

Energy savings on mine ventilation fans using ‘Quick-Win’ Hermit Crab Technology-A perspective

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ABSTRACT: The beginning of 21st century has heralded the global strategic importance, as evidenced by increase in energy prices and energy generation-emission-utilization dilemmas. In January 2008, the South African energy supplier, ESKOM had tabled the concept of power conservation and acknowledged the energy crisis until 2016. The concept is required of all energy users to reduce their electricity consumption, intensify energy efficiency and cautiously proceed with new projects. The generation of energy results in by-products called “green house gases” (GHGs). To make a positive response to climate change and their effect on the environment, every energy user must ensure efficient energy use through technical and administrative means referred to generally as energy savings. This paper identifies mine ventilation engineering, in particular the electricity consumed by main fan units, as an area of potential energy savings. For a major mining company, electricity consumed by main ventilation fans alone can be in the order of 120 MW. Although a known fan engineering technique but scantily applied technology identified as the Hermit Crab can be seen as a “quick win” project, due to its success in other industries such as cement and steel. The ‘Hermit Crab’ technique® involves upgrading or replacement of an impeller - whatever its origin - with a design impeller to suit the actual ventilation requirements, resulting in increased fan efficiencies. The cash flow benefits associated with a case study and its rollout of this technology have been calculated. For a 10% increase in main fan efficiency, would have a net present benefit of US\$ 16.08m over 10 years. With the inclusion of carbon credits, this benefit rises to US\$ 29.40m in total. Application of other available technologies, viz., composite materials, ventilation-on-demand and variable speed drives are discussed.

1 Introduction

The efficient use of energy has become increasingly important against the backdrop of a growing world economy constrained by the quantity and price of energy resources available to do so. Energy usage affects the environment directly because of the emission of GHGs, primarily as a result of the burning of fossil fuels, such as coal, oil and gas. Good business practice and legislation have put the onus on future-minded companies to make a positive response to climate change and their effect on the environment. This has resulted in a twofold benefit for increasing the efficiency with which energy is used: firstly, by lowering the amount and, therefore, costs associated with energy used and, secondly, by a reduction in the emissions resultant from electricity generation. This paper identifies the discipline of mine ventilation as an area of potential energy savings through the implementation of new technologies.

2 The Energy Market

In 2004, the global energy business was estimated to be in the order of USD 2 trillion per year. The World Energy Council has estimated that between 1990 and 2020 global investment in energy will be of the order of USD 16 trillion, making energy the world’s largest industry (AA plc, 2004). Due to its strategic value, the energy sector is being driven by various forces such as risks associated

with security & reliability of energy supply; worldwide trend of energy sector de-regulation; birth of environmentally conscious societies; state-of-the-art energy efficient technologies; and changing geo-political patterns linked to energy. Following the Earth Summit (Rio 1992), economic development and concerns about the environment have increasingly gained importance resulting in the Kyoto Protocol (1997) with energy taxes, emission restrictions and levies on emissions of harmful GHGs. These events have forced the industry into the pursuit of energy efficient technologies and management practices. In January 2008, the South African energy supplier, ESKOM had tabled the concept of power conservation and acknowledged the energy crisis until 2016. The concept is required of all energy users to reduce their electricity consumption, intensify energy efficiency and cautiously proceed with new projects.

2.1 Energy Legislation

The effect of energy on the environment has resulted in a host of new legislation and global community agreements. The most notable of these is the Kyoto Protocol. South Africa acceded to Kyoto in March 2002 and had ratified the United Nations Framework Convention on Climate Change in 1997. The Energy Efficiency Strategy (DME, 2004) document sets a national target for energy improvement of 15% by 2015 for the Industry and Mining Sector. The document states that relatively high theoretical

potential for energy saving exists in the magnitude of 50% of current consumption. It believes that a savings potential of at least 11% would be readily achievable using low to medium cost technical interventions.

2.2 Electricity Costs and Improving Energy Efficiency

Mining company's are a major energy user and typically in the order of (various types including electricity) 300 GJ. Typically, energy comprises approximately 7-10% of operating cost. Mining industry is facing the challenges of increased energy costs and continued supply in all its operations (as experienced in Southern Africa). Therefore introduction of energy efficiency systems could, result in tremendous gains.

The rapidly escalating value of "carbon credits-a reciprocal monetary value gained in reducing the GHGs," could have serious implications. In 2003, carbon credits were trading at USD 6/tonne of CO₂ equivalent (CO₂e). However, in August 2005 cost of trading carbon was approximately USD 30/tonne CO₂e, suggesting that future prices may be even higher than previously forecast.

Some of the major mining company's electricity energy demand amounts to 7-8% of South Africa's national demand. Therefore, any involvement of the power sector in South Africa would be a risk and an opportunity for mines. South Africa currently enjoys the lowest electrical power tariffs in the world. For example, electricity cost in South Africa, Canada, Australia, Ireland and Botswana are 0.023 US\$/kWh, 0.075 US\$/kWh, 0.026 US\$/kWh, 0.086 US\$/kWh and 0.028 US\$/kWh respectively. This year, the existing generation capacity has lagged the demand due to increased use of residential, commercial sector and the government electrification program. These demands will significantly increase the price (up to 2.5 times the current price) of electricity in South Africa. A shortage of power supply would have serious implications in terms of business interruption costs.

Sustainable development is central to mining industry's future and energy savings being one of the strands of activities under sustainable development. During 2004, mining industry in South Africa had made commitments to an aggregated 12% reduction in energy intensity and a 10% reduction in carbon emissions over the next 10 years, working off the 2003 baseline. Initial assessments have shown that significant opportunity for energy efficiency with both economic and environmental benefits (over 200 potential energy saving projects). With growing global concerns about accelerated climate change resulting from human activities, industry has been working on energy efficiency measures for some years. Any higher-than inflation rises in electricity costs in South Africa or elsewhere and exceptionally high oil prices as evidenced this year, would probably pay for the cost of implementing new technologies.

2.3 Energy Savings in Mine Ventilation

This section of the paper gives a brief background on the mine ventilation engineering energy saving technologies.

Ventilation of underground mines in its most simple form involves the control of the underground atmospheric environment. This requires control of air and air movement to satisfy the requirements for health and safety standards and the comfort of workers.

Recently traditional underground mine ventilation designs are being increasingly challenged by ever more stringent health and safety issues and the economics of mine exploitation. Over the years "air factors" have been used in estimating the fresh air quantity requirement for a new mine. The air factor is defined as the ratio between cubic meter per sec of air and kilo ton of excavated ore per month from underground. Each mineral commodity and country of operation has respective air factors. These factors have been based on heat loads, gas and dust levels, diesel particulate matter (DPM), mining method and production rates. Depleted shallow mine reserves and increased deep level mining, new legislative requirements, increasing power costs and pressure from shareholders to obtain high rates of returns require the effective, efficient and economic use of mine air requiring innovative practices in mine ventilation design and technology. The cost of providing ventilation air to a mine increases as the cube of the air quantity. Underground mine ventilation is a significant cost component of mining. The major component of mine ventilation is the main fans that supply the fresh air underground.

2.4 Fan Performance and Electricity Consumption

The work done by a fan can be measured by the quantity of air it delivers and the pressure against which this air is delivered. Assuming the fan is 100% efficient, the theoretical power (kW) required is obtained by multiplying the given air quantity (m³/s) to be moved against a total pressure in kPa. The overall fan efficiency relates the theoretical output against the electrical power supplied to the fan system and includes fan losses, belt drive losses, and motor losses. It should be noted that the efficiency stated by most fan manufacturers is for the fan unit alone; (i.e. the theoretical output as a ratio of the power input to the fan shaft). The performance of a fan is usually indicated by a relationship between pressure and air quantity in m³/s expressed using graphically defined curves called fan characteristic or performance curves. In practice the fan supplier provides a performance range whereby the fan can be operated optimally.

A fan operates along a performance curve given by the manufacturer for a particular fan speed. In any fan system, the resistance to air flow (pressure) increases when the flow of air is increased. The pressure required by a system (low resistance or high resistance) over a range of flows can be determined and a "system performance curve" can be developed. This system curve can then be plotted on the fan curve to show the fan's actual operating point where the two curves intersect. This operating point is at airflow delivered against a particular pressure. Each fan curve has the 'highest efficiency point' on the curve using lowest power. Ideally, for a given underground mine, this

operating point should match with the optimum efficiency of the fan resulting in optimum energy consumption. However, due to changes in mine design, the operating point will be either on low resistance or high resistance system, necessitating re-visit of highest fan operating efficiencies.

3 Opportunities to Improve Mine Fan Efficiency

Ventilation energy demand can be reduced considerably by adopting a variety of energy efficient ventilation techniques. Depending on mining types, ventilation systems can consume up to 50% of the electricity used in underground mines. Over the years, efficiencies of fans have reduced drastically due to changes in system resistance and also particularly, as the components of the fan wear down. Therefore, the first step in assessing a fan is to return it to design operating conditions through proper maintenance. Some of the low cost opportunities are, viz., reduce fan speed to suit optimum system airflow with balancing dampers in their maximum open position for balanced air distribution; improve fan inlet and outlet duct connections to reduce entrance and discharge losses.

Main fan inefficiencies result as a consequence of modifications to the initial mine planning and design that result in different resistances than originally expected. This could be as a result of the need to mine deeper, changes in mine layout or increased mine resistance that change the resistance at a particular depth necessitating different power requirements to those originally planned. There are various types of retrofit opportunities to improve the fan efficiencies, viz., Hermit Crab technique, composite materials, variable speed drive, replacing over sized motors or ventilation on demand (VOD) systems. The following sections discuss each of these techniques:

3.1 Hermit Crab Technique

As an initiative on energy efficiency solutions by the author's employer, consultations with fan manufacturers were made. A technique called the 'Hermit Crab' to increase main fan efficiencies was identified. Whilst rarely implemented in a mining environment, demonstrations of the cost savings in non-mining operations were impressive. The Hermit Crab® technique is a registered fan technology trademark of Fläkt Woods. The technique involves the upgrading or replacement of an impeller - whatever its origin - with new design impeller to suit the actual ventilation requirements, resulting in increased fan efficiencies (other suppliers can also provide such a solution). Once a main fan has been identified with lower efficiency levels, the optimal operating point can be determined and the new Hermit Crab impeller can be designed or altered. This can be done by changing the blade aerodynamics, blade angles and/or blade materials so as to reach the desired operating point. This new or altered impeller is then inserted into the existing fan case. The flexibility of this concept enables one to define the optimal solution for the existing main fans. This retrofit can be

achieved through shorter downtime and includes erosion resistant impellers that provide improved air capacities and reduced energy consumption. On the contrary, conservative comments with regard to the application of this technique are discussed in Section 6.

3.2 Composite Materials

Composite materials are a mix of carbon fibre and steel, which is lighter than steel and has higher resistance to fatigue. To date there are no fans using composite materials available for mining applications, although there are suggestions of such applications. Impeller and blade failure is a major problem with small mine axial flow fans usually due to foreign material (usually rocks) passing through the fan. The rocks get into the fan because the fans and ducting are often pushed around on the footwall before being suspended, and they scoop up rocks and dirt. The advantage of flat mild steel impellers is that they can be easily panel-beaten or welded onto the hub. The cast aluminum impellers shatter when they fail, and are more expensive to fix.

There are some manufacturers approaching mining houses with an idea to make lightweight composite fan blades for underground fans. The suggested benefits are viz., cheaper, less frequent failures and less electricity usage. However, there is lack of evidence in terms of fan blade failure problems. The author has come across a case study involving composite materials carried out on mine fans. The study evaluated Fiber Reinforced Plastic (FRP) composite material blades in a coal mine for an axial flow fan (80 m³/s capacity). The data suggests 22% energy savings against conventional fans with aluminum and steel impellers along with reduced noise.

Composite blades would probably behave like aluminum blades and would likely shatter. The cast aluminum impellers and blades have aerofoil profiles and are significantly better but at a cost. Generally, the steel-bladed small mine fans run at high speeds (2950 rpm), which provide suitable performance. There would probably be few advantages of a composite blade over the well-proven aluminium aerofoil blades, unless there is a significant cost benefit. If the handling of fans underground would improve, there could be scope for different impeller materials. In the case of a relatively large fan (i.e. booster fan or bulk air cooler fan), application of a composite impeller is unknown and hence this technology is not proposed for now.

3.3 Variable Speed Drives (VSDs)

The VSDs (sometimes called a variable frequency drive) as applied to fans is not new in South Africa. Its principle of operation, inherent system drawbacks and efficiencies as applied to different VSDs, viz., mechanical system, direct current system, alternating current system, hydraulic system have been discussed elsewhere (Lombard, 1981). A VSD consists of an electronic power converter that converts constant frequency AC (alternating current) power input into a variable frequency output. Fan power

(kW) will vary by the cube of the speed. Varying the speed by 10% decreases or increases the power requirement by 27%. Most motors turn at nearly constant speed. However, much of the time the devices they drive may operate at less than maximum design speed. This speed reduction can be accommodated by an Adjustable Speed Drive (ASD) that varies the shaft speed to the driven load (ASMD, 2003). Slowing a fan in this manner reduces energy consumption much more effectively than allowing the motor to run at constant speed and then restricting or bypassing the flow with a valve or damper. In addition to providing speed control, ASD's provide soft starting, whereby a motor starts slowly and then speeds up. This reduces the mechanical stress on both the motor and fan. This also reduces the voltage sag that can occur when a large motor starts quickly. Voltage sags can dim lights and cause other equipment to shut down or restart. Initial assessments have indicated that this is a highly expensive technique and the technology is likely suitable for new underground mine fans rather than existing fan upgrading for variable speed drives. Currently, Anglo Coal (South Africa) is carrying out an evaluation of VSD fan at one of its collieries.

3.4 Replace Over Sized Motors

In this technique, potential over-sized motors are replaced with 'right' sized motors. Assessments have, however, indicated that most of the motors used for mining applications are not 'oversized' and do not require the use of this technique. Lately, manufacturers are using various design modifications to the motor to reduce energy consumption, viz., improved steel with superior magnetic properties; reducing the air gaps; reducing the lamination width; increasing the thickness of the conductors; and using better insulation materials. As a result of these modifications, high efficiency motors can reduce energy consumption by as much as 45% in comparison to standard motors (Annon 2005). Due to the dynamic nature of mining applications, the fan designs must not be compared to the surface static fan designs for improved efficiencies.

3.5 Ventilation on Demand (VOD) systems

Ventilation on demand (VOD) is a strategy of matching design ventilation needs to actual ventilation needs, to in turn minimize energy consumption, while maintaining the underground mining environment. Due to the newness of this technology, VOD is not widely used, but its benefits can be envisaged in multi-level ventilation with multitudes of fans. The application of VOD (in addition to a collision avoidance system) has been proposed for the new expansion project using sublevel/incline cave mining options of Kimberlite ore in South Africa (Belle, 2006). Envisaged benefits of VOD are, viz., better ventilation controls, considerable energy savings; automatic time controlled and operator controlled ventilation; real time access to ventilation status, overview and control. At the heart of the VOD system is the integration of a control and monitoring system, a mine ventilation modeling and simulation system, and an expert system.

4 Hermit Crab Applications-Quick Win Technology

From the initial assessment it was noted that this specific technique or concept is scarcely applied within the mining industry. However, it was noted that the Hermit Crab application was successfully implemented in the non-mining industry such as cement factories and steel mills. Table 2 shows the summary of actual electricity savings by the use of the fan technology in non-mining operations (Kirkman, 2005).

The Hermit Crab technique can be seen as a "Quick Win" project due to its success in other fields with small capital and implementation costs. Due to scarce data for comparison of technologies and their risks, the study does not exclude the above techniques and indeed several of the other options could be successfully used in conjunction. These options could be revisited in the future when more data becomes available.

Table 1. Hermit crab application in non-mining industry.

Area	PE, %	PB, kW	NE, %	PA, kW	ROI
Cement, Philippines	70.7	1050	81	915	1 year
Cement, Spain	63	688	74	513	<1 year
Steel, Korea	76.3	5780	88.6	5400	<1 year

* PE-prior efficiency; PB-power before; NE-new efficiency; PA-power after; ROI-return on investment

Figure 1 is an example of a schematic drawing of a Hermit Crab Impeller. The diagram shows how the impeller fits inside the existing fan structure.

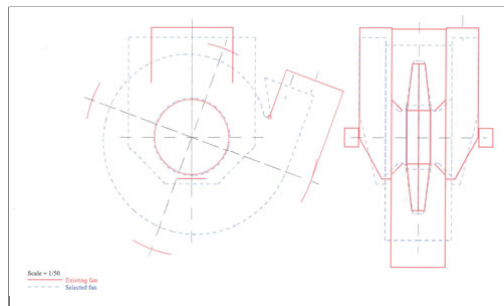


Figure 1. Recommended Impeller design to improve fan efficiency (Source: Kirkman, 2005)

4.1 Methodology and Data Collection

In order to estimate the impact of energy savings a hypothetical mining group-A with underground operations was considered. To estimate the main fan energy consumption for the mining group, the following method was used:

- Identify each ore type (i.e., coal, gold, etc.)
- Enumerate latest available production rates (Kilo tonnes per month - ktpm)
- Use air factors for calculating air quantities, i.e., m³/s/ktpm for estimating mine air quantities.
- Use benchmark air pressures (kPa) for respective operations.
- Total air power is obtained by multiplying air pressure and air quantity.
- Total electric power input is obtained by dividing air power by efficiencies of fan and motors.

The cost of ventilation in its simplest form is proportional to the air power supplied by fans. Air Pressure is directly related to the square of the air quantity. Therefore air power and cost is related to the cube of the air quantity. Based on the above, for a typical global mining group-A, the fan operating cost can be in the range of US\$ 20million and US\$ 25 million.

5 Financial Evaluation of Hermit Crab Technique

In order to simplify the potential benefits, the following, conservative qualifications and assumptions have been made for the hypothetical mining group-A with underground operations:

- The capital cost associated with implementing the project for an individual mine fan is highly complex due to a general lack of data on main fan units operating on mines and their relevant fan efficiency curves. Therefore, having consulted with the supplier and given the aggregate basis of this calculation, estimation was made using the non-mining uses of this technology. The capital and implementation costs are directly associated with the desired power reduction and the prevailing price of electricity.
- For the purposes of modeling the financial benefits it was assumed that the reductions in energy-spend will build up and last for a total of 10 years following rollout of the project.
- A cost of capital rate of 10% pa was used to discount the relevant cash flows. A different rate would have to be used to evaluate the project in another region.
- Implementation costs are built into the initial capital cost
- Operating costs, i.e. electricity prices grow at the assumed electricity price index forecasts based on oil price forecasts.
- A 30% tax rate has been included. The equipment is assumed to be written off in the first year, given that it is associated with the process of mining and a tax benefit has been recorded for this.

5.1 Estimated Electricity Savings

The specific goals of this investigation were, the reduction of specific energy consumption by increasing efficiency, and the reduction of GHGs. Figure 2, indicates the net present value (NPV) of benefits under various desired

power reduction levels, allowing for changes in the underlying price of electricity. The emission intensity rate has been held constant at 0.85 CO₂e/kWh respectively.

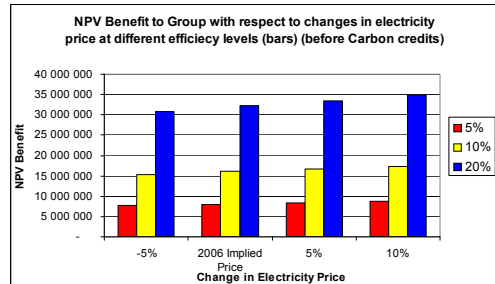


Figure 2 Estimated benefits using Hermit Crab Technique

The benefits evidenced above are considerable. Should a 10% reduction in power usage by main fans be desirable and achievable across all fans and should prices rise as currently forecast, this would result in a saving of USD 16.1m (NPV) over a 10 year period. This benefit is before carbon credits, which are included into the analysis in the next section.

To simplify the carbon emissions intensity, the following two scenarios are used for calculation purposes, namely average emissions of 0.85 kg CO₂/kWh and maximum emissions of 1.08 kg CO₂/kWh. It is observed that the new technology at 5% increase in efficiency would save an estimated 5 MW per year of electricity for the underground fan electricity consumption network and between 39,000 and 52,000 tonnes of CO₂ equivalent each year. When these benefits are added to the previous benefits derived from the efficiency gain the total benefits of the Hermit Crab project are reflected. Should electricity prices evolve as forecast currently and using an average emission intensity rate of 0.85 kg CO₂/kWh, a desired power reduction of 10% for the hypothetical mining group-A would cost around USD 4.6m to purchase and install the Hermit Crab system but, over 10 years, would result in a NPV benefit of USD 18.6m at carbon credit cost (in 2004) of US\$ 5/tCO₂. If the price of carbon credits rises to US\$ 40/tCO₂ then the NPV of this benefit rises to USD 36.3m.

5.2 Cost-Benefit Analysis of Project

In order to evaluate the benefits of the Hermit Crab technology, an aggregate cost-benefit analysis was conducted. The cost component of this analysis and the implementation of this technique involve only the capital costs of the item. The following scenarios were considered for the evaluation: Increases in efficiency or reduced electricity consumption with the use of technology, viz., 5%, 10% and 20%; average and high emission intensity rates were considered. The Figure 3 shows the net benefits of the implementation of the Hermit Crab technology under the various scenarios.

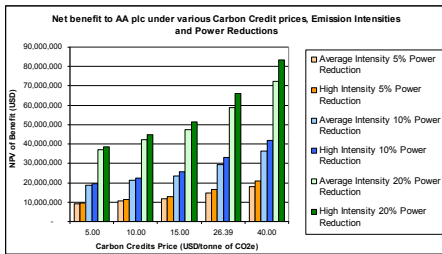


Figure 3 Net benefit scenarios of Hermit Crab technique

From the study it can be noted that the combined effect of both the electricity savings and carbon credits is significant at low expected increases in main fan efficiencies. A 10% increase in fan efficiency with 10% reduction electricity consumption results in a saving of 10.81 MW per annum of electricity, the present value of this benefit amounts to USD 16.08m over 10 years. With the inclusion of carbon credits at US\$ 26.39, this benefit rises to US\$ 29.4m in total. An amount of 80'745 tonnes of CO₂e is saved.

5.3 Implementation Issues/Change Management

The paragraph below discusses the implementation related issues of this technique. A past example of an Eskom energy savings project is the AngloGold Ashanti Three-Chamber-Pipe-Feeder System (3CPFS) energy efficiency project, which has secured a 50% contribution to the total USD ~10.5million project cost. The project presented a saving of 4.4 MW of electricity in pumping costs and 0.2 MW of electricity in reduced refrigeration costs. The health and safety issues pertaining to the installation of the current ventilation systems are not dissimilar to that of the implementation of Hermit Crab technique. The technology poses a low financial risk in that the efficiencies expected could be less and the payback period could be extended. Even though the implementation of the Hermit Crab is relatively simple, it is believed that there is a need to sensitize mines to the benefits, in terms of the electricity cost-savings effect and the carbon credits generated. It is hoped that the approach of sensitizing the mines to establish a fan related energy database would provide an opportunity to identify specific fan installations. An initial external reviews, negative feedback such as this 'technique is not new' besides the absence of fan efficiency data which is critical for adjudicating any energy saving project.

6 Summary and Conclusions

The Hermit Crab technology has been successfully rolled-out in cement and steel operations. This study has demonstrated that within the narrow focus of main fans, despite the general lack of data, there exists an opportunity for significant savings in both the electricity savings and carbon credits. A 10% increase in fan efficiency with 10% reduction electricity consumption results in a saving

of 10.81 MW per annum of electricity, the present value of this benefit amounts to US\$ 16.08m over 10 years. With the inclusion of carbon credits at the price of US\$ 26.39, this benefit rises to US\$ 29.4m in total. An amount of 80'745 tonnes of CO₂e per annum could be saved.

The simple and "quick win" nature of this technique could aid the creation of an increasingly energy-conscious culture in the mining industry. It is agreed that this engineering solution is not unique or exclusive or new but often less thought of at mines with inefficient fan installations. On the other hand, a perception still exists that the majority of fans are operating efficiently, even in the absence of fan data and where these mine fans are operating over two decades. Furthermore, the reasons attributed to inefficiencies cannot be attributed to the fan installations alone but for mining reasons.

In addition, a recent benchmark study on determining the optimum up cast shaft velocity for the South African mines of varying depth recommended an optimum up cast velocity of 32 to 35 m/s against the current design velocities of 20 to 22 m/s. This significant finding is an additional motivation to re-visit all the fans and up cast shaft potential for global underground mining operations (Belle, 2008). Therefore, the first step is to identify specific installations where the performance is not energy efficient. Once this has been done, specialist fan suppliers and project consultants must be approached to apply relevant implementation of this technology. Furthermore, in the absence of a tangible value for carbon credits, the perception exists that one cannot assign monetary value for project evaluation, thus further hindering the improvement opportunities in the ventilation engineering discipline. The paper does not exclude other technologies that have been identified in this study, viz., composite materials, ventilation-on-demand and variable speed drives. Finally, it is hoped that the views made herein on energy savings on mine ventilation fans would contribute positively to overcome the current South African energy crisis and drive towards the concept of power conservation which would enable new projects for the mining industry.

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