CHAPTER 6. FEASIBILITY STUDY OF DEVELOPED ENERGY SAVING STRATEGY

6.1 Introduction

The large-scale potential of implementing VSD technology on various South African mines has been estimated and quantified. The development of variable water flow strategies to implement pump VSDs and an energy management system to integrate the strategies has subsequently been discussed. Next, the feasibility of the developed DSM strategy needed to be evaluated before it could be considered for implementation with financial support (HVACI 2012) for experimental validation.

A feasibility study was thus done and included the use of a simulation model to determine potential savings more accurately than in the high-level preliminary investigation of VSD technology in Chapter 3. A more detailed cost analysis was also performed to determine the economic viability of the strategy.

Simulation and cost analysis details are site-specific. The focus of the feasibility study is therefore on the particular site that was chosen as the primary case study for *in situ* strategy implementation, the surface cooling system of the Kusasalethu gold mine near Carletonville, South Africa.

The system details of the Kusasalethu surface cooling system are discussed first, along with a description of how the developed strategies are to be implemented and thus also simulated on this specific site. The simulation model that was used, adapted and verified is then discussed. Simulated energy saving results of the considered case study site are then presented. Finally, a techno-economic analysis is presented to investigate the financial feasibility of the strategy on Kusasalethu.

The overview and use of the simulation model to predict energy savings form part of the submitted article in Annexure B.1.

6.2 Kusasalethu mine surface cooling system

An overview of the site details and the way that the energy saving strategy is to be applied on Kusasalethu are required. This will provide suitable background to contextualise the simulation, cost analysis and *in situ* experimental implementation presented in further chapters.

System description

The Kusasalethu gold mine has a cooling system on surface level, level 78 and level 110. Collectively these systems provide the required cooling for typical deep gold mine operations at the mine, such as drilling, sweeping and air cooling, as discussed in Chapter 2. The integrated surface cooling system is the most complex of the three and also has the largest cooling and electrical installed capacities.

The surface cooling system has a layout very similar to the generic mine cooling system described in Figure 5. It supplies chilled water as well as cool ventilation air to the mine, using a parallel-series chiller design for seasonal temperature and flow requirement variations such as shown in Figure 6.

The layout of the Kusasalethu surface cooling system, including the proposed equipment required to implement the variable-flow DSM strategy, is shown in Figure 38 (Du Plessis et al. 2013b).

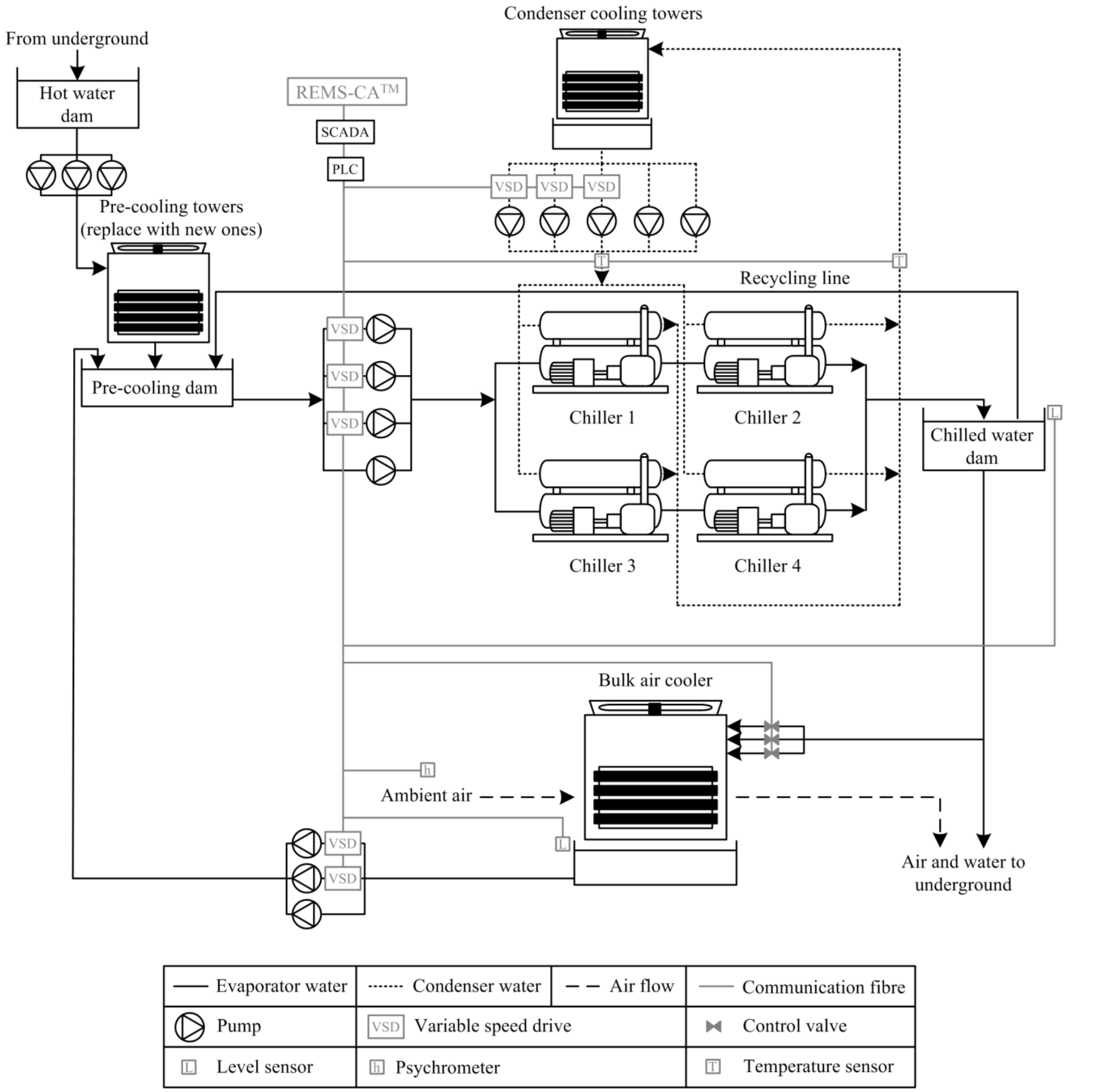

Figure 38 Kusasalethu surface cooling system layout (Reprinted from *Case study: The effects of a variable flow energy saving strategy on a deep-mine cooling system*, Du Plessis G.E., Liebenberg L., Mathews E.H., Applied Energy, 102, 700-709, Copyright (2013), with permission from Elsevier)

Figure 38 shows that used underground water enters the hot water storage dam, from where it is pumped through pre-cooling towers into a pre-cooling dam. This water is then pumped through two parallel sets of series-connected chillers before entering the chilled water storage dam. Some of the chilled water is used to cool ventilation air in a surface BAC and is then returned to the pre-cooling dam. The remainder of the chilled water is sent underground on demand.

Depending on the demand, chilled water can also be returned directly to the pre-cooling dam. Furthermore, coolant water is pumped through each chiller condenser in a parallel configuration and subsequently cooled by its own set of cooling towers. The design specifications of the Kusasalethu cooling system and its components are given in Table 13 (Du Plessis et al. 2013a).

Table 13 Kusasalethu surface cooling system specifications (Reprinted from *Case study: The effects of a variable flow energy saving strategy on a deep-mine cooling system*, Du Plessis G.E., Liebenberg L., Mathews E.H., Applied Energy, 102, 700-709, Copyright (2013), with permission from Elsevier)

Combined plant	
Hot water dam temperature (ºC)	30
Chilled water dam temperature (ºC)	6
Chilled water dam level (%)	95
Volume of water sent underground (Mℓ/day)	27
Combined COP	5
Combined cooling capacity (kW)	42 000
Individual chillers	
Cooling capacity (kW)	13 300
Evaporator outlet temperature (ºC)	5.9
Condenser inlet temperature (ºC)	18.5
Evaporator water flow rate (ℓ/s)	300
Condenser water flow rate (ℓ/s)	600
COP	6.65
Refrigerant	R134a
Compressor type	Centrifugal
Water pumps	
Evaporator pump motor rating (kW)	90
Number of evaporator pumps	4
Condenser pump motor rating (kW)	185
Number of condenser pumps	5
BAC return pump motor rating (kW)	75
Number of BAC return pumps	3
Cooling towers	
Pre-cooling towers	
Number	8
Water inlet temperature (ºC)	28
Water outlet temperature (ºC)	24
Air inlet wet-bulb temperature (ºC)	22
Condenser cooling towers	
Number	4
Water inlet temperature (ºC)	32
Water outlet temperature (ºC)	27.5
Air inlet wet-bulb temperature (ºC)	22
BACs	
Number	3
Water inlet temperature (ºC)	3
Water outlet temperature (ºC)	14
Air inlet wet-bulb temperature (ºC)	22

Variable-flow strategies overview

It was apparent at Kusasalethu that the pre-cooling towers needed replacement to enable the efficient implementation of the variable water flow strategy. VSDs could thus not be considered for all the pumps because of budgetary constraints. It was decided to omit pre-cooling flow control and selected VSDs on common pump manifolds. The energy saving strategies from Chapter 4 that were therefore proposed for Kusasalethu include evaporator, condenser water and BAC water flow control, in addition to pre-cooling tower replacement. The proposed equipment additions are indicated in Figure 38.

The generic control strategies discussed in Chapter 4 are directly applicable. Further detail and a summary of each strategy proposed specifically for Kusasalethu are given below.

Evaporator water flow control

- Install VSDs on three of the four evaporator water pumps.
- Control the speed of the pumps by VSD to maintain a specified chilled water dam level of 95% at all times.

The evaporator water pumps are arranged in parallel as part of a common manifold. This design ensures that the pumps can provide a higher flow rate for the same pressure rise as across one pump (White 2008). The three VSDs are to ensure that a specified chilled water dam level is maintained. This will ensure that no chilled water will unnecessarily be back-passed, or recycled, while reducing the evaporator water flow at times of low demand.

Condenser water flow control

- Install VSDs on three of the five condenser water pumps.
- Control the speed of the pumps by VSD to maintain the design average water temperature difference across the condensers of 5 ºC.

The condenser water pumps are also arranged in a common manifold to supply water to all of the chiller condensers in a parallel water distribution circuit. The three VSDs are to ensure that a specified average water temperature rise across all the condensers is maintained.

This will ensure that the condenser water flow is modulated according to the changes in cooling load and that the full design temperature difference is maintained at all times.

BAC water flow control

- Install electrically actuated control valves in the gravity fed BAC water supply lines.
- Control the valves in direct proportion to the ambient enthalpy for a provisionally suggested enthalpy range of 25 to 70 kJ/kg.
- Install VSDs on two of the three BAC return water pumps.
- Control the speed of the return pumps by VSD to maintain a specified BAC drainage dam level of 95%.

There are no BAC supply water pumps because the BACs are gravity fed. BAC water flow control is thus proposed by means of an electrically actuated control valve in each of the three BAC water supply lines. These valves are to be controlled to synchronise with the ambient air enthalpy to ensure that the ventilation air requirements are not unnecessarily exceeded, as discussed before. Two BAC return pump VSDs are to ensure that a specified BAC drainage dam level is maintained to retain water mass flow equilibrium in the system.

Pre-cooling tower replacement

- Replace all eight pre-cooling towers with new cooling towers that are more efficient.
- New cooling towers must have the following specifications:

  Inlet water temperature: 30 ºC

  Outlet water temperature: 23 ºC

  Inlet air wet-bulb temperature: 20 ºC
- The lower water temperature provided by the more efficient towers enables and compliments the successful integration of the variable water flow strategies.

When the site was initially investigated, it was found that the pre-cooling towers were poorly maintained and very close to being dysfunctional. Most of the fill material was either completely clogged up or missing, leading to poor heat transfer efficiencies and to high outlet water temperatures.

The average cooling load on the chillers was therefore unnecessarily high, sometimes due to higher inlet temperatures and sometimes due to higher average flows handled by the chillers to ensure sufficient back-passed flows keeping the inlet temperature low. It is proposed to replace the pre-cooling towers at Kusasalethu with new ones that will provide water at a lower temperature than before. This will complement the variable water flow strategies by ensuring that the pre-cooling dam water temperature does not increase significantly due to the back-passing of chilled water being decommissioned as a result of evaporator flow control while simultaneously allowing for the reduced average flow rate through the chillers.

The proposed variable water flow strategies will merely ensure that the water demand and supply will be balanced in the Kusasalethu surface cooling system. Unnecessary actions such as continuous water recycling and flow throttling will also be eliminated and it will be ensured that only enough water is sent to the BAC. The strategies will be integrated and controlled by means of REMS-CA™.

6.3 Simulation model

A simulation model of the Kusasalethu cooling system was required to simulate and thereby predict the effects that the proposed energy saving strategies will have over a period of a year. The performance of mine chiller plants and the effects of load shifting on mine cooling systems have been simulated (Bailey-McEwan and Penman 1987, Van der Bijl 2007). However, no simulation models have been developed for integrated mine cooling systems specifically to simulate the application and effects of variable-flow energy saving strategies. An existing model for large thermal systems was used and adapted slightly for the use of simulating the proposed strategies. This section discusses the model briefly and also shows how the accuracy of the mathematical model was verified by comparing actual baseline performance to simulated baseline performance.

Model description

An integrated simulation model of large thermal systems was developed and validated by Arndt (2000). The basis of this simulation was used and adapted slightly to simulate various specific mine cooling systems that were investigated, including the Kusasalethu system which will be discussed further.

The simulation model is integrated, dynamic and component-based and balances energy and mass over defined time intervals. A Microsoft Visual Basic platform was used with simulation inputs and outputs provided via Microsoft Excel.

The integrated Kusasalethu surface cooling system was considered as presented in Figure 38. Each subsystem was modelled as a component with its own inputs and outputs. The outputs were then used as inputs to other components as applicable to the cooling system process.

Inputs are provided as an Excel document in the form of hourly ambient conditions, mine demands of chilled water, scheduling of subsystems as operated by the mine, and system specifications. Provision was made for hourly inputs over a period of 365 days, or one year, in order to reflect daily and seasonal changes in system boundaries.

Output of the simulation is given in the form of individual component output values for the same time intervals as the input values. This includes outputs such as hourly dam levels, water temperatures, water flow rates and system power usage.

The mathematical models of the various components are based on thermodynamic and physical properties of the components. A brief overview of the mathematical models is given below. Detail of the simulation is given by Arndt (2000). Further code and modelling details are not included here because the development of the simulation is not a main focus point of this study. The model is rather used and adapted as part of the feasibility study of the strategies.

Direct contact heat exchangers: pre-cooling towers, condenser cooling towers and BACs
(Lombard 1996, Kröger 1998)

$$h_{ao} = \frac{(1-r)}{(\tau - r)} h_{ai} + \frac{(\tau - 1)}{(\tau - r)} \varphi T_{wi} \tag{21}$$

$$T_{wo} = \frac{r(\tau - 1) h_{ai}}{(\tau - r)\varphi} + \frac{\tau(1-r)}{(\tau - r)} T_{wi} \tag{22}$$

$$\tau = \exp\left\{ -UA\left(\frac{\varphi}{c_{pw}\dot{m}_w} - \frac{1}{\dot{m}_a} \right) \right\} \tag{23}$$

$$r = \frac{\dot{m}_a \varphi}{c_{pw}\dot{m}_w} \tag{24}$$

$$\varphi = \frac{h_{sat,wavg}}{T_{wavg}} \tag{25}$$

Chillers (Çengel 2006, Arndt 2000)

$$\dot{Q}_e = \dot{Q}_{e,ref}\left((T_e - T_{e,ref})(C_e) + 1 \right)\left((T_{c,ref} - T_c)(C_c) + 1 \right) \tag{26}$$

$$COP = COP_{ref} \frac{\dot{Q}_e}{\dot{Q}_{e,ref}} \left(-0.781 PL^2 + 1.25 PL + 0.5313 \right) \tag{27}$$

$$\dot{W}_c = \frac{\dot{Q}_e}{COP} \tag{28}$$

Water pumps (White 2008)

$$\Delta p_p = \frac{\dot{m}_w^{\ 2}}{\rho_w A} \qquad (29)$$

$$\dot{W}_p = \frac{\Delta p_p \dot{m}_w}{\rho_w \eta} \qquad (30)$$

Water storage dams (White 2008)

$$\Sigma \dot{m}_{wi} = \Sigma \dot{m}_{wo} \qquad (31)$$

$$L_{t=x} = L_{t=0} + \frac{\left(V_i - V_o\right)_{t=0-x}}{V_{dam}} \qquad (32)$$

PID controllers (Dorf and Bishop 2008)

$$o = e_p k_p + e_i k_i + e_d k_d \qquad (33)$$

The model was adapted to be applied to the Kusasalethu surface cooling system. A schematic flow chart summary of the simulation model is depicted in Figure 39. This shows the inputs and outputs of each component, the relation and integration of all the inputs and outputs as well as a summary of the user-provided constraints and overall output results.

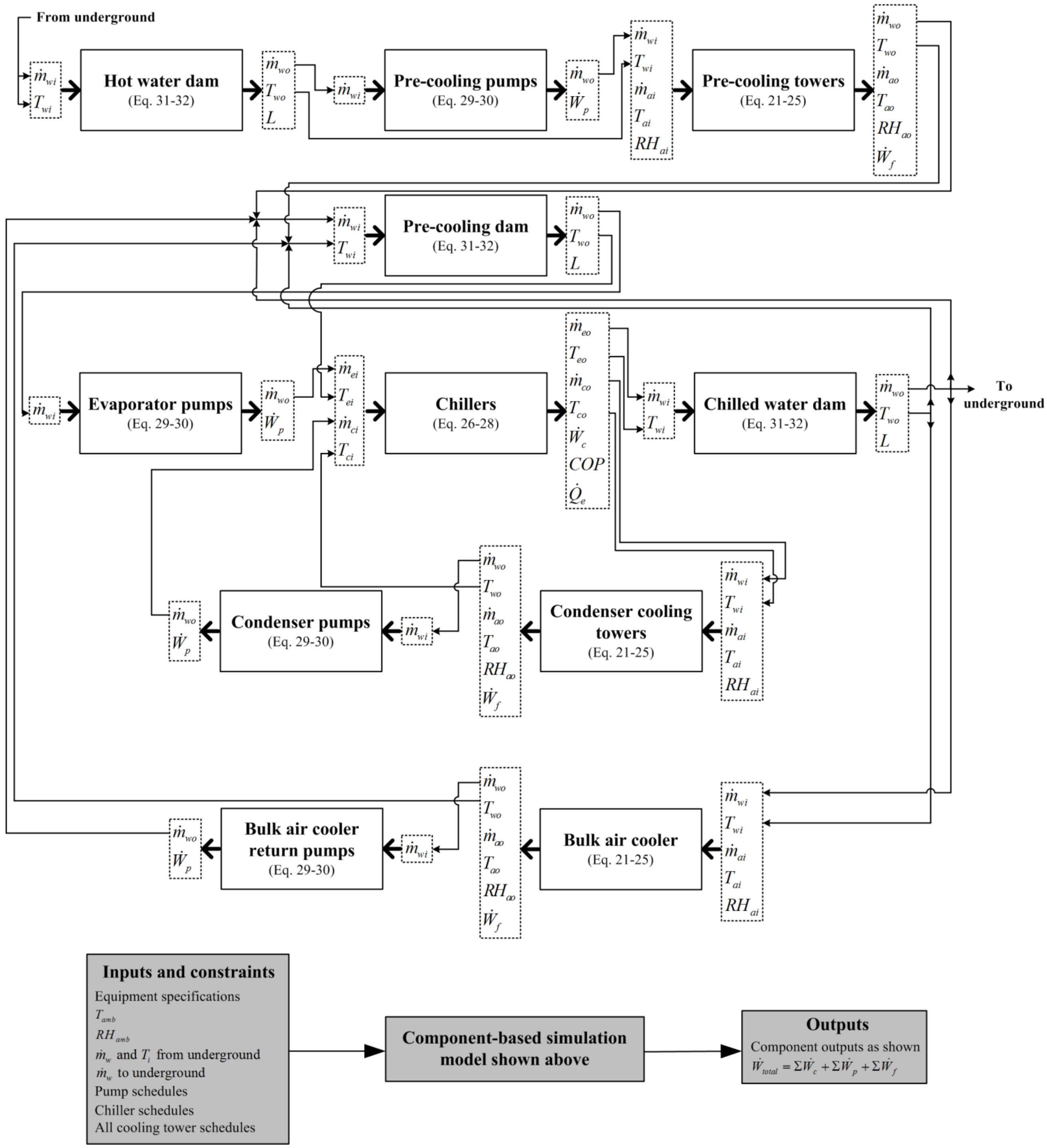

Figure 39 Schematic summary of the Kusasalethu surface cooling system simulation model

Figure 39 shows that the hourly user inputs are values of ambient conditions, mine chilled and hot water flow and temperature requirements as well as running schedules of subsystems such as chillers or water pumps. Such hourly data were obtained from the mine SCADA historic database. Equipment specifications as shown in Table 13 are also used in the simulation. The high-level output is indicated to be the total system power usage, although the individual component outputs are also available. All outputs are provided in hourly values to reflect the changes in system electrical energy usage for different seasons and operational methods.

The model enables the simulation of the total system electrical energy usage for an entire year. It can therefore be used to model the performance of the existing system to draw up an electricity baseline. Its primary purpose will be to simulate the performance of the system when the energy saving measures and proposed control strategies are added and thereby assist in assessing the feasibility of the strategies.

Model verification

Before the adapted simulation model could be used to predict potential savings from the variable-flow strategies, the model had to be verified to ensure that its mathematical representation of the real system is sufficiently accurate. Verification generally refers to a process whereby inspection and reviews are carried out to ensure that a given system or model was developed with sufficient accuracy (Schutte 2007). To verify this accuracy, the performance of the Kusasalethu surface cooling system (before any energy saving interventions) was simulated using measured historic data as input. Simulation results were then compared to the actual measured performance over the same period. The time period considered was the entire 2009, translating to 8 760 hourly data points that could be simulated and compared to actual measurements.

The simulation model accounts for system constraints such as required chilled water flow. It follows that the mine service delivery requirements are implicitly met by the simulation. Since the accurate prediction of an energy saving strategy is the primary goal of the simulation model, the main output that was evaluated during simulation verification was the electrical power usage of the combined cooling system.

To simulate the performance of the cooling system as accurately as possible, mine schedules and operation methods - on a daily basis as well as a seasonal basis - had to be considered. For example, in winter Kusasalethu shuts down all the BACs and two chillers. Table 14 gives a summary of the average constant values used in simulating the baseline power usage of the integrated cooling system, as supplied by logged historic SCADA data from the Kusasalethu mine (2012).

Table 14 Summary of input data used in simulation model verification of the Kusasalethu surface cooling system

	Summer (Sept-May)	**Winter (June-Aug)**
Equipment specifications	As per Table 13	As per Table 13
Ambient conditions (hourly)	Klerksdorp 2009	Klerksdorp 2009
Average hot water flow from underground (ℓ/s)	305	280
Average hot water temperature from underground (ºC)	28	28
Average chilled water to underground (ℓ/s)	305	280
Pre-cooling pump schedules	3 pumps full-time	3 pumps full-time
Evaporator pump schedules	4 pumps full-time	2 pumps full-time
Condenser pump schedules	5 pumps full-time	5 pumps full-time
BAC return pump schedules	3 pumps full-time	All pumps off
Pre-cooling towers in operation	8	8
Chillers in operation	4	2
Condenser cooling towers in operation	4	4
BACs in operation	3	0

Care was taken to remove data points on days where data was lost due to irregularities such as power interruption or system failures. This is part of standard measurement and verification procedures to ensure an accurate analysis (Xia and Zhang 2012), as will be discussed further in Chapter 7.

An annual profile (at hourly intervals) of ambient temperature, relative humidity and system constraints for 2009 were imported into the Excel platform of the model and simulated power usage profiles were extracted as output. Only weekdays were considered because the mine cooling system operates in standby mode over most weekends and thus does not reflect typical operations.

The simulated and actual measured electrical power input profiles of the integrated cooling system for weekdays of 2009 are plotted in Figure 40 and the key results are summarised in Table 15.

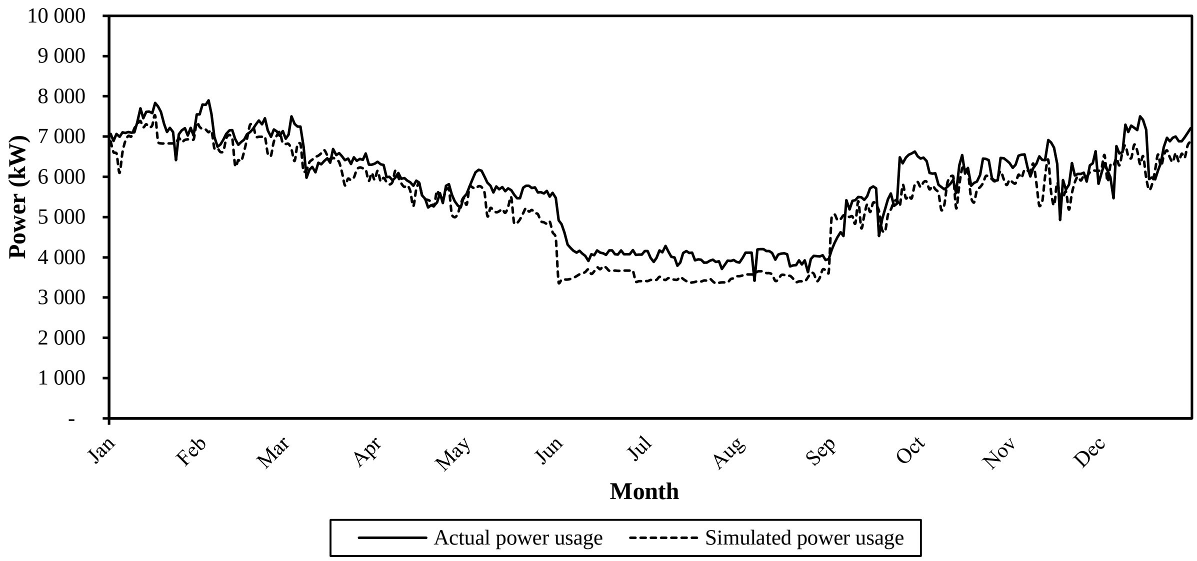

Figure 40 Simulated and actual baseline power usage of the Kusasalethu surface cooling system (2009)

Figure 40 shows that, generally, the simulated power profile closely follows the actual power profile of the cooling system. This is true for the average trend resulting from large climatic changes as well as for smaller sub-trends resulting from daily or weekly fluctuations in ambient conditions and mine requirements.

Table 15 Simulated and actual baseline power usage of the Kusasalethu surface cooling system (monthly averages)

Month	Simulated average power (kW)	Actual average power (kW)	Difference (%)
January	6 965	7 258	4.0
February	6 870	7 166	4.1
March	6 334	6 548	3.3
April	5 615	5 729	2.0
May	5 175	5 727	9.6
June	3 586	4 177	14.1
July	3 430	3 978	13.8
August	3 542	3 980	11.0
September	5 196	5 489	5.3
October	5 802	6 110	5.0
November	5 868	6 233	5.9
December	6 411	6 713	4.5
Average	**5 399**	**5 759**	**6.9**

The simulated power usage is shown to be higher than the actual power usage. This is the case for the summer as well as winter months. The absolute values of these differences are shown as percentages in Table 15, with reference to the actual measured power input. These differences can be attributed to various factors.

It is possible that the mechanical efficiencies of machinery such as chiller compressors and pumps have degraded or are slightly different than taken into account in the simulation. With the severity depending largely on proper maintenance and operation, this can have a negative impact on the actual power delivered for a specific electrical power input.

The thermal efficiencies of equipment such as cooling towers and chiller heat exchangers have possibly also been reduced from design values due to scale build-up, fouling and corrosion. All of these factors lead to reduced heat transfer rates and will result in higher electrical energy requirements for any given cooling requirement.

Lastly, the differences between the actual and simulated power might be the result of the mine occasionally varying set schedules used in the simulation. For example, this might have been necessary to perform routine maintenance on a specific machine without it necessary reflecting clearly in the data.

It is clear from Figure 40 and Table 15 that the difference between the simulated power and the actual power is the largest during the three winter months of June to August, as classified by Eskom (2012). The reason for this offset is suggested to be mainly a result of the relative changes in cooling load to the efficiency of equipment in operation. As seen in Table 14, the mine schedules change significantly in winter and they operate almost at half of the electric capacity of the cooling plant. However, the cooling load might not have been reduced proportionally due to a relatively hot winter. The efficiencies of the mechanical and thermal machines might also have been reduced from their design values as already discussed. It follows that it is possible that for winter months the cooling load per electrical input available is higher than it should be for relatively constant COPs as used in the simulation, leading to the increased discrepancy between the simulation and real power profiles.

The result is that half of the machines must supply a cooling demand that is not significantly less than full load. Although the colder ambient conditions make a valuable contribution, the overall result is relatively higher electrical power usage of those machines that are in operation (lower COPs). This is specifically the case when comparing these actual power profiles to the simulation where only design COPs and ideally-scheduled values were considered.

Table 15 shows that the average values of the actual (5 759 kW) and simulated (5 399 kW) annual electrical power usage differ by 6.9%. When considering that the eventual purpose of this high-level simulation is to make valid predictions regarding energy saving strategies to evaluate the general strategy feasibility, it was decided that this is sufficiently accurate for the span of a full year. The fact that the simulation conservatively predicts the electrical power as slightly lower than the real usage is acceptable, since this implies a safety factor when predicting energy savings in the feasibility study.

Daily profiles of the actual and simulated electrical baseline power were also considered. Figure 41 and Figure 42 depict the average weekday profiles for the summer and winter months respectively.

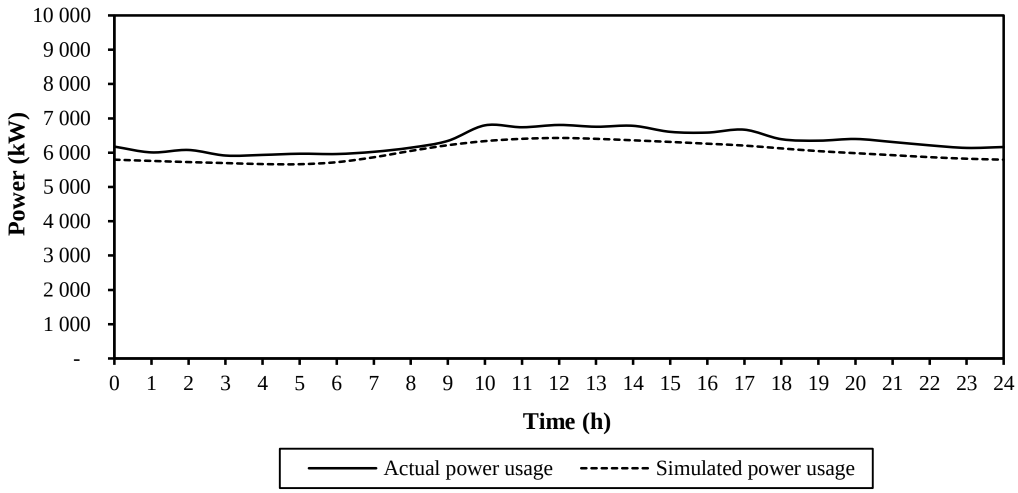

Figure 41 Simulated and actual baseline power usage of the Kusasalethu surface cooling system (average daily profile of Sept-May)

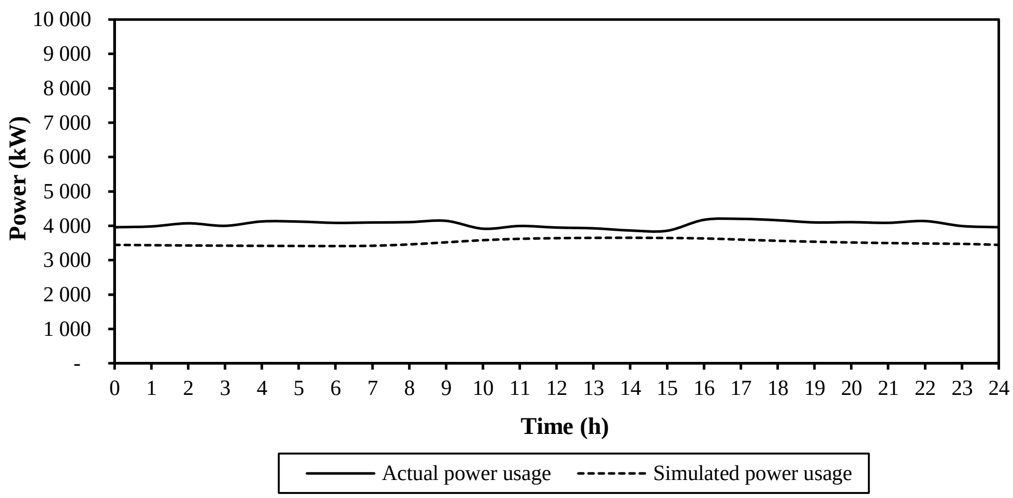

Figure 42 Simulated and actual baseline power usage of the Kusasalethu surface cooling system (average daily profile of June-Aug)

Figure 41 indicates that the simulation profile follows the actual profile relatively closely in shape. The positive actual power offset discussed already is also apparent. The actual average summer power usage (6 330 kW) is 4.1% higher than the simulated power (6 027 kW).

Similarly, Figure 42 shows that the simulation profile also follows the actual profile relatively closely in shape, which is seen to be flatter than for summer as a result of fewer fluctuations in system scheduling. The actual average winter power usage (4 045 kW) is 12.9% higher than the simulated power (3 519 kW).

The daily profiles of simulated power usage are acceptable in serving their intended purpose of predicting energy saving measures sufficiently accurately. This is because the general shapes reflect the same trends as measured for the actual power. The daily fluctuations in electrical power resulting from ambient and operational changes are therefore suitably catered for by the simulation. An average daily profile comparison was made for every month of the year to analyse lower level effects. An example of this is the profile of February, which is given in Annexure B.1. The results were very similar to those shown in Figures 41 and 42 in terms of shapes and general trends, confirming the suitability of the simulation model.

It can be concluded that the integrated simulation model of the Kusasalethu surface cooling system was adapted suitably from existing models by Arndt (2000). The Microsoft Visual Basic simulation consists of simple mathematical component-based models that are integrated and linked through respective inputs and outputs. Inputs are provided as hourly system constraints and ambient data in Microsoft Excel. Output is provided as simulated hourly power usage of the integrated cooling system.

The model was verified by comparing the measured baseline power usage of 2009 with simulated values for the same conditions. The simulated power consumption showed a yearly average difference of only 6.9% to the actual power consumption of the system without any energy saving interventions. The daily power profiles of different seasons and months also indicated good correlation between the simulation and the actual measurements. It was thus found that the model is suitably accurate for its intended purpose of predicting power usage on a high level. The slight conservative discrepancy is acceptable as it introduces a safety factor in the simulation model. It follows that the model is deemed suitable for use in predicting energy savings over an annual period by varying model constraints as required and thereby investigating the feasibility of the simulated DSM strategy.

6.4 Simulation results

The simulation model that was adapted and verified for sufficient accuracy in the previous section was subsequently used to simulate the power usage of the Kusasalethu cooling system when the operation conditions are changed as suggested by the developed variable water flow strategy. The same time period (2009) was used as for the verification procedure. The simulated power baseline shown in Figure 40 was used as a pre-implementation baseline since this presents the simulated operation of the system before implementation of the energy saving strategy, and will therefore enable comparison on the same relative basis.

To simulate the application of the new strategy, the mine service delivery requirements and ambient condition profiles remained unchanged. However, the simulated operation of the water pumps and BACs as well as the pre-cooling towers specifications changed according to the strategies outlined for Kusasalethu in Chapter 6.2. The relevant system constraints and input data used for simulation purposes are summarised in Table 16

Table 16 Summary of input data used in simulation of energy savings of the Kusasalethu surface cooling system

	Summer (Sept-May)	**Winter (June-Aug)**
Equipment specifications (except pre-cooling towers)	As per Table 13	As per Table 13
Ambient conditions (hourly)	Klerksdorp 2009	Klerksdorp 2009
Average hot water flow from underground (ℓ/s)	305	280
Average hot water temperature from underground (ºC)	28	28
Average chilled water to underground (ℓ/s)	305	280
Pre-cooling pump schedules	3 pumps full-time	3 pumps full-time
Evaporator pump operation	PID control to maintain chilled water dam level at 95%	
Condenser pump operation	PID control to maintain condenser water temperature rise at 5 ºC	
BAC return pump operation	Forward loop control according to ambient enthalpy (25-70 kJ/kg)	
Pre-cooling towers in operation	8	8
Chillers in operation	4	2
Condenser cooling towers in operation	4	4
BACs in operation	3	0
New pre-cooling tower specifications:		
Inlet water temperature (ºC)	30	
Outlet water temperature (ºC)	23	
Inlet air wet-bulb temperature (ºC)	20	

The simulation model was adapted for the conditions in Table 16 by replacing the fixed pump on/off schedules with simple PID control models (Equation 33). For model simplicity, the BAC supply water flow control was simulated only as VSDs controlling the BAC return water flow rate. This is equivalent to the proposed strategy of controlling the gravity fed supply water with valves and pumping the return water with dam level-controlled VSDs as discussed in Chapter 6.2.

The simulated electrical input power profiles of the Kusasalethu surface cooling system before and after the simulated energy saving interventions for 2009 are shown in Figure 43.

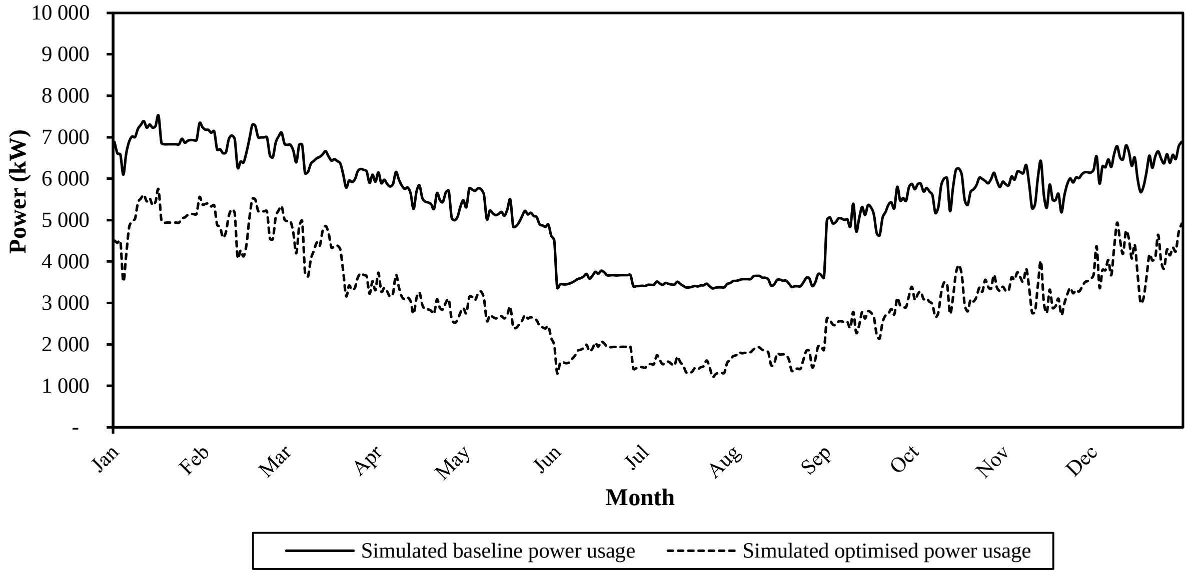

Figure 43 Simulated power usage of the Kusasalethu surface cooling system before and after simulation of energy saving strategies (2009)

It is apparent from Figure 43 that there is a large reduction in input power throughout the yearly profile when the suggested energy saving measures are simulated. The profiles are shown to follow the same general trends, mainly because the mine requirements and ambient condition profiles stay constant for both simulations. However, the saving offset is not exactly constant throughout the year. To display this more clearly, the simulated 24-hour power profiles after saving interventions are shown for the summer and winter seasons in Figures 44 and 45 respectively. A typical daily power profile of an individual month is shown for February in Annexure B.1.

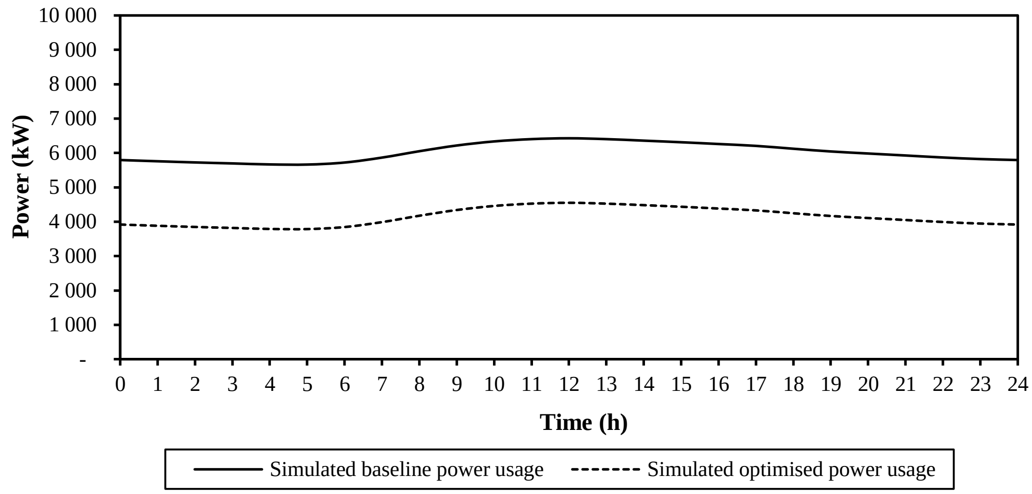

Figure 44 Simulated power usage of the Kusasalethu surface cooling system before and after simulation of energy saving strategies (average daily profile of Sept-May)

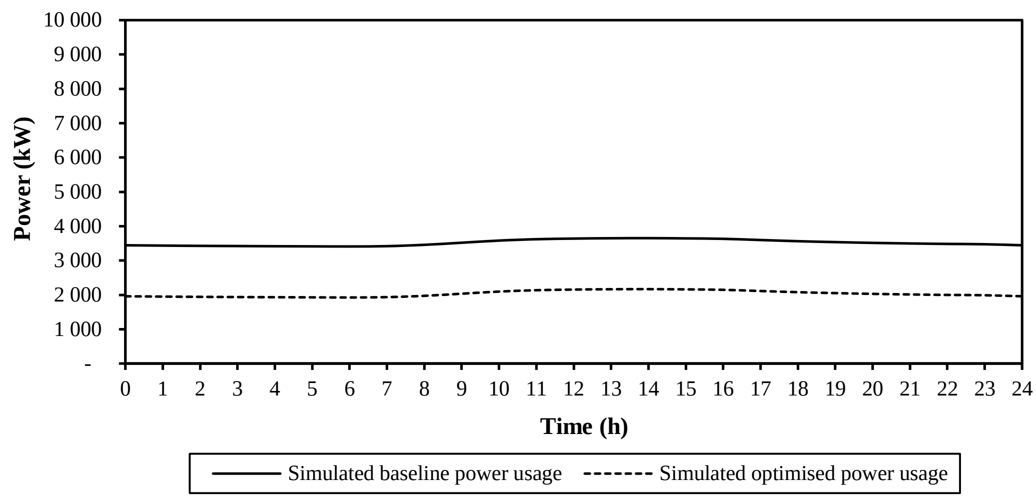

Figure 45 Simulated power usage of the Kusasalethu surface cooling system before and after simulation of energy saving strategies (average daily profile of June-Aug)

Figure 44 indicates the average summer energy saving of 1 877 kW and Figure 45 the average winter energy saving of 1 485 kW. The difference can be attributed mainly to two factors.

First, the BACs are shut down during the winter. Although this presents a large reduction in the power baseline, it also means that the percentage of the summer saving that can be realised from reducing and controlling the BAC water flow cannot be realised.

Second, only two of the chillers operate during the winter. Only half of the installed cooling capacity is available, but the cooling load is not decreased by as much, as was discussed previously. This means that a slightly higher water flow would be required for prolonged periods to satisfy the water cooling demand. The VSDs would have to control the pumps at slightly higher speeds than for the summer, resulting in reductions in the possible savings.

Even though the predicted value of the energy saving is smaller in winter than in summer, the winter saving as a percentage of the baseline power is much larger than for the summer. This is because of the lower operational and power requirements of the plant during colder conditions. The percentage savings and monthly summaries of simulated potential savings possible are shown in Table 17.

Table 17 Simulated electrical energy savings of the Kusasalethu surface cooling system (monthly averages)

Month	Baseline power (kW)	Optimised power (kW)	Total savings (kW)	Total savings (%)
January	6 965	5 424	1 541	22
February	6 870	5 361	1 509	22
March	6 334	4 533	1 801	28
April	5 615	3 551	2 064	37
May	5 175	3 170	2 005	39
June	3 586	2 144	1 442	40
July	3 430	1 871	1 559	45
August	3 542	2 088	1 454	41
September	5 196	3 180	2 016	39
October	5 802	3 747	2 055	35
November	5 868	3 811	2 057	35
December	6 411	4 567	1 844	29
Average	**5 399**	**3 621**	**1 779**	**33**

Table 17 displays the variation in predicted energy savings throughout the year. The average summer saving is predicted to be 31% and the average winter saving 42% of the summer and winter power baselines, respectively. The overall annual electrical load reduction is predicted to be 1 779 kW, or 33% of the simulated baseline.

The simulated average energy saving of 33% is predicted with confidence. This is because of the good correlation shown between the simulation model and the actual cooling system performance in Chapter 6.3. The verified conservative nature of the simulation adds further confidence to the prediction.

It should be borne in mind that the adapted simulation model serves only as a tool in the process of evaluating the feasibility of the developed DSM strategies. The focus of this study is not on the simulation model. Further detail, such as a precise breakdown of saving contributions by the different strategies, is therefore not given here. The performance and saving contributions of the various strategies will be evaluated experimentally in Chapter 8.

It can be concluded that the potential was shown to lower the average annual electricity usage of the Kusasalethu surface cooling system by 1 779 kW, or 33%. This will be achieved by controlling the water flow of the evaporators, condensers and BACs as well as replacing the old pre-cooling towers with new ones as described in Chapter 6.2. The potential savings were predicted by a suitably accurate simulation model adapted for the surface cooling system of the Kusasalethu mine.

6.5 Cost-benefit analysis

The simulated electrical load reduction for the Kusasalethu surface cooling system was discussed in the preceding sections. Although simulated electricity savings of 33% were indicated, it is not sufficient to base viability decisions solely on these results. A cost-benefit analysis was thus carried out to investigate the economic feasibility of the variable-flow strategies at Kusasalethu. This included the calculation of cost savings, a breakdown of costs required, the calculation of relevant viability indicators and a brief sensitivity analysis. It is important to note that this analysis was done from the perspective of the same investor financing the implementation and benefitting from the cost savings. For simplicity and confidentiality reasons, the financial contributions of and relations between the ESCO, contractor, mine management and power supply utility (Eskom) are not considered. These considerations are also not significant to this study because the purpose is merely to establish the feasibility of the developed strategy. The relevant implementation costs and savings will remain unchanged, independent of the financier.

Cost savings

The monetary savings realised by the developed strategy need to be calculated first. Most South African mines, including Kusasalethu, are charged for electricity usage on a time-of-use basis named the Megaflex tariff structure (Eskom 2012). These electricity tariffs are based on peak, standard and off-peak times as defined by the daily hours shown in Figure 46 (Eskom 2012).

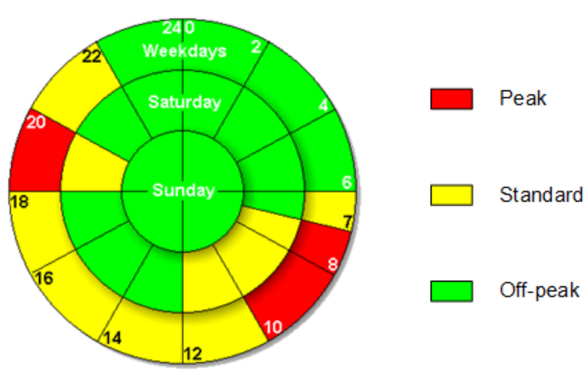

Figure 46 Eskom Megaflex demand period definitions (Eskom 2012)

The 2012/2013 Megaflex tariffs applicable to the Kusasalethu mine are summarised in Table 18 (Eskom 2012).

Table 18 Eskom 2012/2013 Megaflex tariff structure (Eskom 2012)

Demand time	September to May tariffs (c/kWh)	June to August tariffs (c/kWh)
Peak	66.98	237.72
Standard	41.04	61.78
Off-peak	28.69	33.03

The tariffs are not only different for the various demand times during the day, but are also significantly higher in the peak winter season, defined as June to August. It follows that to calculate the cost savings correctly, daily as well as seasonal profiles of power usage must be taken into account.

Simulated power input values of the surface cooling system were obtained for every hour simulated in Chapter 6.4. These values were used in calculating the expected cost savings. Although the simulation was done using data from 2009, the tariffs shown in Table 18 were used to be as up to date as possible at the time of the simulation. An example of the calculation of daily cost savings is shown for a sample summer day in Table 19.

Table 19 Sample summer day cost savings profile

Hour	Electricity tariff (c/kWh)	Baseline electricity (kWh)	Baseline cost (R)	Electricity with DSM strategy (kWh)	Cost with DSM strategy (R)	Cost saving (R)	Cost saving (%)
0	28.69	6 369	1 827	4 442	1 274	553	30
1	28.69	6 355	1 823	4 418	1 267	556	30
2	28.69	6 317	1 812	4 351	1 248	564	31
3	28.69	6 257	1 795	4 250	1 219	576	32
4	28.69	6 196	1 778	4 160	1 194	584	33
5	28.69	6 193	1 777	4 166	1 195	582	33
6	41.04	6 275	2 575	4 296	1 763	812	32
7	66.98	6 495	4 350	4 579	3 067	1 283	29
8	66.98	6 854	4 591	4 968	3 328	1 263	28
9	66.98	6 969	4 668	5 039	3 375	1 293	28
10	41.04	7 001	2 873	4 969	2 039	834	29
11	41.04	6 876	2 822	4 677	1 919	903	32
12	41.04	6 637	2 724	4 646	1 907	817	30
13	41.04	6 530	2 680	4 688	1 924	756	28
14	41.04	6 478	2 658	4 413	1 811	847	32
15	41.04	6 375	2 616	3 977	1 632	984	38
16	41.04	6 261	2 570	3 714	1 524	1 046	41
17	41.04	6 108	2 507	3 411	1 400	1 107	44
18	66.98	6 152	4 121	3 493	2 340	1 781	43
19	66.98	6 184	4 142	3 457	2 316	1 827	44
20	41.04	6 119	2 511	3 361	1 379	1 132	45
21	41.04	6 067	2 490	3 359	1 379	1 111	45
22	28.69	6 069	1 741	3 424	982	759	44
23	28.69	6 007	1 723	3 347	960	763	44
Avg	**42.33**	**6 381**	**2 716**	**4 150**	**1 768**	**947**	**35**
Total			**65 175**		**42 442**	**22 733**	

It can be seen in Table 19 that the cost savings fluctuate throughout the day as a function of electricity tariffs and energy savings profiles. For this sample day, cost savings of R22 733 were predicted by the simulation. This is 35% of the baseline electricity cost that would have been incurred for that day without the variable water flow strategy.

The same analysis as shown in Table 19 was applied to every day of the year using the output data from the simulation model. Table 20 shows a summary of cost savings predicted for Kusasalethu for each calendar month.

Table 20 Simulated monthly cost savings for Kusasalethu (2012/2013 electricity tariffs)

Month	Baseline cost (R)	Cost with DSM strategy (R)	Cost savings (R)	Cost savings (%)
January	2 193 479	1 708 053	485 426	22
February	1 953 968	1 524 865	429 103	22
March	1 994 835	1 427 600	567 235	28
April	1 711 192	1 082 279	628 913	37
May	1 629 563	998 158	631 405	39
June	2 293 948	1 371 532	922 416	40
July	2 267 504	1 236 859	1 030 645	45
August	2 341 657	1 380 411	961 246	41
September	1 583 413	969 000	614 413	39
October	1 827 112	1 180 085	647 027	35
November	1 788 239	1 161 379	626 860	35
December	2 019 025	1 438 211	580 814	29
Avg	**1 966 995**	**1 289 869**	**677 125**	**34**
Total	**23 603 934**	**15 478 432**	**8 125 502**	

Table 20 shows that the percentage cost savings are the highest in winter, as can be expected from the tariff structure used. It is shown that the simulated electricity usage of the combined surface cooling system on Kusaslethu predicts an annual cost saving of R8 125 502, or 34% of the simulated electricity cost before the variable-flow strategy intervention. It is possible that further costs will be saved in the operational life of the VSDs as a result of reduced pump maintenance requirements, but this is not easy to calculate and to be conservative this is not taken into account.

Costs incurred

Having calculated the potential benefits of the variable-flow strategy, it follows that the required expenses must be quantified. The incurred costs consist of initial capital expense and annual maintenance. The maintenance requirements are almost negligible as reported in Chapter 3, but will be included to ensure completeness. No monthly running costs are introduced by the strategies.

To quantify the initial capital required to implement the strategy on Kusasalethu, various system integrator contractors were requested to provide detailed quotations for the high-level scope of work defined in Chapter 6.2. The VSDs, pre-cooling towers and all auxiliary equipment such as PLCs, field instruments and cables needed to be specified accurately and according to the standards of the Kusasalethu mine. Various site visits were conducted to establish the details required for accurate equipment specification. The most complete and reasonable quotation was subsequently chosen. A detailed breakdown of the bill of quantities and the associated costs is shown in Table 21.

Table 21 Strategy implementation bill of quantities and costs for the Kusasalethu surface cooling system

Item	Specification	Quantity	Total cost (R)
Equipment costs			**4 485 414**
Evaporator water flow control			
VSD	Schneider Electric Altivar 61 90 kW (525 V/122 A) including circuit breakers, line choke, motor choke and bottom cable entry	3	506 904
PLC	Siemens Simatic S7-300 including Ethernet Profinet interface, micro memory card, stable PS307 power supply (input: 120/230 V AC output: 24 V DC/5 A)	1	29 282
PLC panel	PLA1073 PLA enclosure, 100x75x32 mm, IP 65, galvanised steel	1	11 678
Condenser water flow control			
VSD	Schneider Electric Altivar 61 200 kW (525 V/252 A) including circuit breakers, line choke, motor choke and bottom cable entry	3	741 354
Water temperature sensor	Wika TR31 PT-100 probe including 4-20 mA transmitter (accuracy: 0.2% in measurement range)	5	12 346
BAC water flow control			
Control valve	400 mm 2014W butterfly valve including cast iron body, stainless steel disc and EPDM liner	3	23 580
Electrical valve actuator	Rotork actuator 400 mm BFV	3	86 178
VSD	Schneider Electric Altivar 61 75 kW (525 V/105 A) including circuit breakers, line choke, motor choke and bottom cable entry	2	295 552
PLC	Siemens Simatic S7-300 including Ethernet Profinet interface, micro memory card, stable PS307 power supply (input: 120/230 V AC output: 24 V DC)	1	29 282
Digital psychrometer	Testo 6 681 humidity transmitter including Testo 6 610 probes (accuracy: 1% RH, 0.6% Dry-bulb temperature, 1% Enthalpy in range of measurement)	1	13 164

Item	Specification	Quantity	Total cost (R)
Pre-cooling tower replacement			
Cooling tower bank	ICT model 3CR12 including stainless steel frame, galvanised piping, LBO mesh “splash” type fill (depth 1500 mm) and 4 x 5.5 kW electric fans (525 V, 960 /min)	2	2 564 094
Cables (miscellaneous)			
Power cable	4 mm^2 4 core SWA PVC (black with red stripe) 1 000 V/500 A cable	500 m	19 500
Power cable	8 mm^2 4 core SWA PVC (black with red stripe) 1 000 V/500 A cable	500 m	39 000
Network cable	1 mm^2 19 core XLPE PVC (blue with white stripe) cable	200 m	33 500
Network cable	UTP network cable	200 m	3 000
Fibre cable	4-core fibre	500 m	14 000
Cable racking	150 mm galvanised steel	100 m	15 000
Cable racking	300 mm galvanised steel	100 m	30 000
Cable rack droppers	Galvanised steel	100 m	18 000
System integration costs			**755 908**
Installation and commissioning	Labour: boilermakers, technicians		399 460
PLC programming	Labour: software engineer		74 900
SCADA development	Labour: software engineer		21 848
Site establishment	Health and safety induction, medicals, etc.		137 300
Project management			60 400
Travelling			62 000
Total			**5 241 322**

Table 21 shows that the total implementation cost is R5 241 322. Of this total, R755 908 is quoted to integrate the developed REMS-CA^{TM} system into the existing control network as specified in Chapter 5. The remainder is quoted for the equipment needed for the variable-flow strategy implementation.

The total of R5 241 322 is a function of the exchange rate between the South African Rand and Euro (*EXR*), because a large portion of the equipment is imported from Europe. Considering the prevailing European and VSD prices at the time of the quote, the costs that are sensitive to the exchange rate can be separated from those that are not. The implementation cost (*IC*) is then:

$$IC = 3\ 503\ 680 + (146\ 636)(EXR) \tag{34}$$

The sensitivity of the cost as a function of exchange rate was considered in the brief sensitivity analysis later in this section.

The total installed capacity of VSD installations quoted for is 1 020 kW. The total cost of the VSDs only is R1 543 810. This gives a VSD-only R/kW cost of R1 514/kW. Similarly, the installation of the VSDs costs R392/kW. These costs are in relative agreement with the average market-related values used in Table 2 for the preliminary high-level VSD investigation, considering that most of the drives (75 kW and 90 kW) have reasonably low installed capacities.

It was discussed in Chapter 3 that VSD maintenance is usually negligible if it is properly installed and all cables and connections are suitably specified. Under normal operating conditions the only component that needs to be changed is the air filter on the VSD panel ventilation air intake. This is typically required annually at low costs. VSD suppliers also typically include 12-month warranties. Therefore, maintenance costs were not included in the generalised analysis in Chapter 3. However, an annual site audit of the VSDs and on-site maintenance of small parts can be provided if required at a cost of about R90/kW (Schneider Electric 2010). For Kusasalethu, this translates to an annual cost of R91 800. No replacement of any major parts is expected under normal operating conditions of a typical VSD with a lifespan of 20 years (Schneider Electric 2010). To be conservative, this annual service cost (*ASC*) was included in this analysis.

Additional annual costs are not introduced by any of the other components listed in Table 21. Items such as instrumentation and cabling form part of existing mine maintenance plans. The new cooling towers will also not introduce maintenance requirements different to those of the existing towers. In fact, the new cooling towers should require less maintenance due to more advanced and modern fill and construction materials.

It can be concluded that the implementation of the variable water flow strategy at Kusasalethu will incur an initial implementation cost of R5 241 322 (at present exchange rates) and a conservative annual maintenance cost of R91 800.

Cost of conserved energy

A preliminary estimate of energy efficiency viability is the cost of conserved energy (*CCE*) as defined by Equation 12. A value of R383/MWh has been indicated as feasible by McKane and Hasanbeigi (2011) and an average of R563/MWh was reported in Table 8 for a general pump and fan VSD survey.

Using only the costs of the first year and average energy savings as estimates, the CCE is found as:

$$CCE = \frac{C_{VSD}}{ES_{VSD}} = \frac{IC + ASC}{Average\ annual\ power\ savings \times annual\ hours} = \frac{5\ 241\ 322 + 91\ 800}{1.779 \times 8\,760} = \text{R342/MWh}$$

The calculated *CCE* of R342/MWh is shown to be slightly less than the referenced viability benchmark and much lower than the average value determined during the preliminary investigation. This indicates that the strategy should be viable for consideration.

Payback period

One of the most common indicators for energy savings projects is the payback period. It is defined as the estimated time that it will take for economic benefits, or savings, to recover the initial investment (Blank and Tarquin 2011). A typical feasible payback period for a VSD-related project has been indicated to be less than two years (Johansson 2009, Ozdemir 2004).

The simple payback period (*PBP*) is estimated by Equation 10, using the annual incurred costs and cost savings calculated in the previous two sections as estimates:

$$PBP = \frac{C_{VSD}}{CS_{VSD}} = \frac{IC + AC}{CS} = \frac{5\ 241\ 322 + 91\ 800}{8\ 125\ 502} = 0.656 \text{ years} = 8 \text{ months}$$

The net cash flow of the first year is shown in Figure 47, taking into account the different savings per month.

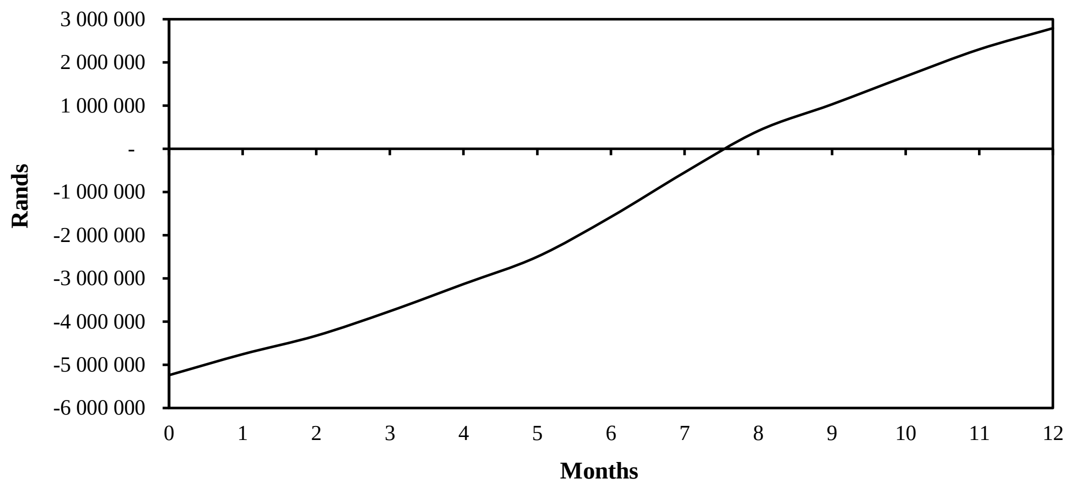

Figure 47 Net cash flow for Kusasalethu using simulated results

The break-even point can be seen to occur during the eighth month in Figure 47, confirming the calculation graphically. The payback period of eight months is exceptionally short and significantly less than the benchmark of two years, further indicating feasibility.

An alternative, more accurate method to calculate the payback period is to also account for the influence of inflation (*f'*) during the year. This method is shown by using Equation 35 (Webber-Youngman 2005) to confirm the payback period.

$$PBP_{f'} = \frac{\log\left(\left(1 - \frac{(f')(IC)}{(CS - AC)}\right)^{-1}\right)}{\log(1 + f')} \qquad (35)$$

Using the present South African inflation rate (*f'*) as 5.7% (Statistics South Africa 2012), the payback period is calculated as:

$$PBP_{f'} = \frac{\log\left(\left(1 - \frac{(0.057)(5\,241\,322)}{(8\,125\,502 - 91\,800)}\right)^{-1}\right)}{\log(1 + 0.057)} = 0.684 \text{ year} = 8 \text{ months}$$

The inflation-adjusted payback period is slightly longer than the simple payback period (on a yearly basis), but also rounds to eight months. It is therefore confirmed that the estimated payback period indicates feasibility.

Rate of return

An important indicator of the economic worth of a new project or, in this case, an energy savings initiative, is the internal rate of return (*IRR*). It is an indication of the rate earned on the unrecovered balance of an investment. In this case, it is an indication of the rate of cost savings realised relative to the balance of the incurred costs. To be feasible, the *IRR* should be more than the minimum attractive rate of return (*MARR*) for the specific investor. For energy saving projects, a benchmark *MARR* of at least 15% is often used (Webber-Youngman 2005).

To calculate the *IRR*, the present worth of costs (PW_c) is equated to the present worth of receipts (PW_r) for a series of cash flows and the interest rate calculated that will satisfy that condition (Blank and Tarquin 2005). When a detailed series of cash flows is involved, this is most simply done using the *IRR* function of Microsoft Excel.

The cash flow assumed for this strategy is as used for the payback period calculation in the first year, adjusted thereafter according to an inflation rate of 5.7% on annual savings and costs. A life of 20 years was used, as recommended by Schneider Electric (2012). The cash flow and calculated IRR is indicated in Table 22.

Table 22 Cash flow and IRR calculation for Kusasalethu using simulated results

Year	Costs (R)	Savings (R)	Net cash flow (R)
0	5 241 322	0	-5 241 322
1	91 800	8 125 503	8 033 703
2	97 033	8 588 657	8 491 624
3	102 563	9 078 210	8 975 647
4	108 410	9 595 668	9 487 259
5	114 589	10 142 621	10 028 032
6	121 120	10 720 751	10 599 630
7	128 024	11 331 833	11 203 809
8	135 322	11 977 748	11 842 426
9	143 035	12 660 479	12 517 444
10	151 188	13 382 127	13 230 939
11	159 806	14 144 908	13 985 102
12	168 915	14 951 168	14 782 253
13	178 543	15 803 384	15 624 841
14	188 720	16 704 177	16 515 457
15	199 477	17 656 315	17 456 839
16	210 847	18 662 725	18 451 878
17	222 865	19 726 501	19 503 635
18	235 569	20 850 911	20 615 343
19	248 996	22 039 413	21 790 417
20	263 189	23 295 660	23 032 471
IRR (%)			159

The calculated *IRR* of 159% is exceptionally high and significantly more than the assumed *MARR* of 15%. This is because the relative return on the initial investment is very high with a short payback. This rate of return is a definite indication of economic feasibility.

Present worth sensitivity analysis

The present worth of a net cash flow is also called the net present value (*NPV*). It is a useful viability indicator, because it essentially transforms a future cash flow to it equivalent present worth. If the *NPV* is positive when calculated at the *MARR*, the cash flow is feasible (Blank and Tarquin 2005). Similar to the *IRR* calculation, this is most easily done for a detailed cash flow and given interest rate, using the Microsoft Excel *NPV* functionality.

When considering the cash flow shown in Table 22 (inflation = 5.7%) and a *MARR* of 15% (Webber-Youngman 2005), the *NPV* is found to be R56 650 342. This is significantly more than zero, again emphasising feasibility as expected.

All the indicators calculated thus far show that it is economically viable to implement the proposed variable-flow strategy on the Kusasalethu surface cooling system. However, these indicators were calculated assuming a constant electricity tariff structure, Rand/Euro exchange rate and inflation rate. To investigate the sensitivity of the economic viability to these factors, the *NPV* was therefore calculated for various changes in the three key influencing factors.

The *NPV* of R56 650 342 was used as the base case with all previously-used constants as follows:

- Rand/Euro exchange rate (*EXR*) = R11.85/Euro
- Average daily electricity tariff = 42.3 c/kWh (summer) and 88.9 c/kWh (winter)
- Annual inflation rate (f') = 5.7%

Changes in the exchange rate will be reflected in the initial implementation cost as shown by Equation 34. Changes in the electricity tariffs will be reflected in the realised cost savings as calculated in Table 19 and 20. Changes in the inflation rate will influence savings as well as the annual maintenance costs. The 20-year cash flow and the associated 15% *NPV* was calculated for relative changes in each of the three variables while keeping the others constant. The resulting sensitivity analysis is shown in Figure 48.

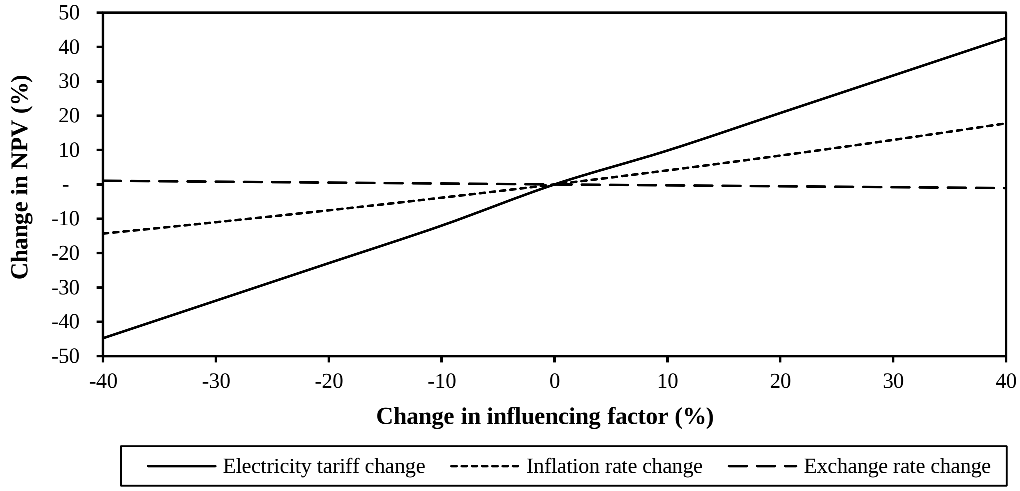

Figure 48 NPV sensitivity analysis for Kusasalethu using simulated values

It can be seen in Figure 48 that the *NPV* is the most sensitive to changes in electricity tariffs. This is to be expected since it greatly affects the savings realised. It is a relevant consideration in South Africa at present, with Eskom proposing an annual tariff increase of 16% (Eskom 2013). However, it is apparent that tariff increases will only favour the viability of the DSM strategy because higher returns will be realised. The limiting case of the implementation becoming economically unfeasible (*NPV* = 0) will only be realised if the present electricity tariffs are reduced by 91%, a highly unlikely situation.

Inflation rate changes will also influence the *NPV* somewhat, but it is not expected to change by more than 40% in the foreseeable future. The exchange rate barely influences the viability of the cash flow, with less than 1% change in *NPV* for a 40% change in exchange rate.

From the brief sensitivity analysis it is clear that the proposed DSM strategy will remain feasible for reasonable changes in electricity tariffs, inflation rate and exchange rate. The most probable case of significantly increasing electricity tariffs and a reduced exchange rate, will favour the feasibility.

Summary

The annual cost savings that will be realised were calculated using the simulated energy savings results and amounted to R8 125 502. The implementation costs were found by analysing a detailed bill of quantities quotation for the scope of work required to implement the strategy. This amounted to R5 241 322. An estimation of maximum annual maintenance costs was found to be R91 800.

The above results were used to find viability indicators for the present exchange rates, inflation rate and electricity tariffs. The cost of conserved energy was found to be R342/MWh, the payback period was shown to be eight months, the internal rate of return was calculated as 159% and the net present value (at 15% minimum accepted rate of return) was shown to be R56 650 342. All of these results strongly indicate viability.

A sensitivity analysis showed that reasonable changes in electricity tariffs, inflation rate and exchange rate will not be detrimental to the feasibility of the cash flow. It can therefore be concluded that the proposed variable water flow DSM strategy for Kusasalethu is shown to be economically viable.

6.6 Conclusion

A study was presented to determine the feasibility of the developed variable-flow strategy before implementing it on site. The focus of the feasibility study was on the Kusasalethu mine surface cooling system because this site is the primary case study of this thesis.

To provide suitable background, the layout and system details of the Kusasalethu surface cooling system were discussed first. A description of how the variable-flow strategies are to be implemented on this site was given. It was shown that it consists of evaporator flow control (three VSDs), condenser flow control (three VSDs), BAC supply flow control (three control valves), BAC return flow control (two VSDs) and pre-cooling tower replacement.

An existing Microsoft Visual Basic simulation model of large thermal systems was adapted and described for the Kusasalethu surface cooling system, based on mathematical models for large cooling systems. The model uses hourly inputs of ambient data, system requirements and operational methods. The outputs are given as hourly system performance values and total power input requirements. The simulation model was verified by comparing measured baseline power input to simulated power input. The simulated baseline power consumption of the case study system showed an annual average correlation of 6.9% to the actual power consumption, indicating suitability for its intended purpose as part of the feasibility study.

The simulation model was used to predict potential savings when changing system constraints according to the described strategies for Kusasalethu. It was shown that there is potential to lower the average annual electrical load of the Kusasalethu surface cooling system by 1 779 kW or 33%.

A cost-benefit analysis was carried out to determine the economic feasibility of the strategies. The annual cost savings that will be realised amounted to R8 125 502. The implementation costs amounted to R5 241 322. An estimation of maximum annual maintenance costs was found to be R91 800. The cost of conserved energy was found to be R342/MWh, the payback period was shown to be eight months, the internal rate of return was calculated as 159% and the net present value (at 15% minimum accepted rate of return) was shown to be R56 650 342.

All of these results strongly indicate viability. A sensitivity analysis showed that reasonable changes in electricity tariffs, inflation rate and exchange rate will not be detrimental to the feasibility of the cash flow.

It can be concluded that the proposed variable water flow DSM strategy for the Kusasalethu surface cooling system was shown to be feasible from energy efficiency as well as economic perspectives. It was therefore decided to implement the proposed strategies on Kusasalethu so that the developed DSM method and simulation can be experimentally validated.