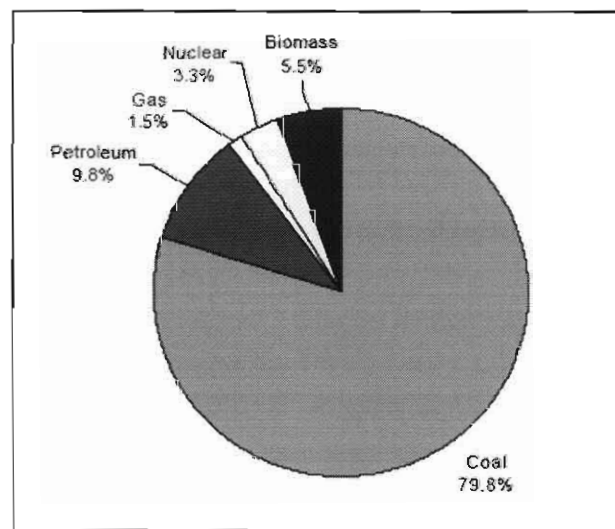


Figure 1.2: Share of total primary energy supply, 2000 [7]

1.2.3 Electricity growth

The energy consumption levels of South Africa are substantially higher in comparison to other developing countries, consuming half of Africa's electricity [10]. Of this electricity bulk, nearly three quarters gets distributed to the industrial and mining sectors [11] as shown in Figure 1.3.

With the major expansions in platinum mining, increased demand for ferrochrome and other industrial project approvals, an electricity growth of 4% per annum [12] was evident up until 2006. The growth will marginally continue to increase but the expansion of electricity intensive industries and the high demand in platinum are expected to decline after 2007/2008 [12].

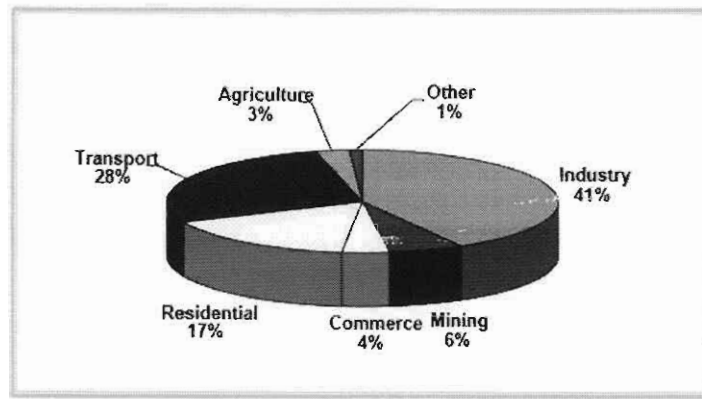


Figure 1.3: Final sectoral consumption of electricity in South Africa. [11]

1.2.4 Mining consumption

The direct consumption of electricity by mining operations amounts to roughly 17,6% of the electricity sold in South Africa [13]. In 2003, the mining industry alone bought 33 372 GWh of electricity from Eskom, but in 2005 the electricity sold to this industry grew to 18% [14]. This is a clear indication that the energy consumption of the mining industry is on a steady but moderate rise.

According to the ERC (Energy Research Centre) electricity-forecasting tool, the demand from the different mining sectors up and till 2020, shown in Figure 1.4 and Table 1.1, will grow with distinct proportion, but the impact of sectors such as the gold mining industry will fade within forthcoming years.

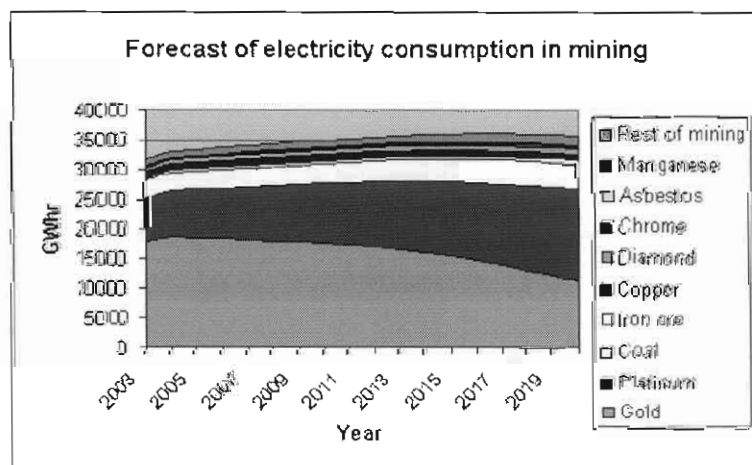


Figure 1.4: Forecast of electricity consumption in mining [13]

Although the mining industry in South Africa is among the richest in the world, the mineral production methods have been very inefficient to date. With a contribution of R 55 billion or 6.2% to gross domestic product (GDP) in 2004 [13], the relation between GDP growth and efficient production remains to be fundamental.

Sector	Demand in 2020 relative to 2003
Gold	-38%
Platinum	115%
Coal	46%
Iron ore	72%
Copper	-20%
Diamond	33%
Chrome	61%
Asbestos	-8%
Maganese	45%
Rest of mining	96%

Table 1.1: Future South African mineral growth projections [14]

1.3 ELECTRICITY SAVINGS OPPORTUNITIES

1.3.1 Energy Efficiency

The challenge of sustainable energy is becoming a primary objective throughout the world today. The aim is to alter the way energy is utilized in support of social, environmental and economical sustainable development objectives.

With the energy intensive industry of South Africa, it is difficult to visualise the apparent paradox between using less energy and the development of the country, based on energy intensive activities [15]. But up until recent years the perspective has changed due to the success of energy efficient methodologies.

The White Paper on Energy Policy compiled by the Department of Minerals and Energy (DME) identified energy efficiency as an area that needs to be developed and promoted to meet the requirements of the future energy demand [16].

Energy efficiency (EE) refers to the reduction of overall electricity consumption by means of energy efficient technologies and retrofits [17]. The impact of energy efficient programs is visible during all time periods, it enables the reduction of peak demand that is more expensive to generate, and it has a positive impact on the environment.

The EE initiative puts a downward pressure on energy prices by curbing the demand instead of increasing the supply [18]. This allows the preserving of the resource base in South Africa, acting as a pollution prevention technique and as a key ingredient for sustainable development [19].

The energy intensive economy of South Africa will be affected by the efficiency initiative, the shift towards better practice and the aim to reach the energy efficient boundary, will be the strategy to realise policy goals [4].

1.3.2 Goals to be achieved by energy efficiency strategies

The energy efficient targets and policy goals set by the government, aim at the reduction of an approximate 12% in electricity demand by 2015 [15] as illustrated in Figure 1.5. The strategic procedure to achieve the policies set by the National Energy Regulator of South Africa (NERSA), will be on a strictly monitory basis by means of an evaluation process [16]. Efficiency improvements and implementation reviews will be the focus area whereby the goals are obtained.

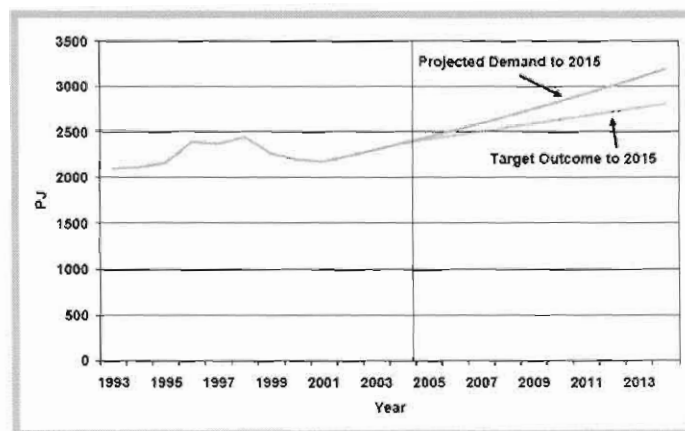


Figure 1.5: Projected energy demand vs. future energy reduction target.

In developing the regulatory policy for EE programmes in South Africa's electricity sectors, the NERSA is guided by the implementation of EE, the restructuring of the electricity industry and government policies on EE to encourage and facilitate the development of the programs in order to control the projected demand [17].

1.3.3 Government Efficiency Deployment Goals

The deployment of the energy efficiency regulatory policy has eight distinctive goals within the social, environmental and economical sustainable fields. These goals are listed below with a brief description on the effect of each model described.

Social Sustainability [20]:

1. Improve the health of the nation – Reduction in atmospheric emissions causes cutback in harmful substances known to have adverse effect on human health.
2. Job creation – Nationwide employment opportunities due to energy efficiency implementations.
3. Alleviate energy poverty – Energy efficiency enables the adequate provision of energy services to the community at an affordable cost.

Environmental Sustainability [20]:

4. Reduce environmental pollution – Energy efficiency will reduce the local environmental impacts of its production and use.
5. Reduce CO₂ emissions – Most cost effective methods of reducing GHG emissions.

Economic Sustainability [20]:

6. Improve industrial competitiveness – Cost-effective way of maximizing commercial profitability with the adoption of appropriate EE measures.
7. Enhance energy security – Will increase the country's resilience against external energy supply disruptions and price fluctuations.
8. Defer the necessity for additional power generation – Contributes 34% towards the 2015 demand reduction target of 7.3 GW.

1.3.4 Demand side management

Together with the current inefficient end-use of electricity as mentioned earlier, the regulatory policy has identified another problematic feature, namely, peak generation capacity. The typical pattern of this peak generation has two distinct peaks, one in the morning and a higher one in the early evening [1]. In the winter the peak demand is more pronounced than in the summer (see Figure 1.6), this causes a requirement for additional peak capacity. With the operational generation capacity in South Africa currently 37 056 MW, it is expected to be sufficient to supply peak demand periods up until 2006/2007 [16], where after the struggle to maintain peak capacity will become reality.

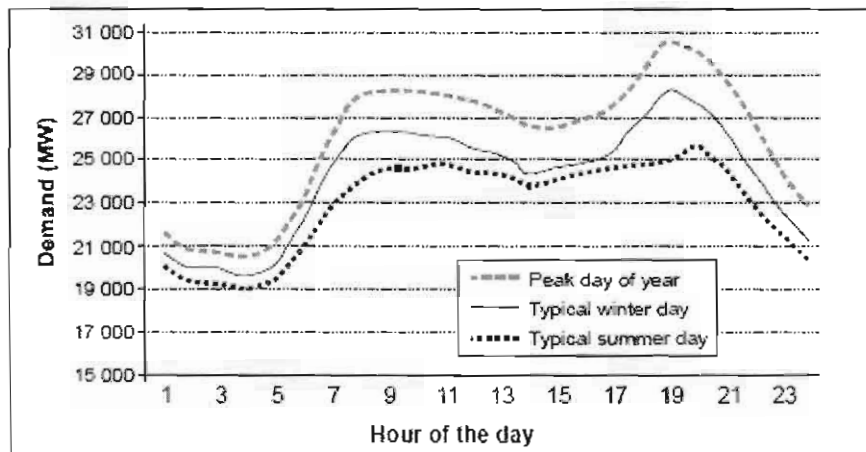


Figure 1.6: Weekday electricity demand profile. [21]

A feasible initiative in controlling the steady growth in demand is possible through the intervention of Demand Side Management (DSM) activities. The DSM term describes the implementation of necessary applications to create a change in the customer's peak load profile, without interfering with the production process and target scheduling [21].

Figure 1.7 shows the typical DSM methodology in use today. Figure 1.7a shows DSM through the increase of energy efficiency, and this simply implies that less energy will be consumed resulting in the reduction of the load curve. Figure 1.7b depicts DSM through the load shift initiative. This implies that load during higher peak demand periods are shifted to lower demand periods without changing the total load profile.

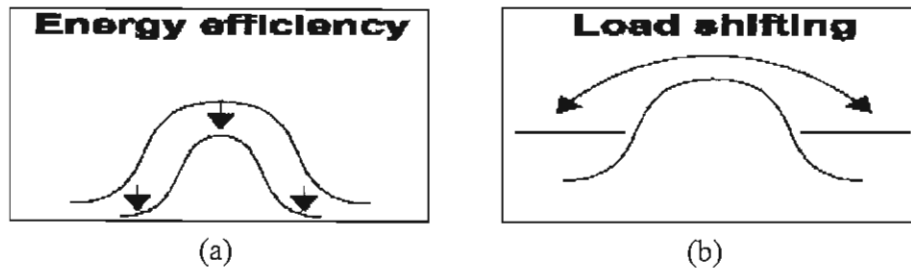


Figure 1.7: DSM (a) Energy Efficiency and (b) Load Management

EE is one of the measures that fall under the umbrella of DSM, but due to additional environmental and social benefits of EE, the referral of EE is proclaimed by the NERSA as a measurement alongside the DSM proposal.

EEDSM is therefore a combined scheme of the energy utility, which aims to reduce the peak electricity demand through the EE and load management initiatives. With the national electricity capacity growing at approximately 1000 MW per annum [21], EEDSM has embarked on a target of 150 MW per annum to stabilize the current peak demand.

Both these initiatives are currently active in the industrial sector, but further discussions will mainly focus on the efficiency practise in the mining industry along with the possible impact of load management.

1.4 EFFICIENCY IN THE MINING INDUSTRY

1.4.1 The impact of mining efficiency on DSM targets

The industrial sector, including all mining operations, contributes 71% to the annual electricity consumption and 52% to the maximum demand [16]. In comparison to the subdivisions of the South African industrial sector, mining consumes by far the most megawatt hours per annum [23]. In 2003, the local mining industry bought 33 372 GWh of electricity from Eskom at an average cost of 15.07 c/kWh, which amounted to more than R 5 billion [14].

Thus, being a dominant force behind the current electricity stance, EEDSM strategies have already been implemented throughout the different mining segments. An example of such a strategy is the underground fresh water pumping system. A real time energy management system controls the pumping schedule and ensures the necessary load to be shifted during the daily energy peak hours.

Although the costs of certain EEDSM implementations are fairly expensive due to the supply and installation costs of certain applications, the benefit of the efficiency program lies in the recuperating effect it has on the operational energy bill of the end-user, the positive environmental impact due to the reduction in CO₂ emissions and the overall delay in electricity demand for the supplier.

1.4.2 Electricity tariffs for the mining industry

Eskom, the largest energy utility in South Africa, has provided alternative electricity pricing for large energy consumers such as the mining industry. The tariffs available to the industry are divided into different categories according to the energy capacity and requirements of a specific operation. Nightsave, Megaflex, Miniflex, Ruraflex and Real Time Pricing are among the selected initiatives available to the industry.

The mining industry is fully aware of all the available initiatives and the possible impact it has on the DSM activities. The advanced tariffs available to the industry could be beneficial to certain mining operations with possible load shift capabilities during specific time intervals.

The Megaflex pricing method is the most popular tariff in the mining industry. This is mainly because it is suitable for the consumers that need a supply of more than 1 MVA. This tariff contains two distinct peak intervals along with the standard and off-peak alternative-pricing ratio.

The weekly peak intervals, between 07:00 – 10:00 and 18:00 – 20:00 are the most rewarding time intervals to the costumer when it comes to the load shift initiative.

The main target for the load shift capable consumer would be to reduce the energy consumption during this peak generation periods with either an efficiency method or a load management strategy.

1.4.3 EEDSM in the mining industry

The method of EEDSM implementation targets different electricity dependent units, such as industrial equipment, that supply the necessary service for successful production. The idea is to provide the consumer with the same quantity service using less energy. Before the initiation of these targets, payback methodology and the cost-ratio (CR) of implementation, play a critical role in distinguishing between the high and low energy content of a specific operation.

This content includes measures such as refrigeration, water reticulation, winder control and ventilation systems to name a few. Possible areas of consideration within the sub divisional mining operations, with efficiency potential, are listed below with a short description of the payback and CR criteria [4]:

1. Variable Speed Drives: It will help in the reduction of power consumption in electrical motors with variable load. A typical payback period is nearly 3 years with a CR of 1.4 [24].
2. Efficient Motors: These motors are usually more expensive but will contribute to the reduction in power consumption. Typical paybacks are 7 years with a CR of 1.4 [24].
3. Compressed Air Management [25]: This measure is considered to be the most cost effective with a significant savings potential. Typical paybacks are 9 months with a CR of 0.9.
4. Efficient Lighting [24]: Natural lighting, more efficient light bulbs and effective task lighting could save up to 1.9% of industrial electricity. Typical paybacks are approximately 3 to 4 years and a CR of 1.2.

5. Heating, Ventilation and Cooling [26]: While maintaining appropriate air quality and temperature, better maintenance and appropriate equipment will ensure load reduction. Typical paybacks are 2 years with a CR of 1.1.
6. Thermal Saving: Refers to more efficient use of heat production. Condensate recovery and improved maintenance are considered methods with a possible 1.4% saving in industrial energy. Typical paybacks are 8 months with a CR of 1.2 [4].

These measures are only guidelines to help with the transformation of the mining industry into an efficient entity. It will allow the industry to allocate funds wherever necessary with the aid of funds previously used for electricity expenses.

1.4.4 Efficient mining production

The challenge any mining operation faces is to ensure a proper management structure for maintenance on all industrial equipment and systems. Without this, the production levels will decrease and the environmental conditions could be placed in jeopardy. By focusing on the individual systems like, water reticulation, compressed air or even environmental control, one gets an idea on how effective and efficient the systems function separately.

The EEDSM strategy is therefore determined to maximize the efficiency of individual systems to make sure that the economical and environmental goals of the South African market are set.

Compressed air, winding systems, and underground pumping station have already been introduced to appropriate energy efficient strategies to date. But the attention is drawn to the environmental control system. This system uses ventilation and refrigeration to ensure feasible working conditions for underground employees.

An area such as environmental control accounts for more than 20% [27] of the total operating costs in a typical gold mine. This gives an indication on how important it is to run the system on the highest efficiency possible for maximum savings on the electricity bill, without interfering with production and most importantly the working environment.

An effective efficiency strategy for this system must coincide with the environmental working conditions of underground mining. This topic of discussion will come into view in the next chapter.

1.4.5 Environmental control system

The environmental control of an average mining operation consists of many features that enable feasible underground working condition. The main energy consumer within this environmental control is the ventilation system.

Surface and underground fans are the backbone of the system directing the flow of fresh air throughout the whole mining operation. The surface fans are the largest energy consumers with sizes that vary from 1.5 MW to 4 MW. The smaller underground fans on the other hand consume nearly 1 MW to 3 MW, approximately equal to the surface fans, when all the units ranging from 15 kW to 75 kW units are combined as one energy consuming unit.

The total ventilated energy consumption of a typical deep level mining operation, could amount to approximately 15 MW of energy use on a 24-hour schedule. With the fan sizes ranging from small 15 kW motors up to the large 3500 kW main fan motors and the fact that nearly 600 fan units are installed at a mining operation such as Mponeng goldmine will make the employment of the EEDSM process difficult.

The only solution would be to establish proper maintenance and efficiency design methodologies that will focus on individual units, to ultimately reduce the total ventilation consumption without a negative impact on the environmental conditions.

With this approach in mind, EEDSM will definitely be a realistic strategy in reducing the energy consumption of the ventilation system. The efficient management and design specifications for both the underground auxiliary and the main surface fans will be the topic of discussion in the rest of the document.

1.5 PROBLEM STATEMENT

The energy costs of the standard ventilation system in various mining operations in South Africa have increased and drawn attention as one of many possibilities towards a more efficient operating system in the mining industry. The implementation of energy efficient and load shift strategies could materialise possible energy reduction and lower the maintenance costs of each unit. Most of the underground auxiliary fans and the main surface fans are currently operating at inefficient rates within the mining ventilation system which leaves room for improvements to materialise the EEDSM strategy.

1.6 CONTRIBUTION OF THIS STUDY

The mining industry is not always capable of optimising underground environmental systems due to the complexity in controlling the system efficiently without interfering with the overall system specifications.

A new design auxiliary fan model with optimised impeller design was introduced in this study. This fan design not only produced better flow and pressure measurements but it also used less input power than that of the current installed applications in the mining industry.

Another commended feature of this study was the possible optimisation of the main surface fans in a mining operation. Both energy efficient and load shift capabilities were brought into perspective whilst analysing the possible methods in achieving optimum energy reduction within the operation of the surface main fans.

Both the underground auxiliary fans and surface main fans were analysed by means of actual data obtained from two South African mining operations namely; Kopanang and Mponeng goldmines.

In this dissertation, the potential electrical energy and monetary saving were calculated to fulfil certain research evaluations that might lead to the overall energy reduction of the ventilation system in the mining industry.

1.7 BRIEF OVERVIEW OF THIS DISSERTATION

Every chapter in this dissertation was written to be read in sequence. This will give a broader perspective on the entire field of research and explain the detailed methodology of every related subject. Each chapter also contains its own introduction, conclusion and reference sections to enhance the preferred decipherability of the dissertation. Some important issues were frequently mentioned throughout the document to highlight the correlation of the chapters.

A short description of each chapter is given below:

- Chapter 2 discusses the importance of proper environmental control in the mining industry. It also looks at certain aspects of concern during the implementation of energy reduction strategies within the mine ventilation system.
- Chapter 3 looks at the certain fan criteria that needs to be resolved before the energy efficiency and demand side management initiatives could materialise in a ventilating system.
- Chapter 4 compares the performance specification of an improved 45 kW auxiliary fan design to that of a standard 45 kW issued fan currently operational in the mining industry. Further discussions show the energy saving potential of the improved design.

- Chapter 5 discusses possible energy reduction methods on main surface fans through load shift and energy efficient applications.
- Chapter 6 discusses the calculated results in energy reduction for both the underground auxiliary fans and the main surface fans at Kopanang and Mponeng goldmines. Energy efficient and load shift savings are compared and analysed in this chapter.
- Chapter 7 is a review of the dissertation and discusses possibilities of future work applications to effectively optimise the current mining ventilation system.

1.8 CONCLUSION

The main idea of this chapter was to indicate the importance of EEDSM practise in the mining industry of South Africa. With the large impact the mining industry has on the South African electricity market, the necessity for more efficient production methods in this industry are evident.

The management and control of the mining operational systems needs to be revised, with a definite focus on all the different mining segments. Environmental control of deep level mining could become a complex procedure with the implementation of energy efficiency methods, due to the continuous increase in rock temperature at deeper production levels. The development of a possible energy efficient system is the subject of discussion in the following chapters.

The EEDSM initiative described in this chapter is a recovery process to successfully alter the energy market into a more efficient industry by means of new or improved production methods. This document will focus on the optimisation of the ventilation system to establish the reduction of energy use in the mining industry by looking at both the operational features of underground auxiliary and the main surface fans. The energy utility of South Africa together with the mining industry strives to enable this strategy with obvious economical and environmental benefits.

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*RESEARCH ON REDUCING COSTS OF UNDERGROUND
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Chapter 2

**ENVIRONMENTAL CONTROL IN MINING
OPERATIONS**

This chapter discusses the importance of environmental control in the mining industry. It looks at the different aspects of concern with the implementation of energy reduction strategies along with the effects it has on the current mining regulations. The relation between effective ventilation and refrigeration methods are examined together with a discussion on more efficient ventilation methods.

2.1 INTRODUCTION

Energy management is the key element for the mining industry in achieving the energy efficiency projections that relate to government policies and a proper energy efficient environmental design is critical to maintain safe working conditions for underground mining employees [1]. This chapter addresses the important issue of underground environmental control through ventilation as a possible energy savings entity.

2.2 MINING ENVIRONMENTAL CONDITIONS

2.2.1 Deep level temperature

As mining operations in South Africa continue to extend towards deeper levels below the surface, the environmental working conditions worsen because of regional geothermal gradients [2]. This will require improved cooling methodologies for many deep level mines. A further concern is that by the year 2010, nearly 60% [3] of all gold mining in South Africa will be operational at depths below 2000m. In this case the only objective will be to supply efficient environmental conditions for production without even mentioning energy efficiency.

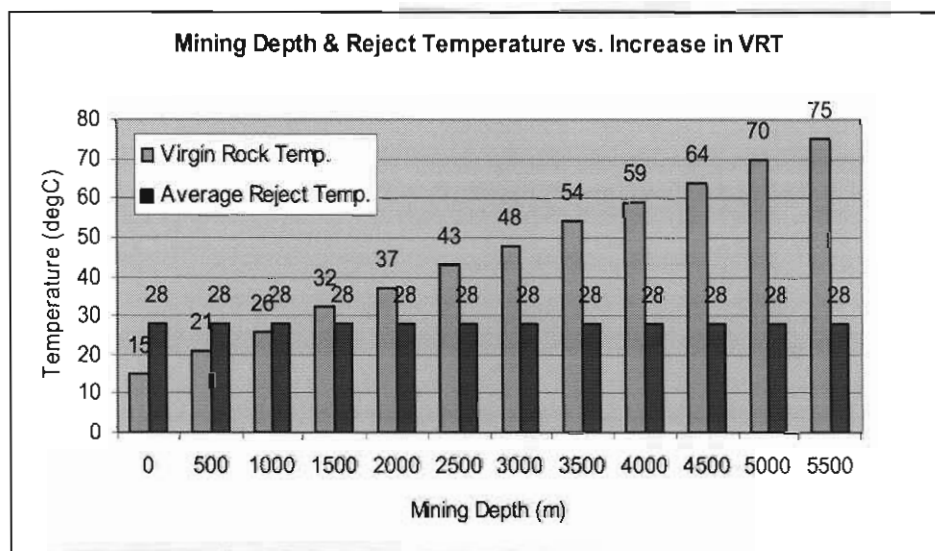


Figure 2.1: Virgin rock temperature and cooling requirements

Figure 2.1 illustrates the relation between mining depth, average reject temperature and virgin rock temperature (VRT). The important issue is to maintain a mean reject temperature according to specific mine regulations, in this case approximately 28⁰C as indicated [2]. At lower depths larger refrigeration plants together with additional ventilation systems are required to maintain the reject temperature. This is a very expensive operation with a definite impact on the energy demand.

2.2.2 Solutions for excessive heat loads

The typical heat load patterns found in most deep level mines are caused by rock temperature and other influential factors such as machinery, mechanical equipment, blasting, fissure water etc. These will always be issues that need to be addressed during the development of new cooling systems.

For the most cost effective cooling solution in existing and future ultra deep (between 4000m - 5000m in depth) mines, the combination of surface and underground cooling installations, as a direct link to an existing infrastructure play a crucial role [4].

Below the 1600m mark, ventilation alone would not be enough to maintain the environmental equilibrium needed [5]. Water chillers, air cooling towers, refrigeration machines and underground ice melting dams are additional elements that support the overall balance of the environmental system in an ultra deep level mine.

A cost effective cooling system will need extensive and accurate strategies to ensure the most energy efficient environmental operation. A list of strategies was conducted for the Proceedings of the 7th International Mine Ventilation Congress to act as a guideline to cost effective measures for deep level ventilating systems. The inventory on cost effective systems will involve the following strategies [6][7][8][9][10]:

1. Accurate control over the recirculation and ventilation air.
2. Both the surface and underground refrigeration installations need to be put into full use.

3. Pre cooling towers together with the surface refrigeration will function as an initial cooling stage of the water from water chillers, ice makers and underground operations.
4. A bulk air cooling system on the surface and at a suitable underground location.
5. Air cooler installations within the stope areas.
6. Minimise all cooling losses.
7. Examine cyclical operations of ventilation and cooling systems.

To achieve this goal of an efficient and reliable environmental control system would acquire optimum management abilities to ensure the mentioned strategic solutions. The large variety of mining operations in South Africa makes use of different methods in their ventilation structure, thus acquiring different strategic procedures for efficient control. But the one common relation between all the operations would be the sustainability of productive working conditions.

2.3 MINE VENTILATION AND COOLING SYSTEM

The two controllable parameters when it comes to the environmental control of an underground mining operation are the quantity of air and the air temperature. The quantity of air is supplied by the ventilation system and the air temperature mainly by the refrigeration plant, bulk air cooling towers and the spot coolers [11]. It is therefore unpractical to optimize these parameters independently. It is a combined unit application for any environmental dependant mining utility.

2.3.1 Refrigeration

Refrigeration plants are distinct from all the simple cooling devices incorporating water sprays only. The capital layout of the refrigeration is quite expensive and in many cooler parts of the world it is considered to be the last resort in mine development. The reason South African mines are so dependant on the mechanical refrigeration process is mainly because of the higher geothermal heat loads in comparison to other mining countries.

The heart of a refrigeration unit is the compressor which pressurizes a gas into a heated state. The gas is then cooled down by means of water spray or air flow in a condenser until in a liquid form. This liquid gets expanded through a valve to cool it down and restore it to a gaseous state in an evaporator. Subsequently, the gas is used to cool down the ventilation air and chill the service water for underground purposes [12].

Deep level mining usually needs extra cooling because of air that loses potential energy while descending down a shaft and mainly due to auto compression and heat pickup from the shaft walls. An underground refrigeration plant is a practical solution for many operations reaching new depths in the industry.

2.3.2 Ventilation

The initial role of mine ventilation in the past was to provide mining employees with enough fresh air to replace the oxygen consumed during operational periods. Excess humidity, high temperature and inadequate oxygen created lower worker efficiency and productivity and in most cases caused illness or death [13]. Today, contemporary mining ventilation primarily deals with noxious gases. Ventilation effectiveness in this role, depends on the fact that once noxious gases mix with air, they remain uniformly diffused and never separate. Therefore, with enough fresh air to ensure the dilution of the noxious gases at specific areas, safe working conditions will be inevitable.

The typical amount of air required to ensure adequate dilution is far more than the amount required replacing oxygen consumed underground. Sufficient ventilated air also improves visibility and removes dust generated underground which reduces numerous health threats [12].

All the underground ventilation is made possible by means of a structured layout of industrial fans. A combination of large surface fans and a refined connection of smaller axial fans ensure the directional flow of the ventilation system.

The essential part of this system is the interaction between every fan unit. This is crucial in the approach to achieve the maximum efficiency for the system as a whole.

2.4 MINE VENTILATION FANS

2.4.1 Introduction

“A fan can be defined as a rotary bladed machine maintaining a continuous flow of air” [15]. The basic purpose of a fan would best be described as a unit that shifts a quantity of vapour or gas with a certain velocity to a desired area of application. The aim in an average mining ventilation system is to move this mass of air without any appreciable increase in pressure.

The only acceptable method is to ensure that all the ventilation fan units operate at the desired working point, which is given in terms of the volume flow and the pressure rise at a certain rotational speed. Surface, booster and underground auxiliary fans work in coalition towards an optimum efficient ventilation system.

2.4.2 Surface and booster fans

The surface main fans and the booster fans predominantly function as hot air extraction units in the ventilation system in South Africa. All the generated heat underground needs to be removed for the cooler downcast ventilation air to come into effect. Figure 2.2 shows a general arrangement of a model deep level mine with booster fans on two levels and the necessary surface fans to balance the extraction process. For most ultra deep mines, the cooling requirements become significantly large, thus the number of booster fans for such an operation may vary.

For main fans, it is preferable to install two fans in parallel rather than a single unit. The reason is that one fan will supply 66% of the normal air capacity while the other (sealed off) is down for repairs. It is better still to select 3 fans, two of which will supply 90% of the normal air capacity [12].

This is usually enough to fulfil the acquired requirements. The third fan is usually kept as a standby unit for maintenance purposes and as a safety measure.

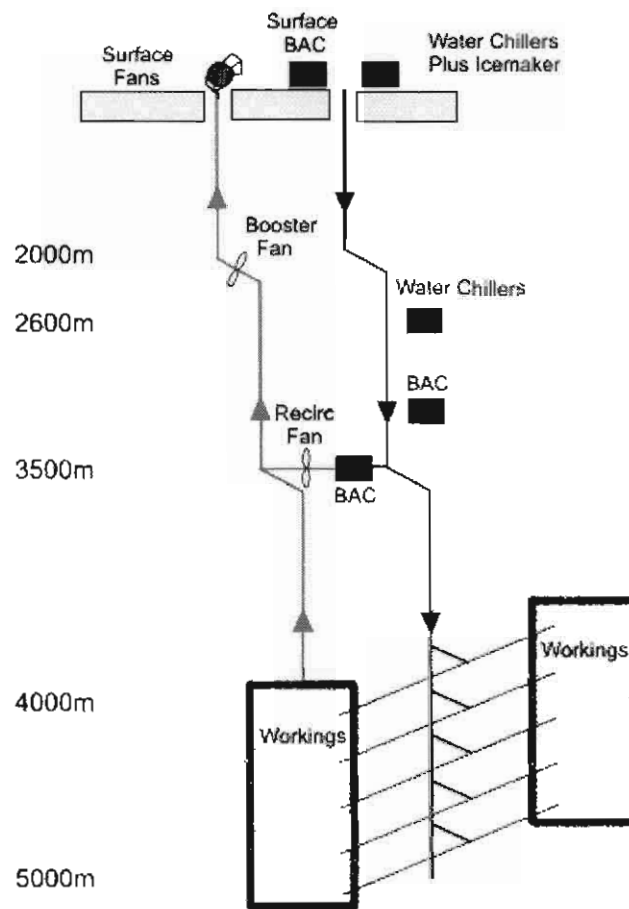


Figure 2.2: Mine ventilation layout

Together with the smaller underground fans, it is essential that proper care should be taken to ensure the efficient use of the mine fans and the relevant ventilation network. This will result in energy savings, flow improvement, noise and vibration reduction.

2.4.3 Underground auxiliary ventilation fans

In deep level mining the directional flow through all the different sections of the ventilation system is controlled by literally hundreds of auxiliary fans. The most common form of auxiliary ventilation is a fan and ducting system that is accessible as the mine goes into further development [16].

The auxiliary ventilation is required to ensure dead end workings, such as headings, draw points and some stopes with a continual circulation of fresh air.

Figure 2.2 shows an animated example of a typical auxiliary fan used in the mining industry today. When looking at the main components of an auxiliary fan; the impeller, hub, blade, motor and the housing casing all contribute to the overall capability of the a unit. If one component of the fan should have an inefficient design specification, it would affect the unit as a whole. Thus together with the ducting system, it is important that the multiple parameters of the fan are determined during a specific design, to ensure the most efficient operating point of the fan.

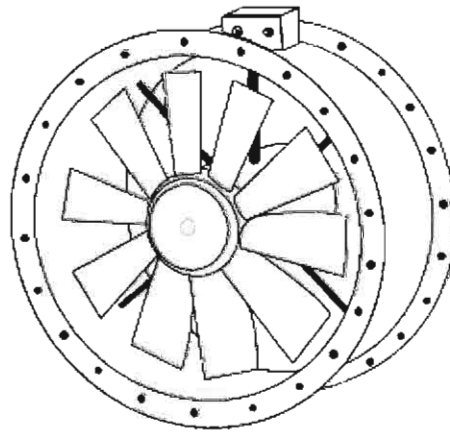


Figure 2.2: Representation of auxiliary fan design

The main categories to be addressed during the efficient design process of the auxiliary fan include the mechanical parameters and aerodynamic performance, motor and electric supply, and the reliability and lifetime of the fan. These categories are summarized in Tables 2.1, 2.2, and 2.3.

Mechanical Parameters and Aerodynamic Performance	
Volume of airflow	Size and diameter
Pressure developed	Hub / Impeller ratio
Efficiency	Blade angle / adjustment
Sound levels	Blade shape
Rotational speed	Impeller solidity / no. of blades
Reversible	Acoustic cladding
Balance	Belt drives
Standard	AMCA, LPCB, BS, CEN, ISO
Temperature	Std, HT, bifurcated

Table 2.1: Parameters and variables for mechanical and aerodynamic performance of fans

Electrical Supply and Motors	
Absorbed power	Motor size / heat loss
Maximum power	Electrical capacity
Starting current	Starters / Inverters
Power factor	Single / 2 speed
Speed / variable	Single / 3 speed
Efficiency	Bearings / Insulation
Life	

Table 2.2: Parameters for electrical supply and motors

Reliability and Life	
Clean / contaminated air	Materials
Ambient / high temperature	Finishes
Smoke / fire duty	Tolerances
Water / dust protection	Sealing
Explosion protection	Bearing selection
High shock protection	Motor selection
Normal life / hours	Lubricants
Reversible	Fasteners

Table 2.3: Parameters and variables for fan reliability of life

Without the correct design methodology of a fan unit, the ventilation system could face major inefficient circulation control. To obtain the desired flow and pressure rating, especially at deep level mining densities, correctly calculated approaches on both fan and ducting related designs must be obligated to ensure the most efficient ventilating system.

2.5 CONCLUSION

The importance of maintaining a cost effective and efficient environmental system has become a priority in the mining industry in the modern era. With the increasing energy and maintenance costs spent on ventilation annually, further avoidance of this issue cannot continue. The different sub divisional sections of the environmental system need to be evaluated for any inefficient operational features. All operations, from air-cooling right up to the guided airflow divisions have been neglected in the past due to the low electricity costs of South Africa.

Reducing the ventilation operating and energy costs in an environmental system has become a necessity because of the continued increase in electricity costs. Better underground fan control and possible load shift management on certain main fan configurations could ultimately contribute to cost effective operations.

The only feasible way to enable such a strategy would be to neutralise all the problematic features that might alter the required production levels. The next chapter discusses the possible grounds and criteria that need to be addressed to facilitate the EEDSM initiative.

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Chapter 3

MINE VENTILATION EEDSM OBSTACLES

With the current inefficiency of the average ventilation fan in a mining ventilation system, solutions need to be put in place to ensure a more efficient design. According to legislation policies, the demand for efficient practise in the mining industry has become more stringent. This chapter investigates the problem features concerning the certain fan policies and includes an investigation on certain criteria of fan designs.

3.1 INTRODUCTION

Ventilation is vital in the mining industry. Inspectors, environmental engineers and clerks are monitoring the ventilation systems at different levels throughout the industry. Millions of rands are spent monthly on investments, maintenance and on the electricity bill for underground ventilation systems. This is where the efficiency concept becomes crucial. The standard ventilation system contains numerous areas where EEDSM strategies could play a major role in the system, but there are certain obstacles that might slow the process. Surface and auxiliary ventilation are dominant areas when it comes to the ventilation capacity and further discussions will solely focus on this subject.

3.2 FAN PROBLEMS AND CAUSES

The problems and causes of inefficient ventilation fans are still experienced today in spite of the advanced technology available, which could minimize the problems and eliminate the causes. Minimum investments in new ventilation equipment and systems are the downfall to efficient practise. Because the investment in new equipment or improved systems is seen as an expense, large sums of money have already been spent on unnecessary maintenance.

Typical problems concerning the average inefficient fan system are listed below [1]:

- (i) Improper flow at fan inlet.
- (ii) Improper loading of fans resulting in flow induced vibrations, turbulence and underperformance of fans.
- (iii) Non-uniform flow distribution between fans in case of multiple fan system.
- (iv) Non-uniform flow across air heaters, external economizer, annulus cooler, and updraft and downdraft drying zones.
- (v) Cold air corrosion in air pre-heater due to temperature stratification.

If the problem identified in a standard ventilation fan system is considered, a clear indication of improper efficiency management is evident. A summary of the common causes is identified through a combination of existing situations in the industry. It includes the following scenarios [1]:

1. Improper air entry conditions at the fan,
2. Poor or no conversion of unproductive velocity pressure to useful static pressure through gradual diffusion of air without flow separation,
3. Poor duct design and flow stratification.
4. Improper mixing of hot and tempering air.

Energy efficiency is a major issue in operating a large complex fan ventilation system in deep level mines, but by introducing energy-savings strategies within the system would possibly contribute significantly.

3.3 FAN MOTOR EFFICIENCY LEGISLATIONS

In the USA, fan motor efficiencies are regulated by a Comprehensive Energy Policy Act, that all general-purpose motors must meet normal efficiencies according to NEMA [2]. Another example is Canada, with a similar energy efficiency act with specific provincial legislations. The problem in South Africa is that no specific motor legislations are available at present; the only trend is to promote the benefits of new efficient fan designs. Possible stages that need to be addressed for policy legislation on efficient motor standards in South Africa are listed below:

1. The possible requirement for marking motor efficiency on a nameplate that comply with certain utility standards.
2. Specific standards for minimum values on full-load efficiencies for (a) standard motors and (b) energy efficient motors published by the national utility.
3. Financial incentives paid by utilities to encourage the purchase of EE motors.
4. Regulatory bodies to verify the efficiencies of all newly installed fan motors.

A thorough legislation on the energy efficiency standards of the mine ventilation fan will definitely have a positive impact on the efficiency targets set by the national energy regulator. In promoting energy efficient fans in the mining industry will not solve the increasing electricity demand, but the direct obligation in energy efficient practises, will ensure the benefit of lower energy costs.

3.4 TOTAL VENTILATION FAN EFFICIENCY

The trend to save money on investments makes the manufacturing companies aware of the pricing of certain ventilation equipment, especially fans. Because of the high costs surrounding the rewinding and repair of underground ventilation fans, the cheaper option of the rewinding and repair of axial fans are being implemented in mining operations with major disadvantages. Electric motor failures and inefficient fan functioning are common problems that influence the lifespan of the ventilation fan.

The fan efficiency is dependent on various influential factors ranging from the fan motor, impeller design, guide vanes and even the casing of the fan plays a major role. Achieving the maximum desired fan efficiency will take a considerable amount of research in certifying the optimum performance for the toughest conditions.

Improving a single fan unit will have little affect on the total system efficiency, but the implementation of an optimised fan system would obviously contribute to a larger saving opportunity. The important factor in achieving a possible fan system saving would be to obtain a balance between the investment and the low energy cost payback.

Many ventilation design standards and schemes only focus on the total installed capacity of a fan system, thus an optimisation process through a specific Life Cycle Cost (LCC) initiative will be an accurate approach to find obtainable energy saving levels in several fan systems. Typically, the share of energy costs on LCC for all motor driven systems is in the range of 50 to 80% [2].

Therefore the energy costs should be main decision criteria when choosing a fan system rather than the improvement of single fan components.

3.5 REDUCING DOWN TIME PRODUCTION

Down time production refers to the unreliability of, for instance, the fan motor. It lacks the required potential to perform consistently according to certain specifications. To ensure the reliability of the fan motor, especially in extending the lifespan, a method of cooling will definitely be an option. The cooling of the motor could be obtained by the using the following methods:

1. Improved design (structural and materials)
2. Reducing electrical losses (increasing performances)
3. Increasing the power factor value (improved rotor design)
4. Decreasing the motor temperature rise
5. Increasing the motor class of insulation
6. Improving the bearing arrangement
7. Improving the manufacturing technological process.

The abovementioned features might fulfil the requirement for motor life span, but without an efficient impeller or for example a proper casing design, the total efficiency might remain at a lower rate.

3.6 FAN COST CONSIDERATION

To present the reliable cost data of a specific fan would be difficult to determine because of the variation in price due to different design specifications. The cost of a fan will strongly depend on the number of fans bought by the customer and the competition in the particular field. Thus, the price of installation on a number of efficient fan units may vary according to market changes, but it remains an investment.

If we assume that the payback period of the investment should not exceed two years, which is a normal industrial assumption, a fan operating at approximately 6000 hours/year should have a nominal motor power of at least 10 kW [4].

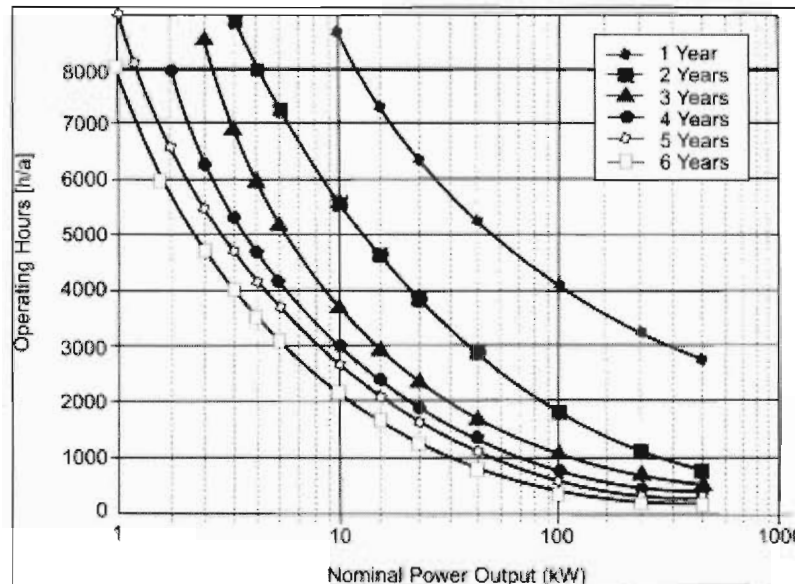


Figure 3.1: Payback period for fan replacement.

When the nominal power of a fan is above 100 kW the practical option would be to consider the most improved fan design possible. Figure 3.1 gives an overview of possible payback periods with the replacement of improved fan designs.

Another important factor when purchasing a fan would be the life cycle costs (LCC). The reason for this is because the LCC is dominated by energy costs. The implications are that a small price premium for an efficient fan can be very cost effective. Looking at the investment criteria on the LCC, additional costs of a high efficient fan comparing to a standard fan would be very small.

3.7 CONCLUSION

With proper investment in a highly efficient ventilation fan system, the payback on energy-savings could accumulate extensively throughout a certain course of time. This is accomplished through an efficient fan system rather than individual component efficiencies to obtain optimum results. With the aid of improved design specifications and criteria on both the underground auxiliary fans and the main surface fans, the satisfaction of a complete efficient ventilation fan system will eventually materialize.

Further discussions in this document will focus on the impact of EE and load shift management on both the auxiliary and surface main fan applications. The next chapter introduces an improved EE auxiliary fan design that could play a crucial role in the development of an efficient ventilation system, whereas chapter 5 shifts the attention towards the energy savings potential the surface main fans have on the ventilation system.

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RESEARCH ON REDUCING COSTS OF UNDERGROUND
VENTILATION NETWORKS IN SOUTH AFRICAN MINES

Chapter 4

**IMPROVED ENERGY EFFICIENT AUXILIARY
MINE VENTILATION FAN**

The most common used axial fan for underground ventilation is the single stage auxiliary fan. This 2 pole generated fan has a weight advantage over the more expensive 4 pole design but it has many disadvantages when it comes to operational features. This chapter introduces a new design 2-pole single stage auxiliary fan with more efficient features and an increased potential lifespan.

4.1 INTRODUCTION

A fan is defined as a rotary, bladed machine maintaining a continuous flow of air, because the air flows steadily into, through and out of the fan. These fans are operational to ensure enough airflow to dilute the dangers of noxious gases and to maintain fresh air for the mining employees.

The design of an efficient fan is crucial for an effective contribution to the ventilation system as a whole. New design specifications for the current two-pole axial fan in operation throughout the mining industry, will be the point of discussion.

4.2 DESCRIPTION OF EQUIPMENT

In the axial fan the effective progress of the air is straight through the impeller at a constant distance from the axis. The primary component of the blade force on the air is directed axially from the inlet to the outlet and thus provides the pressure rise in a process that may be called the direct blade action [1]. The blade force necessarily has an additional component in the tangential direction, providing the reaction to the driving torque. This sets the air spinning about the axis independently on its forward motion [1].

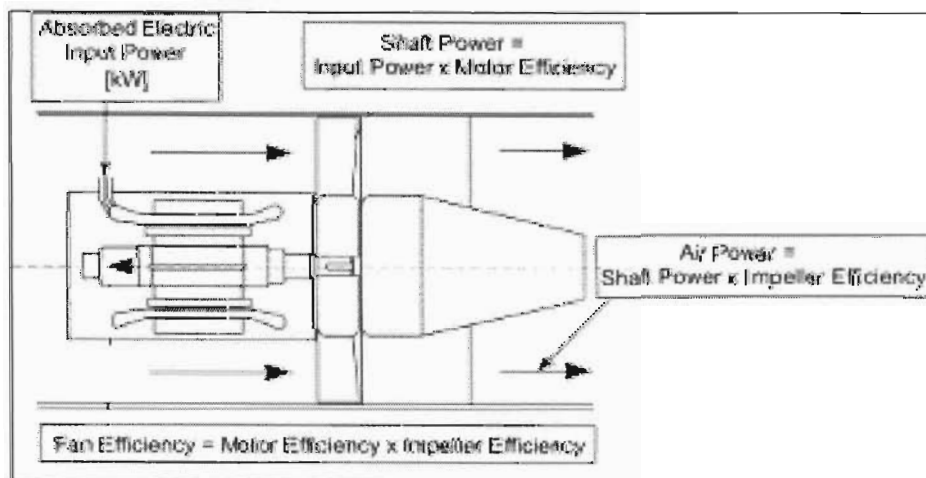


Figure 4.1: A schematic diagram of an axial “F” type fan [1]

As per schematic diagram shown in figure 4.1, a fan is composed of:

1. Electric motor driving the impeller
2. Casing (where the components are installed)
3. Impeller as such causing the incoming air to swirl
4. Diffuser converting some of the fan velocity pressure into fan static pressure
(Only useful at an open outlet)

The electric motor is transforming electric energy in mechanical energy at shaft, facilitating the impeller rotation. The rotating impeller invariably carries blades of some kind. These blades exert force on the air, thereby maintaining the flow and raising the total pressure. These fans are denominated as axial fans in practise.

4.3 EXISTING “F” - TYPE FANS

4.3.1 Market definition

In practise all the underground fans issued for use are defined by certain code-orientated specifications. All the definitions in this document will refer to the AngloGold Ashanti specification 482 issue 2. AngloGold specifications regulate the fan and subsequently the impeller assessment and it also defines the fans according to the motor power inside the fitted casing.

A standard 45 kW fan has a casing size of 762mm and is denominated as a “F” type fan according to the specifications. Figure 4.2 shows the characteristic performance chart for a standard “F” type axial fan at an air density of 1.2 kg/m^3 . The relation between the pressure rise and the volume flow is compared to the characteristic performance of the fan.

The pressure rise of the fan is low to moderate, distinguishing it from a compressor (with great pressure rise). One point on the diagram can always be found at which the efficiency of the fan is maximum. This is called “the best efficiency” point on the diagram, as well as providing the lowest power consumption for a given duty.

Operation at this specific point usually secures the lowest noise level for that particular fan. The fan static pressure is fully available to the user being only recognized as a pressure.

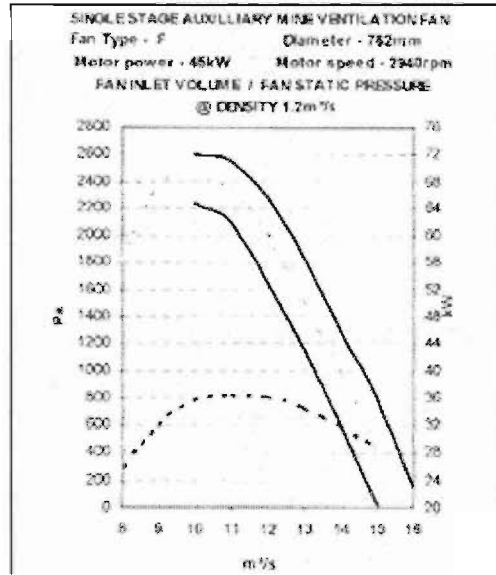


Figure 4.2: Characteristics of a 45 kW “F” type fan defined by AngloGold Ashanti specification 482/4 [2].

4.3.2 Impeller power performance

To obtain the operational characteristics of a fan, one needs to calculate the performance ratio surrounding all the influential factors such as the total fan power, impeller power, electric motor power and efficiency ratings.

The impeller power can be accepted as the power output (P_{fan}) of the fan where,

$$P_{fan} = Q_1 \times P_t$$

With, Q_1 the whole volume flow, and
 P_t the total fan pressure.

The impeller power measures the work done to drive the impeller round against the aerodynamic forces and it is the work required from the axial fan.

For practical purposes the impeller power is calculated as the product between the airflow (m^3/sec) and the static pressure (Pa). As for the notation of this power according to the BS848 standard, it will be referred to as the air power (P_{air}).

4.3.3 Impeller efficiencies

The important coefficient when determining the impeller efficiency is the electric motor power. The electric motor shaft power P_{shaft} is the quantity of mechanical power delivered by the electric motor and required by the impeller. The impeller efficiency is then defined as:

$$\eta_{impeller} = \frac{P_{air}}{P_{shaft}},$$

with:

$$P_{air} = Q_1 (m^3 / sec) \times P_t (Pascal),$$

and

$$P_{shaft} = \eta_{motor} \times P_{input}$$

While the electric input power of the motor is defined as:

$$P_{input} = \sqrt{3} \times U_{line} \times I_{line} \times pf$$

The impeller efficiencies of several 45 kW axial fans tested at Continental Armature Winder in Klerksdorp, South Africa varied between 40% to 60% while the motor efficiencies ranged between 87% to 93%. Figure 4.3 illustrates the design of the current operational impeller design. The inefficiency of the impeller is mainly due to the non-aero dynamical hub design. Re-circulation within the hub is one criterion that creates imbalance between the impeller and motor, which affects the fan efficiency.

The total fan efficiency of the standard single stage axial fan is estimated to be [1]:

$$\eta_{fan} = \eta_{motor} \times \eta_{impeller} = 26\% \rightarrow 55\%$$

This is a clear indication that the current design needs improvement on both the impeller and motor efficiencies.

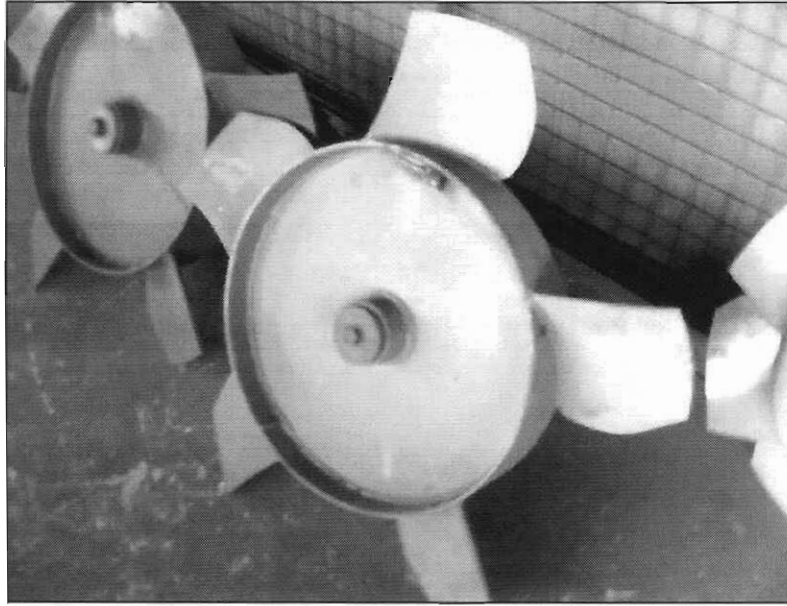


Figure 4.3: Standard impeller design

4.4 EFFICIENCY ASSESSMENT OF STANDARDIZED FAN

The assessment is based on the fan efficiency definition according to the BS 848 standard specifications:

$$\eta_{fan} = \text{Fan output power} / \text{Electric motor input power.}$$

This specification requires specific conditions for the impeller performance, denominated as envelopes or compulsory duty points at 1.2 kg/m^3 air density for the 45 kW “F” type fan with a pressure rate of 1800 pa. This is the standard specification set by AngloGold. These standards are set to characterize specific operational duty points to ensure feasible flow and pressure rates.

For standardized single auxiliary mine ventilation “F” type 45 kW fans, the desired specifications are:

1. Electric Motor input power : $P_{input} = 48.5kW$
2. Fan static pressure : 1800 Pa
3. Fan air flow : $12 \text{ m}^3/\text{sec}$
4. Fan output power : $P_{Air} \approx 21.6kW$

The standard acceptable efficiency of the “F” type fan according to the AngloGold specifications will approximately be:

$$\eta_{fan} = \frac{P_{output}}{P_{input}} = \frac{21.6kW}{42.5kW} = 50.8\%.$$

Although the efficiency is particularly low, it still has the capability of producing the correct flow and pressure, but at particularly high maintenance and electrical costs.

4.5 POWER FLOW DIAGRAM OF STANDARDIZED FAN

With the specifications set for the standard axial fan, one can roughly estimate the combinational power losses to predict possible areas of improvements to the fan. Figure 4.3 illustrates the standardized 45 kW axial fan power flow diagram including power losses due to the inefficiency factor.

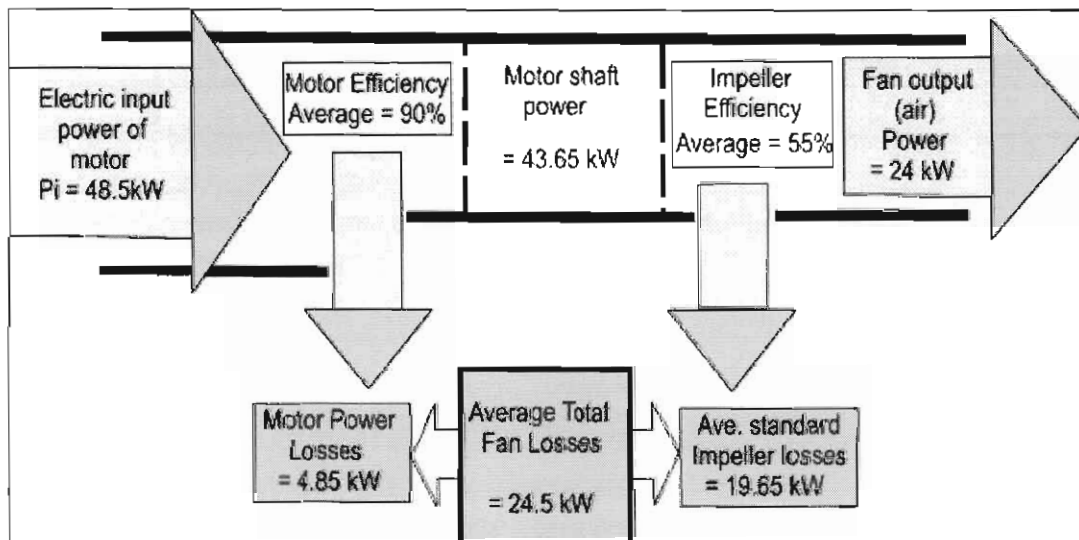


Figure 4.4: Power flow diagram for standardized 45 kW axial fan

The values used in this application were calculated as an average from twenty rewinded 45 kW axial fans used in current mining operations.

According to the power flow diagram shown in figure 4.3, the efficiency of the standardized axial “F” type fan has to be confirmed to be in the range of:

$$\eta_{fan} = 42\% \rightarrow 56\%.$$

The low value in fan efficiency could be because of the following factors:

1. Possible air turbulence on the duct between the motor and the fan casing.
2. Large ratio difference between the electric motor and the overall diameter of the impeller hub.
3. The electric motor design.
4. The impeller design. Possible shortcomings could be one of the following: (i) The outlet and/or inlet side of the hub has edges producing turbulence on the air flow, (2) The size of the hub is not correlated to the motor cross sectional area, (3) The impeller blades and the aerofoil-section guide vanes are not designed according to the required duty, the design has been kept under the same condition as previous application.
5. Discharge area (fan outlet).

Improving the fan specifications by means of the above-mentioned criteria, the actual efficiency rate will have a definite result in fan performance. The next point of discussion will solely focus on a design similar to the standard modification but with additional features that may contribute to better efficiency rates.

4.6 IMPROVED AXIAL FAN DESIGN

With activities moving towards ultra deep mining (as mentioned in earlier sections), 45 kW fan motors experienced very high failure rates and the mines encountered high total ownership costs.

A new design “F” type axial fan is orientated towards a dedicated fan with a more efficient design approach. In the previous section, the standard 45 kW axial fan had significant inefficient characteristics.

The goal with the new design is to increase the total fan efficiency by targeting the individual problem areas. The design features are described within five separate specifications to gain clarity on the targeting approach.

1. General

All the fan components were re-designed to an appropriate aerodynamic profile, avoiding:

- (vi) Air turbulence in different parts of the air tracks,
- (vii) Air re-circulation,
- (viii) Excessive air spinning between the impeller and diffuser,
- (ix) Blades vibrations,
- (x) Air pressure pulsation. These principles also reduce the noise levels of the fan.

2. Aerodynamic features

- (i) The electric motor has an outside diameter in a region of 90% to 105% of the impeller hub diameter.
- (ii) The electric motor has an overall length of 120% to 150% of the motor outside average diameter.
- (iii) The electric motor non-drive side is fitted with an aerodynamic profile device in order to reduce the air inlet turbulence.
- (iv) The impeller design is a special South African registered patent.
- (v) Air discharging area has a special designed diffuser.

3. Mechanical features

- (i) The electric motor is steel manufactured.
- (ii) The aerodynamic profile device is steel manufactured and detachable, it enables the adjustments according to the fan overall sizes and required performances.
- (iii) The diffuser installed at the air outlet is steel manufactured with special noise absorption inserted inside its body.

4. Energy efficient electric motor design features

- (i) Electromagnetic design of the motor is dedicated to the application.
- (ii) The ratio between the stator core OD and the stator pack length is 1.70 to 1.90.
- (iii) The motor output power has been reduced with 15% to 25% against the existing standard shaft power of the current installed fan motors.
- (iv) The motor minimum efficiency is 93.5%.

5. High efficiency impeller design features

- (i) Hub external profile has been rounded on both sides (inlet and outlet) shown in figure 4.5, which gives it a unique property in comparison to the classic design.
- (ii) Hub diameters are a function of the impeller power and casing sizes varying between 50% on small 4 kW fans and 55% on bigger 45 kW fans.
- (iii) The blades are designed with specific angles according to the fan type.
- (iv) The number of blades is a function of the specific fan type.
- (v) The distance of the impeller to the guide vanes has been modified to assist the balance of the fan.

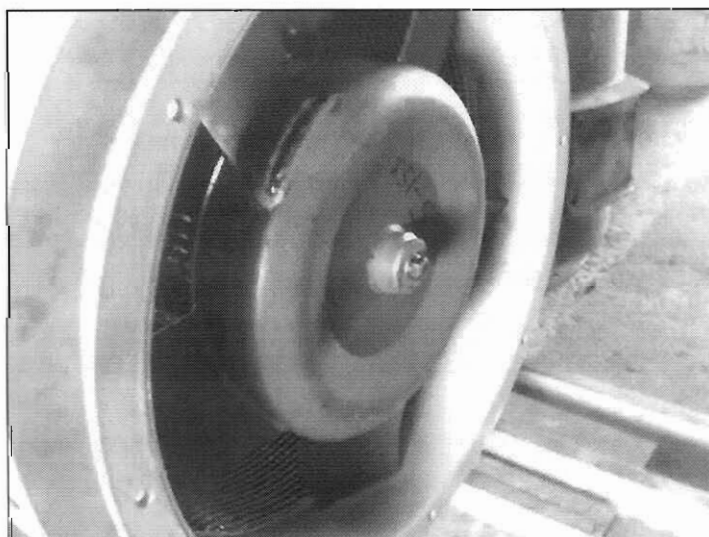


Figure 4.5: Improved impeller design

These design specifications are detailed improvements of the inefficient standard fan. Some of these improved fans are currently in operation in various shafts, with an ongoing efficient lifespan of more than 7 months in comparison to the 3-month lifespan of some standardized fans.

4.7 ADVANTAGES OF THE IMPROVED AXIAL FAN DESIGN

With an intensive look at the design advantages through the analysis of the different improved features, reduced costs of the continued repair activities and motor performance stability will be inevitable. The following summary of advantages will finally indicate the effective benefits in replacing the standardized single stage axial fan.

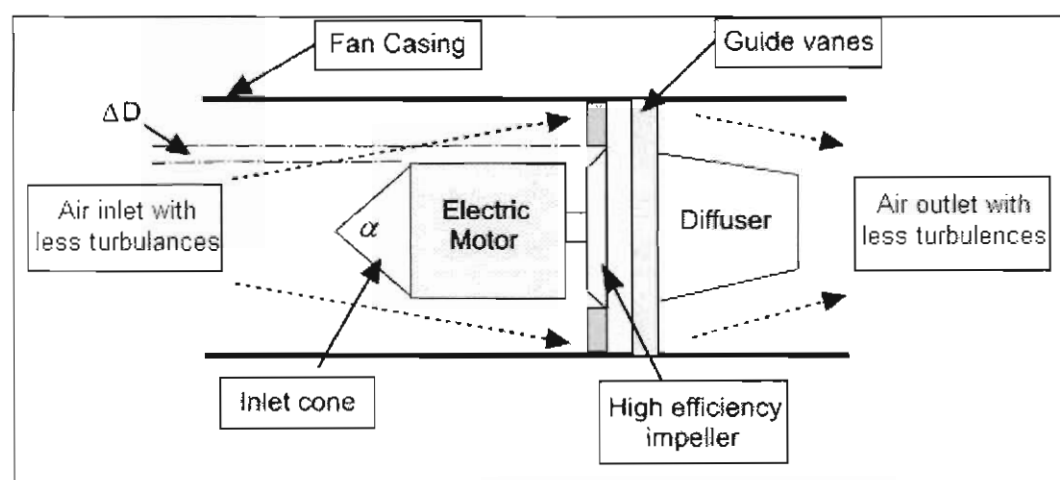


Figure 4.6: Schematic principle of improved efficient axial “F” type fan

Figure 4.6 illustrates the improved design methodology of the single stage 45 kW axial fan. The advantages of the design are defined with the help of figure 4.4 and figure 4.7:

1. The air turbulence at the non-drive end of the motor has strongly been reduced due to an aerodynamic profile device (inlet cone). Air turbulence at the non-drive end will reduce the fan efficiency and will create extra pressure at the motor edges, which is present on standardized fan applications.

2. The solid angle of the cone (α) is designed in such a way as to guide the air fillets straight into the impeller blades. This will avoid air turbulence in the annular space between the motor and the fan casing which is another distinct characteristic of the standard fan design.
3. High efficiency impeller will be supplied with air with reduced turbulence. Laminar profile of the air fillets at the impeller will increase the impeller efficiency. Air turbulence at the impeller inlet reduces impeller efficiency.
4. The aerodynamic quality of the inlet fan has been dramatically improved by reducing the electric motor length. A short motor will avoid the bouncing effect of the air fillets in the annular space between the motor and the fan casing.
5. The electric motor outside diameter has been chosen close to the value of the impeller hub diameter. A reduced value of the difference between the motor diameter and the hub diameter (ΔD) will minimize the air turbulence and vacuum appearance on the drive end side of the motor. This also reduces the step effect when the air approaches the impeller in the hub area and from the motor drive bearing area.

A further comparison can now be drawn between the internal efficiency ratings of figure 4.3 and the improved axial fan design specifications in figure 4.7. This will help with the final evaluation of the two designs.

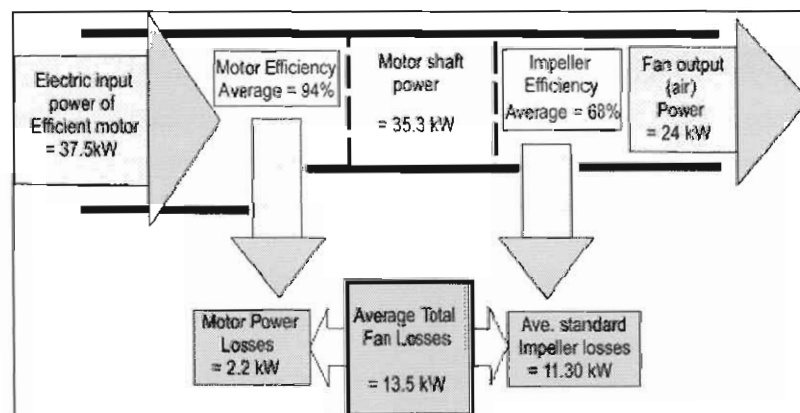


Figure 4.7: Power flow diagram for optimised 45 kW axial fan [1]

4.8 CONCLUSION

The average deep level South African mine has several amounts of auxiliary fans installed for underground ventilation purposes. These fans consume a large sum of the total electricity capacity in most mining operation.

Because the fans operate on a 24-hour sequence, inefficiency may not be dealt with. The obvious solution would be to replace the existing fans with new ones, but for the client, this is a very expensive exercise. The other option would be to replace the existing fan, only when necessary, but with an improved design.

This design must contain an energy efficiency characteristic, extended lifespan with the desired flow and pressure specifications.

Table 4.1 illustrates the comparison between the standard fan issue and a new design fan with the desired criteria as discussed in this chapter. The biggest difference, especially when the electricity savings mechanism comes into play, is the 11 kW absorbed input power. A saving of that margin on a single fan could amount to a huge amount of energy savings when all the fans are brought into account.

ITEM	Standard Fan (kW)	Efficient Fan (kW)	Ave. Losses (kW)	Savings (kW)
Fan air power	24	24		
Impeller power losses	19.65	13.5	6.15	
Motor shaft power	43.65	35.3		
Motor power losses	4.85	2.2	2.65	
Fan total losses	24.5	15.7	8.8	
Absorbed input power	48.5	37.5		
Fan efficiency	50%	64%		
Total savings in absorbed input power				11 kW

Table 4.1: Power performances comparison of a standard fan and an efficient fan

Nevertheless, the only reasonable question to be asked would be whether the mining industry views the energy efficient ventilation approach as a threat to the underground environmental conditions and the production, or as an energy savings method with future financial and environmental benefits.

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*RESEARCH ON REDUCING COSTS OF UNDERGROUND
VENTILATION NETWORKS IN SOUTH AFRICAN MINES*

Chapter 5

**MAIN SURFACE FAN LOAD SHIFT AND
EFFICIENCY ASSESSMENT**

The large energy consumption of the main surface fans in the ventilation system is a possible target for the energy efficient and demand side management initiatives. This chapter looks at estimated energy savings strategies and the environmental impact the main surface fans have on a ventilation system.

5.1 INTRODUCTION

An energy savings approach in the mining industry regarding the ventilation system would be to reduce the annual energy costs of the surface main fans. This is one of the most sensitive subjects in the ventilation system because of the dominant role it plays in providing acceptable underground circulation. Efficiency design methods and possible load shift initiatives might be the answer to possible energy savings, but accurate and intensive measures are of utmost importance to obtain optimum results.

5.2 QUALITY MAIN FAN CONTROL

Normally, the electric motor on a surface ventilation fan is sized to run at near full load capacity and it is running non stop throughout the year. In practice, about 60% of the power produced by the electric motors of all the surface ventilation fans (intake and exhaust) is used to overcome friction in the intake airways and mine workings (final exhaust airways are not considered). Each kilowatt lost to friction (i.e. static head) is converted into heat underground. The objective would be to obtain the most efficient design methodology with the minimum amount of power losses.

Along with the prospect of an efficient fan design, a guarantee of increased flow and pressure levels for underground operations will realize and the minimum amount of power losses will have an impact on the annual electricity bill.

5.3 MPONENG GOLDMINE MAIN SURFACE FANS

Mponeng goldmine, situated approximately 50 km from Johannesburg in South Africa, is an ultra deep level mine that reaches a depth close to the 4000 m mark. The future goal of the mine is to extend the depth of operation to approximately 5000 m, which will have a large impact on the ventilation infrastructure.

To ensure feasible working conditions at these depths, an extended ventilation system is the obvious solution, but this will narrow the opportunity for energy savings initiatives on the main fans. The deeper the mining operation, the more sensitive and fragile the ventilation system becomes. The only alternative would be to ensure a stable environmental condition by means of a highly efficient and controllable ventilation system.

Motor Capacity (kW)	3500
Impeller Speed (rpm)	595
Volume Flow (cu.m/s)	450
Pressure (Pa)	6000
Impeller Diameter (m)	4.5

Table 5.1: Mponeng goldmine surface main fan characteristics

Figure 5.1 shows an image of the three main surface fans on Mponeng goldmine. Each fan has specific operational criteria (see Table 5.1) to achieve maximum flow and pressure rates according to certain mine ventilation policies. These specifications, like any other fan, are important guidelines used to establish the possible energy savings opportunity.

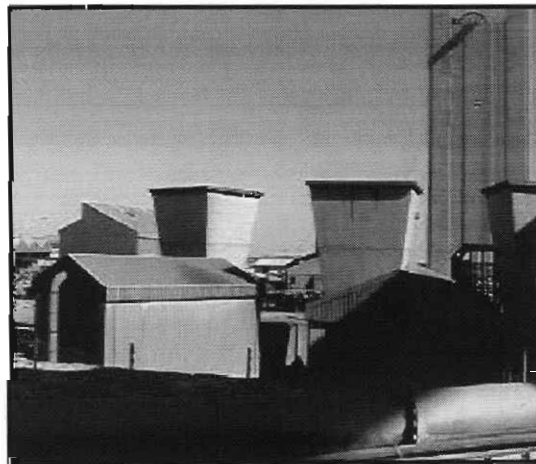


Figure 5.1: Mponeng goldmine main surface fans

The difficult issue surrounding an EE approach at Mponeng goldmine is the future ventilation demand. The continued development will change the current pressure and flow measurements and may cause the implementation of a certain EE strategy to perform below a specific savings potential.

5.4 KOPANANG GOLDMINE MAIN SURFACE FANS

The Kopanang goldmine and Mponeng goldmine shafts are both part of the super mining group AngloGold Ashanti. Being part of such a highly renowned group means that gold production levels must be up to standard to maintain the competitive level in the gold industry. Thus, the only real objective for any operation would be to improve or maintain gold production.

The implications of a production driven industry is that the focus tends to drift when it comes to the inefficient functionalities of certain energy driven units. This results in a constant strive to produce more gold without taking any concern into the matter of increasing energy costs due to inefficient operations.

Kopanang goldmine has three main surface fans in their current ventilation system with a combined capacity of 6.75 MW which is operating at an efficiency rate of approximately 80%. This result was calculated by Howden Safanco Pty (Ltd.) to establish the current efficiency of the main fans. At 80% efficiency the specified pressure and flow rates might be according to the mining operational standards but the amount of power needed to maintain this standard regulation might be at an unstable rate due to certain power losses.

To enable a possible EE strategy will mean that the impeller efficiency of the main fans at Kopanang must increase with at least 10% to ensure feasible flow and pressure measurements. According to the verbal discussion with Howden Safanco Pty (Ltd.), in Johannesburg, South Africa, the 10% increase in impeller efficiency is possible by means of an improved design, but without the proper investment the installation of such a unit might be impossible due to the high costs involved with this design.

The two methods whereby the energy reduction could be attained include a potential load shift initiative and an energy efficiency strategy as mentioned earlier in the document. Both these methods could realise through the implementation of an improved efficient fan design.

5.5 LOAD SHIFT ANALYSIS

Applying a possible load shift control strategy for the main fans will definitely result in profitable energy savings but it might also interfere with the underground environmental balance.

The ideal load shift initiative would be to switch off a couple of main fans simultaneously during evening peak, but this will result in serious repercussions if not controlled to suit the whole ventilation system circulation.

The main idea behind the load shift initiative is to switch off a specific energy unit for a certain amount of time during the peak generation periods. The morning peak interval will most probably be the least significant timeslot to initiate the main fan load shift preparation. This is mainly because of intensive mining activities during the morning. The evening peak would on the other hand be the only realistic timeslot for the load shift initiation because of the reduced amount of employees and mining activities at the production levels.

Looking at the problematic features surrounding the load shift initiation, a few critical issues come to mind that may lead to the rejection of such an implementation. The following areas might be of concern during a load shift initiation:

- a) Recirculation: *if any instability might occur in the ventilation system the possibility of recirculation can result in improper extraction of heat and distribution of fresh air throughout certain mining sections. This could occur due to a reduction in pressure and flow measures from the parallel main surface fan connection.*
- b) Temperature change: *The virgin rock temperature is reduced by means of a constant circulated flow of cooled air produced by the ventilation system. If the system loses a dominant figure such as a surface main fan during evening peak, it will cause a rapid temperature rise and will affect the underground working conditions.*

- c) Hazardous gases: *With unstable directional airflow a shortage of fresh air could cause gases in certain mining sections to become highly flammable. This will cause major hazardous conditions which are unacceptable according to ventilation regulations.*

Although the load shift initiative might seem to be a dangerous proposition for an energy savings proposal, the control of such a system must be up to standard before any realization processes are initiated.

The control of the load reduction method must fulfil the detailed description of the conditional features at every mining operational section. This will ultimately ensure the safe operational feature of the system at all times. The investment of certain equipment must accompany the load shift development. The following summation describes a number of potential equipment for the load shift process:

- a) Automation system: *A real time energy management system must be able to control the main fans automatically, according to specified information on the conditions in the different production sections.*
- b) Variable speed drives: *This will enable the automatic speed control of a selected surface main fan. It will ensure the load shift instigation along with the secure shutdown and starting procedure during commence of every load shift process.*
- c) Pressure and flow meters: *These meters will function in coalition with the automation system. It will supply the sufficient pressure and flow data from different production sections.*
- d) Temperature measuring device: *It will communicate with the automation system to supply the actual temperature rise and conditions at substations and in all areas of operation during the load shift initiation.*

These above mentioned descriptions are merely guidelines that might help with the instigation of a load shift development structure. The investment and energy cost savings potential might vary according to the projected need of a specific mining operation, but it remains to see whether the process will actually be initiated.

5.6 POTENTIAL ENERGY EFFICIENT APPLICATIONS

The implementation of an energy efficient design for the current installed main surface fans is predominantly the safest procedure in obtaining the required energy savings product.

Achieving this goal would require different modifications on the standard main fan unit. Some of the modifications would be a direct imitation of the auxiliary fan changes, but because most main fans are centrifugal fan designs, the impeller modifications are totally different than that of the auxiliary fan.

The important issue regarding the research done on the main surface fan units at Kopanang goldmine would be to modify the unit with a 10% increase in efficiency as stated before. This will again be accomplished through the optimization of the motor and the impeller design methodologies. The determining efficiency factors are considered in the following summary:

- a) Electric input power of the motor
- b) Motor shaft power
- c) Fan output power
- d) Power factor
- e) Impeller efficiency

These are critical factors that contribute to the overall efficiency of the fan. If a single part of the total improved design modification contains a slight inefficient characteristic, the overall efficiency might be in jeopardy during the development of an optimum EE rate.

The advantage of the EE strategy above the load shift initiative is visible in the energy savings potential (to be discussed in the next chapter) as well as the minimal hazardous features the EE strategy contains.

5.7 CONCLUSION

An energy reduction strategy is a fairly new concept when it comes to the standard ventilation system in operation throughout the South African mining industry. To obtain the most effective energy savings structure it is of utmost importance to study the effects on the total ventilation system.

With the large installed capacity of the main surface fan in operation, an effective energy efficient or possible load reduction strategy, might contribute to extensive energy saving with large financial reimbursements on the total annual energy costs in a specific mining operation. The efficient optimisation of the fans and the installation of an appropriate automation system will form the major part of the energy savings strategy for the main surface fan units throughout the mining industry.

The results of the optimised auxiliary fan design showcases in the next chapter along with the estimated results of an improved surface main fan design with a 10% increase in fan efficiency.

*RESEARCH ON REDUCING COSTS OF UNDERGROUND
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Chapter 6

RESULTS

This chapter explains the benefit of the improved auxiliary fan design above the standard design and focuses on the potential annual energy savings for both the improved auxiliary fans and the surface main fans.

6.1 INTRODUCTION

The operating energy costs of the standard auxiliary and surface main fans are increasing annually due to the inefficient operation features. With the aid of the improved design methodologies discussed before, these costs could largely be reduced without the disturbance of a ventilation system. Comparing the current fan costs to that of the improved initiatives will give a clear indication of the potential energy savings opportunities within the standard ventilating system today.

Further discussions will focus on the fan capacities of two AngloGold Ashanti operations namely, Kopanang Goldmine and Mponeng Goldmine, to determine the possible savings.

6.2 IMPROVED AXIAL FAN RESULTS

6.2.1 Standard versus improved axial fan tested results

Replacing the current standard installed auxiliary fan will definitely contribute to the overall energy savings of a ventilation system. The important issue remains to be whether the improved fan designs are capable of producing the required pressure and flow measurements with less input power.

The tested performance criteria on both the standard and improved fan units were gathered to establish the accuracy of the research on the improved fan design. With the aid of the fan testing column supplied by Continental Armature Winders Pty. (Ltd.) situated in Klerksdorp, South Africa, necessary pressure, power and flow data were obtained which enabled the fan comparison process.

The standardized fan unit used during the testing stages contained the specifications shown in Table 6.1. These specifications were identical to that of the optimized fan but the only exceptions were the impeller and casing designs. The production of the optimized motor have not yet been put into practice, but with the installation of the improved impeller and casing designs, EE improvements are possible.

Motor Power (kW)	45
Nominal Speed (rpm)	2940
Volts (V)	525
Amps (A)	65
Frame (mm)	760

Table 6.1: Standardize fan design specifications

The implementation approval of any tested fan relies on the accurate pressure measurement according to certain mine regulations, which includes the operational density. In this case the mean density was approximately 1.07 kg/m^3 . The density at which the fan is tested may vary according to the daily environmental conditions, but the standard testing procedure includes the calculation of the results according to specified density at which the fan operates.

The tested results of this study focus on all the above-mentioned criteria but include input power variations. Both the standardized and impeller optimised fan test reports are attached in Appendix A. Figure 6.1 illustrates the total pressure measurements of both standard and optimised auxiliary fans.

The fans are measured at different densities with similar results in pressure. This is acceptable according to AngloGold Ashanti auxiliary fan specifications, which confirm that the optimised fan is producing accurate pressure measurements.

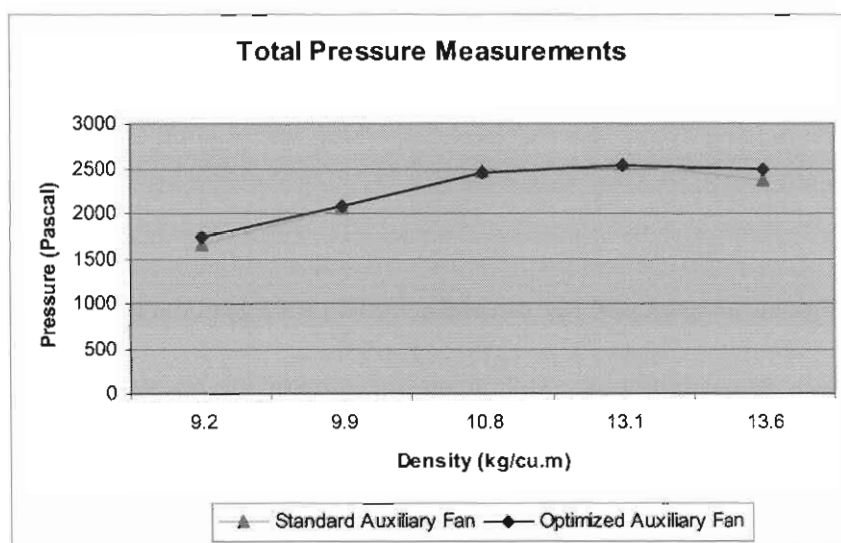


Figure 6.1: Tested total pressure measurements

The tested average input power of the standard auxiliary fan is much higher than that of the optimised auxiliary fan as shown in Figure 6.2. This is mainly because of the fact that the distribution of the working load between the impeller and the motor operates in a balanced state. The inefficient impeller of the standard auxiliary fan causes the imbalance of the fan with most of the working load focused upon the motor power performance.

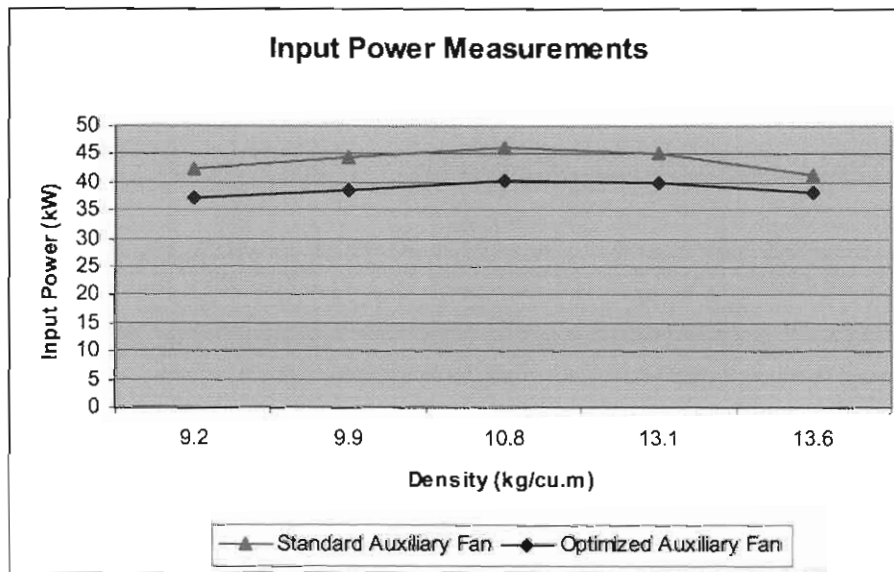


Figure 6.2: Tested input power measurements

The motor efficiency is largely affected by the imbalance state of the fan, and this eventually causes motor power losses that contribute to a decrease in the operational life span along with continuous increase in maintenance and energy costs. On the other hand with a more efficient motor, less input power is required to satisfy the specified regulations with an eventual increase in the total fan efficiency as shown in Figure 6.3.

The improved design initiative is an acceptable fan unit with the capability of producing valid airflow and pressure values according to legislative policies. This enables the main objective in reducing energy costs without interfering with the stability of underground environmental conditions.

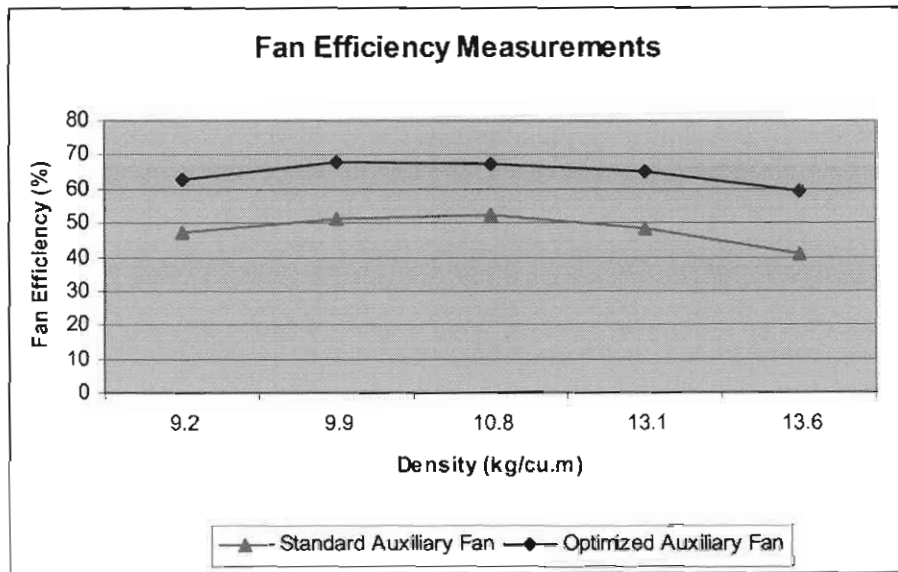


Figure 6.3: Tested fan efficiency measurements

6.2.2 Optimised auxiliary fan energy savings results

With the design of the improved single stage 2 pole 45 kW auxiliary fan described in chapter 4, the saving of 11 kW per fan amounts to nearly, 660 kW of energy savings on the 60 installed 45 kW fans currently at Mponeng Goldmine. Not only does this result in a major savings possibility on the 45 kW fans, but it would also be viable for implementation on other auxiliary fans such as the 15 kW, 18 kW, 22 kW, ect.

The design of the optimised auxiliary fan is based on the principle of a smaller more efficient motor and an improved impeller design that could meet the same pressure and flow duties of the current fan installation with the added bonus of an extended operational lifetime.

When it comes to the fan manufacturing cost analysis, the price difference between a newly installed standard design and a newly installed improved design will practically be on an even scale. The price of a new standard auxiliary fan unit will be approximately in the range of R30 000 to R35 000; the same goes for the improved design. The reason for this being that the improved design uses a smaller 35 kW motor.

The price differences on all the different fan models are usually premeditated according to the size of a fan motor. With this in mind, the obvious approach would be to distinguish the future benefit of the possible investment in the optimised fan design.

The optimised fan design uses approximately 20% less input power than the standardized design. It creates a practical solution to the inefficiency problem of single fan units, but might be a very expensive investment to replace a complete system.

If a mining operation such as Kopanang goldmine would decide to replace the existing fifty one 45 kW auxiliary fans with the improved efficient design, a total investment of nearly R 1,985,000.00 would be approximate cost estimation for all the units to be installed, for an energy saving total of nearly 561 kW.

Although the investment amount might be considerably high in comparison to the total fan energy savings potential, the idea of a definite payback period less than four years would be a determining factor behind a possible implementation strategy. The fact remains that the future savings on the electricity bill will amount in a surplus that could be used for other efficient ventures.

The annual energy cost of the standard auxiliary fans in production operating at an average fan efficiency of 50% is shown in Table 6.2. Eskom bases these values upon the installed capacities of both Kopanang and Mponeng goldmine according to the 2006 Megaflex tariff rates compiled.

Total Annual Costs of Standard Axial Fans		
	Kopanang Goldmine	Mponeng Goldmine
Peak	R 785,504.83	R 924,123.33
Standard	R 830,871.69	R 977,496.11
Off Peak	R 712,340.22	R 838,047.32

Table 6.2: Annual Costs of Standard Auxiliary Fans

The costs shown in Table 6.2 and Table 6.3 are calculated for evaluation purposes on both the standard and improved fan designs, respectively. The actual results of the two mining operations in discussion may vary due to possible changes or replacements in the ventilation systems. This research mainly focuses on an ideal system; it consists of accurate data calculations obtained from both the discussed mining operations.

Total Annual Costs of Efficient Axial Fans		
	Kopanang Goldmine	Mponeng Goldmine
Peak	R 661,477.75	R 778,209.12
Standard	R 699,681.42	R 823,154.62
Off Peak	R 599,865.45	R 705,724.06

Table 6.3: Estimated annual costs of efficient auxiliary fans

Table 6.4 exemplifies the annual energy savings difference between the standard auxiliary fan and the efficient fan design. Not only does it prove the financial savings potential it also guarantees an extended lifespan of the motor together with efficient and healthy environmental conditions.

Total Annual Energy Efficiency Savings		
	Kopanang Goldmine	Mponeng Goldmine
Peak	R 124,027.08	R 145,914.21
Standard	R 131,190.27	R 154,341.49
Off Peak	R 112,474.77	R 132,323.26
Total	R 367,692.12	R 432,578.96

Table 6.4: Estimated total EE savings with improved auxiliary fan

The graphical illustration in Figure 6.4 compares the annual energy savings projection of the different fan designs at Kopanang goldmine during the specified peak, standard and off-peak operational periods.

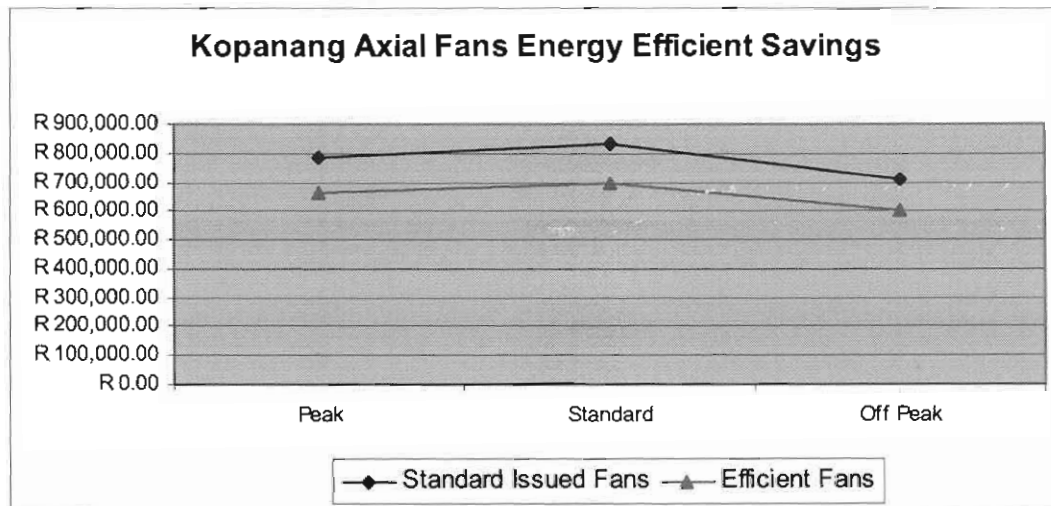


Figure 6.4. Estimated Kopanang goldmine axial fans EE savings

6.3 MAIN SURFACE FAN ENERGY COST ESTIMATIONS

6.3.1 Estimated load shift energy cost reduction

The important issue surrounding the load shift initiative is to reduce energy peak load on a daily basis throughout the annual operational configuration. Both the peak intervals arranged by Eskom are relevant for this practise, but the difficulties in realizing the load shift initiative due to hazardous conditions make it a sensitive subject to control.

The morning peak period is probably the most difficult timeslot for any possible load shift realization. The reason for this lies in the stringent mining activities during a standard day shift. At Mponeng goldmine nearly 3240 mining employees are operational during the morning shift, with 535 and 960 employees active during the afternoon and night shifts, respectively. This gives a clear indication on the importance of the environmental management system during the morning shift.

With the morning peak period being between 7-10am, it will be nearly impossible to initiate any load shift due to the enormous demand in stable underground environmental conditions. The only timeslot that may be acceptable will be the evening peak interval between 6-8pm.

Different mining operations use the evening shift to employ the necessary blasting procedures. This is a problem that could halt the load shift initiation, but it solely depends on the impact of load reduction a single main fan unit has on the underground ventilation system. With a variation of different mining operational depths, the possibility of load shift at lower level mining operations might be a better field of approach for the load shift initiative, but it will depend on the virgin rock temperature of the specific region and the size of the ventilation area in a mining operation.

The estimated two-hour load shift of a single surface fan unit might contribute to a reduction of the total annual energy savings in a mining operation but the load shift of two surface fan units might have a larger impact on the annual energy costs.

The estimated load reduction potential is graphically illustrated in Figure 6.5. This is an example of what the annual financial impact would be, if one surface fan unit could be switched off during a two-hour evening peak interval.

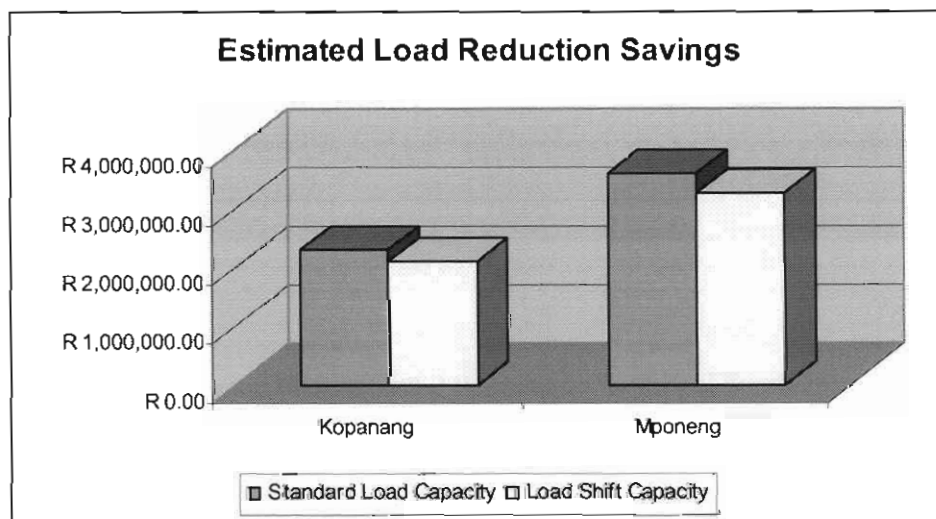


Figure 6.5: Estimated surface main fan peak load reduction

The estimated savings on the load shift capability (see Table 6.5) would be in the order of R 202,658.63 and R 315,246.75 for Kopanang and Mponeng goldmine, respectively. This amount may vary according the availability of the main fans during the annual operational period.

Estimated Load Shift Savings		
	Kopanang Goldmine	Mponeng Goldmine
Annual fan costs without load shift	R 2,310,308.33	R 3,593,812.95
Annual fan costs with load shift	R 2,107,649.70	R 3,278,566.20
Total	R 202,658.63	R 315,246.75

Table 6.5: Estimated annual load shift energy savings

Although the load shift initiative might seem to be a hazardous method to obtain certain savings projections, the option of utilizing such a method will ultimately result in a more manageable and controllable system due to the constant evaluation of the ventilation process, with the benefit of annual energy savings and possible fan life extension and efficiency.

6.3.2 Energy efficient savings estimation

The best possible way to enable an energy savings initiative would be to establish whether the operational features of the main surface fans are running at an appropriate efficient level.

Howden Safanco Pty (Ltd.) evaluated the efficiency levels of the surface main fans on Kopanang goldmine, by means of the obligated monthly main fan flow and pressure results for a tested period of four years. These results showed that the surface main fans were operating at an efficiency rate of nearly 80%. It is evident that an increase in energy efficiency will be possible with an even better flow and pressure rate if an improved design were to replace the current applications.

According to a study done by Howden Safanco, an efficiency increase of 10% on the current surface main fan units will be a possibility with the aid of some improvements on the current design. It will definitely have a major impact on the annual energy costs along with the flow and pressure rates of all the installed units.

Figure 6.6 illustrates the possible difference in annual energy costs if the current installed surface fans at Kopanang goldmine should be replaced by the efficient fan design of Howden Safanco.

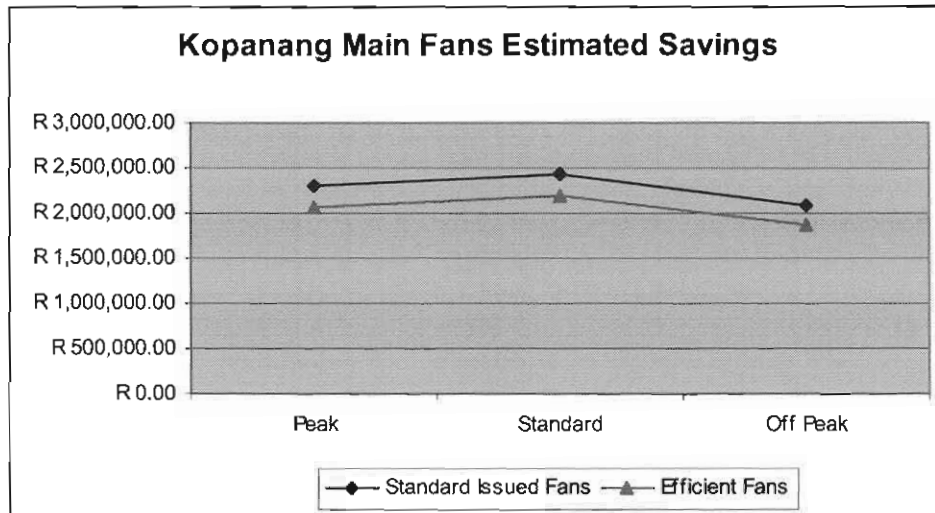


Figure 6.6: Kopanang goldmine estimated savings with efficient fan design

If the assumption could be made that the main surface fans at Mponeng goldmine are operating at an efficiency rate of 80%, the implementation of an improved design will have a similar effect, in comparison to that of Kopanang goldmine, on the annual energy savings projection shown in Figure 6.6. The savings are again calculated according to the peak, standard and off-peak periods compiled by Eskom's megaflex tariff rates.

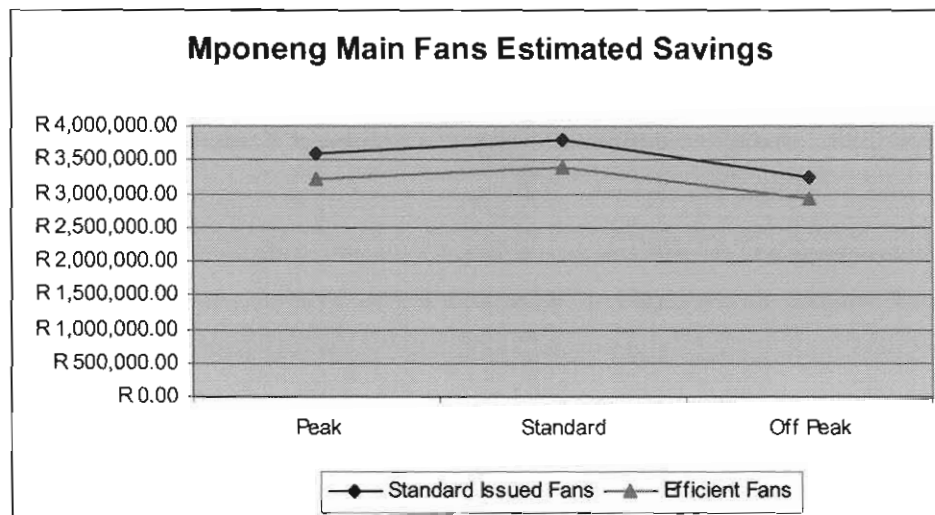


Figure 6.6: Mponeng goldmine estimated savings with efficient fan design

The approximate annual EE cost savings for both Kopanang and Mponeng goldmines are shown in Table 6.6. These savings are considerably higher than that of the estimated load shift initiative.

The final implementation of either the EE approach or the load shift initiative will depend on the specific mining operation characteristics. If the efficiency rate of the main fans in a mining operation is within an acceptable range, the load shift initiative would most probably be a considerable option, but with inefficient fan applications, EE will lead to extensive energy savings in a ventilation system.

Total Estimated Energy Efficiency Savings		
	Kopanang Goldmine	Mponeng Goldmine
Total	R 720,964.94	R 1,121,501.01

Table 6.6: Total estimated EE savings on surface main fans

6.4 ESKOM DSM PROGRAM

The DSM initiative from an Eskom point of view is the only reliable factor to date that will have a positive impact on the annual energy growth impediment. The only worrying factor to the industry is to obtain the necessary funding for possible EE and load shift development.

Eskom has developed a program to help the different major consuming industries financially with the development of efficiency strategies. This initiative solely focuses on the potential savings in megawatts each operation might consist of. The requirement for the Eskom DSM funding program is a minimum load shift or load reduction of 0.5 MW. If a mining operation has the potential in shifting 1 MW load during the peak generation interval, Eskom will fund an approximate R 3, 000,000.00 to enable this load shift prospect. This will facilitate the advantage of energy reduction for both the consumer and the supplier without any financial drawback on behalf of the consumer.

The main surface fans at Mponeng goldmine should have a possible potential load shift capability of 3.5 MW if a single fan unit is switched off during the evening peak interval.

Eskom will invest an estimated R 10, 500,000.00 if this load shift prospect should realize. Thus, with enough funding the accurate ventilation design system and the additional automation control system should not be an issue of concern. The only crucial factor would be to establish the most accurate design and automation measures.

The savings potential in replacing the installed capacity of the 45 kW fans at Kopanang and Mponeng goldmines would amount to approximately 561 kW and 660 kW respectively shown in Table 6.7. Eskom will invest up to R 2, 000,000.00 for this efficient development initiation.

The implementation costs to replace the current operational auxiliary fans with that of more efficient auxiliary fan design are shown in Table 6.7. These costs may be the main obstacle to overcome ensuring the EE initiation, but the future savings value illustrates the impact it might have should the EE approach be neglected. The Eskom funding will cover the necessary expenses with a slight chance of additional costs, depending on the infrastructure of the mining operation and the possibility in breakage costs.

	Initiation Costs	EE Savings	5 Year EE Savings
Kopanang Goldmine	R 1,985,000.00	561 kW	R 2,206,152.72
Mponeng Goldmine	R 2,100,000.00	660 kW	R 2,595,473.76

Table 6.7: Auxiliary fans EE annual savings prospect

The same goes for the EE and load shift approach on the main surface fans (shown in Table 6.8). The only minor difference is that the annual savings potential is greater than that of the auxiliary fan improvements due to the difference in total consumption.

Both the EE and load shift initiatives on the smaller auxiliary and surface main fans are possible investment areas for the Eskom DSM program. The mining industry should consider the energy reduction method on the ventilation system as an obligation for future energy savings.

	Estimated Initiation Costs	Peak Load Shift	EE Saving	5 Year EE Savings
Kopanang Goldmine	R 2,000,000.00	2.25 MW	675 kW	R 3,604,824.70
Mponeng Goldmine	R 2,500,000.00	3.5 MW	1.05 MW	R 5,607,505.05

Table 6.8: Main surface fans annual savings projection

The sole responsibility would be to gather the necessary information regarding the inefficient installed capacities and determining the method of initiation.

6.5 CONCLUSION

Energy savings through the implementation of energy efficient and load shift strategies are evident when looking at both the auxiliary and main fan efficient methodological results in this chapter.

Some auxiliary fan applications, with improved impeller and casing designs, have already been installed in several mining operations, with major improvement in efficiency along with an extended fan operating life. However, the industry has not yet established a process to ensure the implementation of the potentially efficient approach.

In the future, the impact of the newly developed auxiliary fans together with potential main fan efficiency designs or strategies, can assist the exploration in further energy efficient improvement in the current inefficient ventilation system.

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Chapter 7

CLOSURE

This chapter discusses the main objectives behind the energy efficiency strategies of mine ventilation fan control and summarizes the recommendations for possible future work.

7.1 SUMMARY AND CONCLUSION

The objective of this study was to develop an energy reduction control method on mine ventilation fan units, to create a more energy efficient ventilation system without interfering with underground environmental conditions.

By gathering information on the inefficient auxiliary and main fan operational characteristics and the current electricity tariff charges, it was found that the improved auxiliary fan design and the estimated efficient main fan control will be financially beneficial to the mining industry as well as to the electricity supply industry.

The research on the improved 45 kW auxiliary fans showed the importance of a balanced working load distribution between the impeller and the motor design. Both the standard and improved auxiliary fans were tested to compare the operational characteristics. Pressure measurements, total fan efficiency and the input power ratio were among the tested results. The efficient fan design produced acceptable pressure and flow parameters, with higher motor efficiency than the standard fan unit and the benefit of a reduction in input power of nearly 11 kW.

A secondary study was to gather information on the main surface fan operational features at Kopanang and Mponeng goldmines. The gathered information illustrated an estimated possibility for load shift and efficiency strategies, which will result in fan operating life expansion and electricity savings capabilities.

The load shift possibility of the surface main fans must be accompanied by a real time energy management system and a possible variable speed drive on the fan, this will in effect help with the quality control of the fan. The energy efficiency strategy for the surface main fans would be to increase the total fan efficiency by means of new impeller and motor design methodologies.

The annual electricity consumption of the standard and improved fan designs were compared to measure future investment possibilities.

An investment on replacing the standard auxiliary fan with the optimised units were in the region of R 2, 000,000.00 which proved to be expensive , but the benefit of a definite payback period less than five years would materialise due to the 561 kW and 660 kW energy saving possibility at Kopanang and Mponeng goldmines respectively.

Annual electricity savings of up to R 1,500,000.00 for EE or load shift strategies give an indication on how costly inefficiency can be. The calculated 10% increase in main fan efficiency resulted in an annual energy saving of nearly R 1,100,000.00, with the constant load shift of 3.5 MW for a single main fan unit at Mponeng goldmine while an annual estimated energy savings potential of nearly R 721,000.00 was evident at Kopanang goldmine with a constant load shift of 2.25 MW for a single fan unit.

Capital investments will most probably play a crucial part in the realization of these efficient measures. It may include, improved fan installations, variable speed drives for the main fans and real time management systems. If the mine should decide to invest in these efficient strategies, the proposed Eskom DSM initiatives might result in a net savings opportunity of a mining operation.

This study proved that a large energy savings potential exists in the optimisation of an underground ventilation system, with the aid of efficient fan units that contribute to the total efficiency characteristic of a ventilation system.

7.2 RECOMMENDATIONS FOR FUTURE WORK

The improved auxiliary fan unit has not yet been fully developed according to the all specification in this research analysis, but numerous installation with the improved impeller design are in operation at various mining operations.

With further motor modifications along with the high efficient impeller design, the possibility of increased efficiencies will definitely become a source of even larger energy savings. The replacement of the improved 2-pole motor with an improved 4-pole motor will extend the operational lifespan but might be a more expensive fan unit.

The load shift estimations of the surface main fans are dependant upon a new intelligent control system. This system must be able to control the selected fan speed and guide vanes or impeller blades to reduce the load capacity of the fan. By having full control over the environmental conditions would mean that the pressure, flow and temperature readings should be directly linked to the fan control system. This will enable the possibility of fan control according to the underground environmental conditions at certain time periods.

7.3 CONCLUSION

The inefficient operation of a standard ventilation system in South African mines is evident when looking at the annual costs related to this issue. Without a proper management scheme surrounding the control of the underground environmental system, the maintenance and energy costs of this system will change with a dramatic impact on the overall production assets.

The introduction of efficient design methodologies is a definite must in today's mining industry especially within the environmental system. The optimisation of the system will solely depend on the individual fan operation features, with an estimated effect on the total production and energy costs.

APPENDIX A

FAN TEST REPORTS

This appendix presents the fan-tested reports obtained using the fan test column at Continental Winders Pty. (Ltd.).

A.1 Standardized Auxiliary Fan Test Report

CONTINENTAL ARMATURE WINDERS FAN UNIT TEST REPORT							
Motor Power:	45 kW	Nominal Speed:	2940 rpm	Volts:	525 V		
Amps:	65 A	Frame:	760 mm	Mean density:	1.07 Kg/cu.m		
		Units	Open	Pos 2	Pos 3	Pos 4	Stall
Static Pressure		Pa	1256.19	1742.87	2201.43	2360.65	2231.79
Volume Flow		cu.m/s	12.27	11.14	9.97	8.61	7.21
Fan Total Pressure		Pa	1648.33	2066.25	2460.21	2553.62	2366.96
Total Air Power		W	20025.32	22783.88	24281.03	21770.13	16893.75
Fan Static Power		W	34035.15	36453.74	38145.18	36765.96	32517.32
Impeller Speed		rpm	2954.85	2951.59	2949.3	2951.16	2956.89
Average Current		A	57.33	60.00	62.34	60.66	56.00
Average Voltage		V	495.06	494.05	489.68	491.37	492.71
Power Factor		cos phi	0.86	0.87	0.87	0.87	0.86
Input Power		W	42375.34	44618.35	46266.14	44967.05	41147.63
Shaft Power		W	34035.15	36453.74	38145.18	36765.96	32517.32
Motor Efficiency		%	80.32	81.70	82.45	81.76	79.03
Fan Efficiency		%	47.26	51.06	52.48	48.41	41.06
AAC538 standard and Anglogold 482 requirements @ densities			Kg/cu.m		Tested Machine		
Motor efficiency at point of maximum input power			1.07		82.4		
Temperature rise at maximum input power			1.07		19.63		
			1.20		21.97		
Motor output power at duty point for rated voltage			1.07		38145		
			1.20		42686		
The motor tested as per SABS 1561 / IEC 34 and losses separation for Maximum Output Power of: 46266 W							
Iron-Friction:	800 W	Stator-Copper:	1627 W	Additional:	212 W	Rotor-Copper:	598 W
Maximum Measured Speed:	2957 rpm	Maximum Efficiency:	52.8%	Maximum Power Factor:	0.87 cos phi		
Bearing Temp. Rise NDE:	22.00 deg.C	Bearing Temp. Rise DE:	20.00 deg.C	Tested for:	2.00 hrs		
Electric Input at 42375.34 W for 2.00 hrs							

A.1 Optimised Auxiliary Fan Test Report

CONTINENTAL ARMATURE WINDERS FAN UNIT TEST REPORT							
Motor Power:	45 kW	Nominal Speed:	2940 rpm	Volts:	525 V		
Amps:	65 A	Frame:	760 mm	Mean density:	1.07 Kg/cu.m		
	Units	Open	Pos 2	Pos 3	Pos 4	Stall	
Static Pressure	Pa	1274.33	1675.85	2124.87	2246.71	2271.41	
Volume Flow	cu.m/s	13.49	12.64	11.22	10.44	9.19	
Fan Total Pressure	Pa	1735.78	2080.5	2443.44	2522.85	2485.52	
Total Air Power	W	23176.77	26024.72	27135.49	26086	22608.91	
Fan Static Power	W	24662.03	26706.92	29169.92	29062.45	26473.84	
Impeller Speed	rpm	2967.42	2964.69	2961.39	2961.53	2965	
Average Current	A	51	53.01	55.67	55.33	52.67	
Average Voltage	V	479.52	479.52	477.5	479.52	480.53	
Power Factor	cos phi	0.87	0.87	0.87	0.87	0.87	
Input Power	W	37020.68	38435.98	40149.26	40072.5	38269.7	
Shaft Power	W	24662.03	26706.92	29169.92	29062.45	26473.84	
Motor Efficiency	%	66.62	69.48	72.65	72.52	69.18	
Fan Efficiency	%	62.6	67.71	67.59	65.1	59.08	
AAC538 standard and Anglogold 482 requirements @ densities		Kg/cu.m		Tested Machine			
Motor efficiency at point of maximum input power		1.07		73.2			
Temperature rise at maximum input power		1.07		11.54			
		1.20		13.26			
Motor output power at duty point for rated voltage		1.07		29593			
		1.20		33993			
The motor tested as per SABS 1561 / IEC 34 and losses separation for Maximum Output Power of:				40451 W			
Iron-Friction:	800 W	Stator-Copper:	1366 W	Additional:	185 W	Rotor-Copper:	377 W
Maximum Measured Speed:	2967 rpm	Maximum Efficiency:	67.8%	Maximum Power Factor:	0.87	cos phi	
Bearing Temp. Rise NDE:	24.00 deg.C	Bearing Temp. Rise DE:	22.00 deg.C	Tested for:	2.00 hrs		
Electric Input at 37020.68 W for 2.00 hrs							