
1 Introduction

1.1 Energy consumption of South African mines

According to 2011 figures, Eskom generates approximately 95 % of all electricity used in South Africa and 45 % used in Africa respectively. Of all Eskom-supplied electricity in South Africa, 45 % is supplied directly to the industries. The other 55 % is redistributed through various entities such as municipalities ⁽¹⁾.

The electricity supplied directly to the end users includes the industrial, commercial, mining and agricultural sectors. Eskom supplies electrical energy to approximately 3 000 industrial consumers, 1000 mining consumers, 49 000 commercial consumers, 84 000 agricultural consumers and over 4 000 000 residential consumers.

Figure 1 shows the relative electricity sales of various end users. From this figure it can be seen that the mining sector is the third largest electrical energy consumer in South Africa. Due to the mining sector being responsible for such a large amount of the country's electricity usage, opportunities arose for investigations into their daily load profiles and especially the usage of their cooling systems.

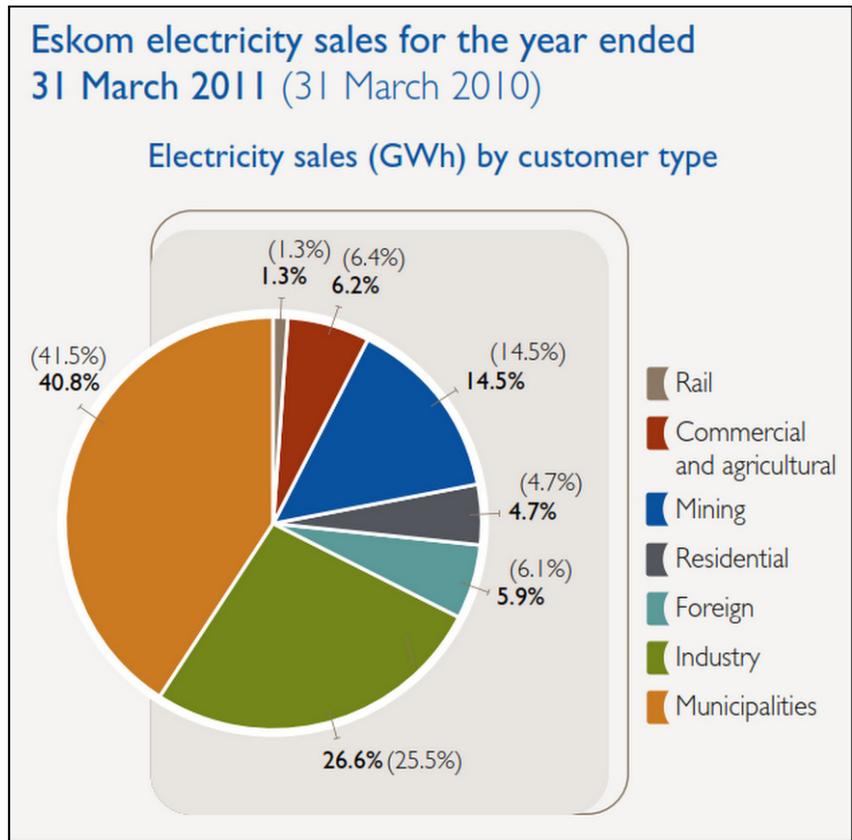


Figure 1: Eskom electricity sales for the year ended 31 March 2011 ⁽¹⁾

1.2 Mine cooling systems

In the early days of underground mining, ice blocks were produced on the surface. During the 1860's, the ice blocks were subsequently transported underground in ore carts as was the case in the Camstock Lode mine in Nevada, USA ⁽²⁾. The vapour compression refrigeration cycle is presently the most widespread means of man-made cooling and has been used since the early 1920's in the Morro Velho mine, Brazil. It was implemented in South African gold mines during the 1930's. *Figure 2* shows a typical cold water reticulation layout of a deep level mine where the refrigeration plant is situated on the surface.

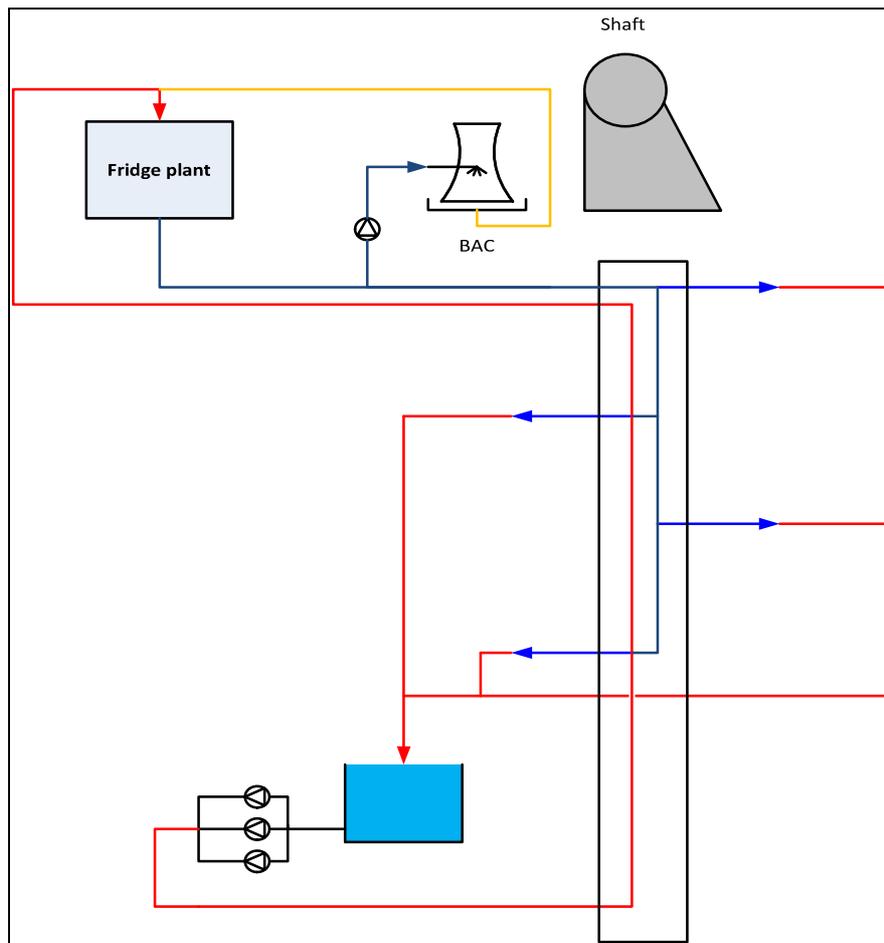


Figure 2: Basic cold water reticulation on a deep level mine

Underground refrigeration plants also became commonly used in deep level mines in South Africa. One of the main limitations is the heat rejection through the condenser which has to be ventilated out of the mine in addition to the normal mine ventilation, thus limiting the coefficient of performance of these plants.

Typical mine refrigeration systems account for between 13 % to 25 % of the total energy consumption on South African mines depending on the season ⁽³⁾.

1.3 Savings initiatives on industrial cooling systems

Over the years, various methods to minimise the electricity usage of cooling systems have been investigated and implemented in industry. Investigations for selective usage of cooling units out of peak electricity demand periods have also been conducted and the solutions implemented with attractive results.

1.3.1 Ice storage

Ice storage is an energy saving method where water is frozen during off peak periods when the electrical demand is at a low and less expensive. The iced water is used for cooling during the peak time periods while the refrigeration units are not required to operate at full load.

Some of the disadvantages of ice storage include the low efficiency of the ice-making process as well as the intricacy of the system itself ⁽⁴⁾. These systems are also very costly and are only cost effective for relatively small storage quantities of up to around 1000 ton-hr.

Another disadvantage of these systems is the disparting forces the ice exerts when the water expands during the freezing process. Furthermore, ice has a very poor thermal conductivity inducing the need for lower evaporator temperatures to freeze the ice as it becomes thicker.

1.3.2 Chilled water storage

Chilled water storage is common practice in the industry where more water is cooled, during off peak periods, by means of the refrigeration plant than the actual system demand ⁽³⁾. By storing the additional water in chilled water dams for use during peak time periods, operation of the refrigeration units, as well as the electrical load of the system, can be kept to a minimum. Some of the drawbacks of such a system are the thermal losses of the water stored in the dam, the subsequent heating by the environment as well as the need for additional storage capacity.

For these systems to operate, sufficient monitoring and control are required to ensure that enough water will be cooled during the off-peak period. Enough chilled water needs to be available during the peak period when no, or very little, water will be cooled. It is important not to cool more water than needed during the peak period. This would be a waste of electrical energy and also leaving chilled water exposed to the environment for prolonged periods causing it to lose its chilled energy by heating up again. The amount of cooling required during the peak period divided by the amount of cooling stored during the off-peak time is known as the storage efficiency and is in the range of 0.9 for water systems and 0.95 for ice storage ⁽⁴⁾.

1.3.3 Pre-cooling towers

Pre-cooling towers also play an important role in the energy efficiency of industrial refrigeration systems. Cooling towers are often not serviced frequently enough, causing its thermal performance to deteriorate significantly. This is caused primarily by dirt accumulating inside the tower on the fill media. The fill media breaks up the water and increases the heat transfer area. The accumulation of dirt process occurs much faster in open-looped water systems, than those of closed-loop systems. In open loop systems, the water becomes contaminated in the outside process by which it is utilised. In closed loop systems, dirt can accumulate on the fill material inside the cooling tower due to dust in the ambient air flowing through the tower to perform the cooling.

New types of fill media are developed in order to delay the process of dirt accumulating and to make the system more efficient over a longer period of time. The performance of a cooling tower is measured by how close it can bring the water being cooled to the ambient wet bulb temperature. The ambient web bulb temperature is a function of the ambient air dry bulb temperature and humidity. Low ambient wet bulb temperatures represent either cool air or low humidity or a combination thereof ⁽⁵⁾.

Setting up maintenance schedules to have the tower cleaned at the right time intervals will ensure better performance throughout the tower's lifespan, resulting in lower energy consumption by the refrigeration machines.

Another method of controlling the thermal performance and simultaneously allowing the operation to control the outlet temperature, to an extent, is by installing variable speed fans to the tower; enabling a controlled variance of the air flow through the cooling tower ⁽⁶⁾.

1.3.4 Flow reduction

On some systems, energy savings were implemented via lowering the evaporator inlet temperature by circulating some of the chilled water back into the pre-cooling dam ⁽⁷⁾. Although this strategy is effective, it is limited by using only existing infrastructure and consequently the saving potential in varying the pump or compressor loads is not realised.

Additional cooling electrical energy savings have been achieved by implementing methods to reduce chilled water consumption on the demand side. By investigating the water usage and applying more precise control to eliminate unnecessary water usage, reduced water cooling demand can be achieved ^{(8), (9)}.

Variable electrical motor speed technology has been considered as a standard energy-efficiency feature for some time and has been implemented in various ways ⁽¹⁰⁾. These include the use of variable speed drives on the refrigeration machine compressor to change the operating frequency at part-load conditions ^{(11), (12)}.

1.4 Objectives of this study

The objective of this study is to investigate and develop potential electrical energy saving strategies which can be applied to industrial cooling systems to decrease the current electrical energy consumption. With the ever increasing electrical energy tariffs in South Africa, the need to implement such strategies is becoming more important by the day to keep industrial operations financially viable by decreasing their electricity bill.

The effect of applying each strategy to the system can be accurately simulated to predict the system's behaviour after the implementation of each strategy as well as determining its electrical saving contribution.

1.5 Overview of the document

This document commences with a brief overview of the present electrical energy situation in South Africa by investigating a number of energy consuming sectors in Chapter 1. Various potential energy saving strategies were investigated, developed and presented in Chapter 2. A brief discussion of the simulation software that was used is given in Chapter 3. The equations used by the simulation model are presented but not detailed; as this is merely a tool used and was not developed by this study. Two case studies were performed and discussed in Chapter 4. Baselines, to be used as the electrical consumption baselines, were simulated. Various identified energy saving strategies and its effect on the system were then simulated and compared to the simulated baselines to determine the potential savings. The simulation models were verified by comparison to measured data or first principle calculations. Chapter

5 validates the simulation models by means of the practical implementation of the energy saving strategies applicable to the specific systems and comparing it to the simulated results of Chapter 4.