CHAPTER 9. FURTHER IMPLEMENTATION CASE STUDIES

9.1 Introduction

The newly developed variable water flow strategy and the energy management system to implement it on large cooling systems have been validated successfully by considering its *in situ* implementation on the Kusasalethu mine surface cooling system as a primary case study. The strategy was subsequently implemented on three more large cooling systems. The layouts and operation of these systems differ from the Kusasalethu cooling system. The key results from these case studies are presented here to show the versatility of the developed DSM strategy in a larger context. The potential to extend the strategy to non-mining large cooling systems is also discussed.

The application of the new strategy on the surface cooling system of the Kopanang mine is discussed first. This system has a parallel chiller arrangement and chills water for use in a BAC and underground. The surface cooling system of the South Deep mine's South Shaft is considered next. Chilled water is only sent underground in this cascaded dam arrangement. Implementation at South Deep's Twin Shaft cooling system is also described. This system is a closed-loop BAC cooling system. Finally, the potential to implement the strategy on the large air-cooled cooling system of the Saldanha steel plant is discussed. These key results form part of Annexure C.1 (Du Plessis et al. 2013b).

Only the key results are presented for each case study. The layout and specifications, strategy customisations, realised savings, effects on cooling system performance and service delivery and economic viability are briefly described in each case. The chapter only serves to provide an overview of the versatility and simplicity of the variable-flow strategy for application on various large cooling systems.

9.2 Kopanang

System layout

The variable-flow strategy was first extended to the surface cooling system of the Kopanang gold mine near Orkney, South Africa. Figure 112 shows the layout of the cooling system, including the control equipment added to enable REMS-CA™ to implement the variable-flow strategy.

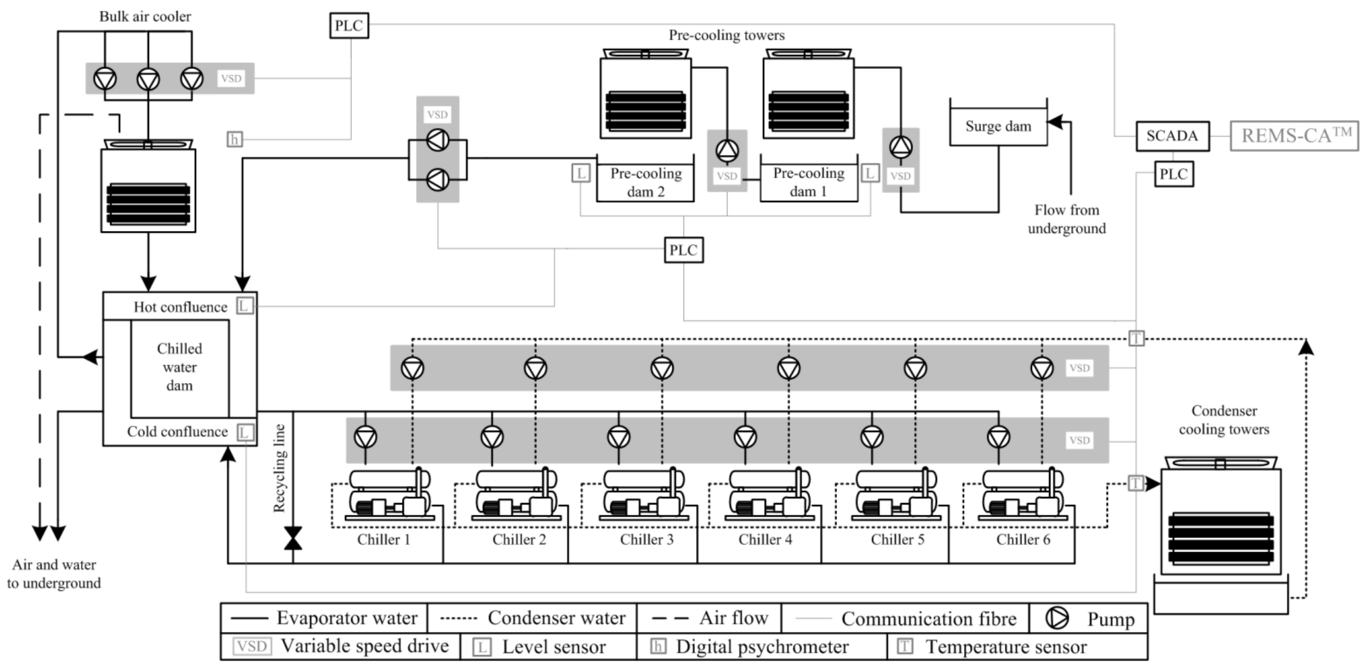

Figure 112 Kopanang surface cooling system layout

It can be seen in Figure 112 that the Kopanang system features a parallel chiller arrangement, such as shown for variable seasonal flow processes in Figure 6. Each chiller has its own dedicated evaporator and condenser pump. The system supplies chilled water underground as well as to a BAC, similar to Kusasalethu's requirements. It also features a recycling chilled water line. The system specifications and details are given in Table 28.

Table 28 Kopanang surface cooling system specifications

Combined plant	
Hot water dam temperature (ºC)	26
Chilled water dam temperature (ºC)	3
Volume of water sent underground (Mℓ/day)	20
Combined COP	5.5
Combined cooling capacity (kW)	39 000
Individual chillers	
Cooling capacity (kW)	6 500
Evaporator outlet temperature (ºC)	3
Condenser inlet temperature (ºC)	27
Evaporator water flow rate (ℓ/s)	250
Condenser water flow rate (ℓ/s)	450
COP	5.5
Refrigerant	R134a
Compressor type	Centrifugal
Water pumps	
Evaporator pump motor rating (kW)	110
Number of evaporator pumps	6
Condenser pump motor rating (kW)	160
Number of condenser pumps	6
BAC return pump motor rating (kW)	75
Number of BAC return pumps	3
Pre-cooling pump motor rating (kW)	70
Number of pre-cooling pumps	4
Cooling towers	
Pre-cooling towers	
Number	2
Water outlet temperature (ºC)	24
Air inlet wet-bulb temperature (ºC)	22
Condenser cooling towers	
Number	6
Water outlet temperature (ºC)	27.5
Air inlet wet-bulb temperature (ºC)	22
BACs	
Number	3
Water outlet temperature (ºC)	9
Air outlet wet-bulb temperature (ºC)	7

Implemented strategies

All the generic variable water flow strategies described in Chapter 4 were applied at Kopanang. Table 29 gives a summary of how the strategies were adapted and what equipment was installed during implementation.

Table 29 Variable water flow strategies implemented at Kopanang

Strategy	Set point	Equipment installed
1. Evaporator flow control		
- Install a VSD on each evaporator pump	-	6 x 110 kW Schneider Electric Altivar 61VSDs (525 V/122 A, including circuit breakers, line choke, motor choke)
- Maintain a constant chilled water dam cold confluence level	90%	-
2. Condenser flow control		
- Install a VSD on each condenser pump	-	6 x 160 kW Schneider Electric Altivar 61VSDs (525 V/122 A, including circuit breakers, line choke, motor choke)
- Maintain a constant water temperature rise over each condenser	4.5 ºC	-
3. BAC flow control		
- Install a VSD on each BAC supply pump	-	3 x 75 kW Schneider Electric Altivar 61VSDs (525 V/122 A, including circuit breakers, line choke, motor choke)
- Modulate the VSDs in proportion to ambient enthalpy	30-70 kJ/kg	1 x Testo 6681 humidity transmitter including Testo 6610 probes
4. Pre-cooling tower flow control		
- Install a VSD on each pre-cooling tower pump	-	4 x 70 kW Schneider Electric Altivar 61VSDs (525 V/122 A, including circuit breakers, line choke, motor choke)
- Maintain a constant pre-cooling dam 1 level	90%	-
- Maintain a constant pre-cooling dam 2 level	90%	-
- Maintain a constant hot confluence dam level	90%	-

It is shown in Table 29 that similar equipment was used as at Kusasalethu. VSD control for the BAC supply flow modulation was used instead of valves and pre-cooling tower flow control based on dam levels was added. The set points specified by the mine and determined during commissioning are also shown. In addition to its basic hierarchical control functionalities, REMS-CA™ was also used to calculate the real-time system cooling load and make real-time recommendations as to how many chillers should ideally be in operation.

Realised savings

Figure 113 (Du Plessis et al. 2013b) shows the average daily power baseline and post-implementation power usage of the combined cooling system. The period under consideration included the same three months as for the Kusasalethu case study. The daily baseline adjustments were again calculated by a regression model determined by an independent auditing body. It can be seen that, with the exception of a few days in the first two months, positive savings were realised.

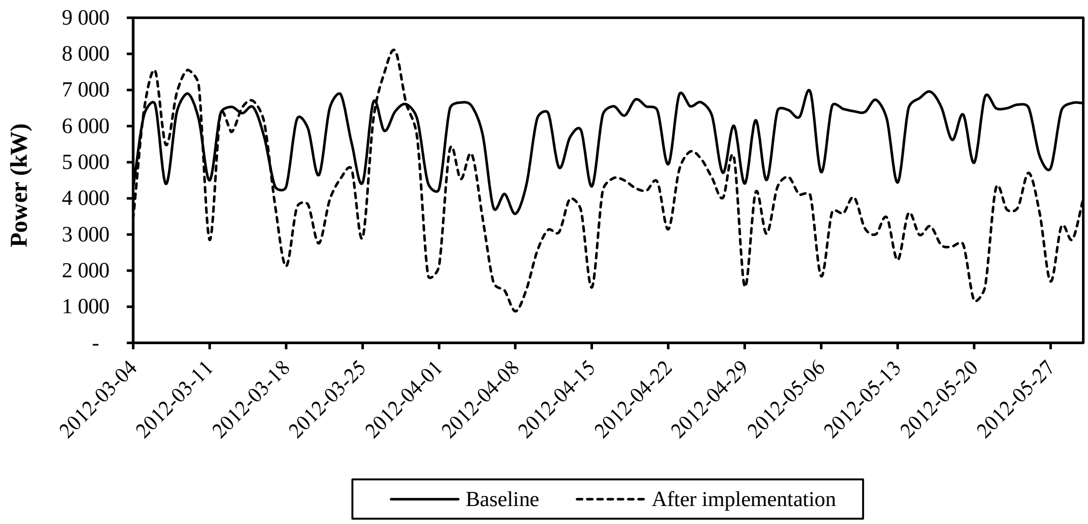

Figure 113 Daily average power input of combined cooling system (Kopanang) (Reprinted from *A versatile energy management system for large integrated cooling systems*, Du Plessis G.E., Liebenberg L., Mathews E.H., Du Plessis J.N., Energy Conversion and Management, 66, 312-325, Copyright (2013), with permission from Elsevier)

Figure 114 shows the average daily power profiles for the three assessment months. It can be seen that the post-implementation profile peaks slightly for the typically hotter periods of an average day. This shows that the BAC flow control was effectively modulating according to the demand. It is also apparent that significant base savings were once again realised, predominantly from valve control elimination, back-passing elimination and constant modulation of VSDs.

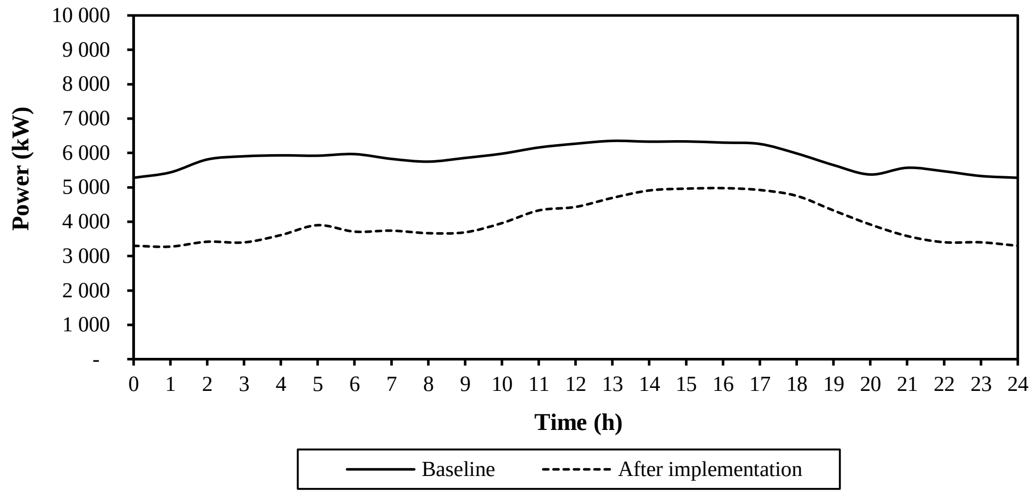

Figure 114 Average daily profile of combined cooling system power input (Kopanang)

Table 30 provides a summary of the savings realised at Kopanang. The lower saving of March can be attributed to high water demands due to high ambient temperatures during that month, leading to less scope for part load control. It is shown that the average saving is 1 865 kW, or 31.7%. This is once again more than predicted by a simulation before implementation. The 31.7% saving corresponds relatively well with the 35.4% of Kusasalethu, especially considering that these two systems are similar in size and in the specific energy saving strategies applied.

Table 30 Combined cooling system energy saving summary (Kopanang)

	Baseline power (kW)	**Actual power (kW)**	**Power saving (kW)**	**Measured saving (% of baseline)**	**Simulated saving (% of baseline)**
March 2012	5 787	5 262	525	9.1	
April 2012	5 678	3 604	2 074	36.5	
May 2012	6 161	3 253	2 908	47.2	
Average	**5 877**	**4 012**	**1 865**	**31.7**	**25**

Effects on cooling system

Figure 115 shows daily average chilled water volumes sent underground and average chilled water temperatures.

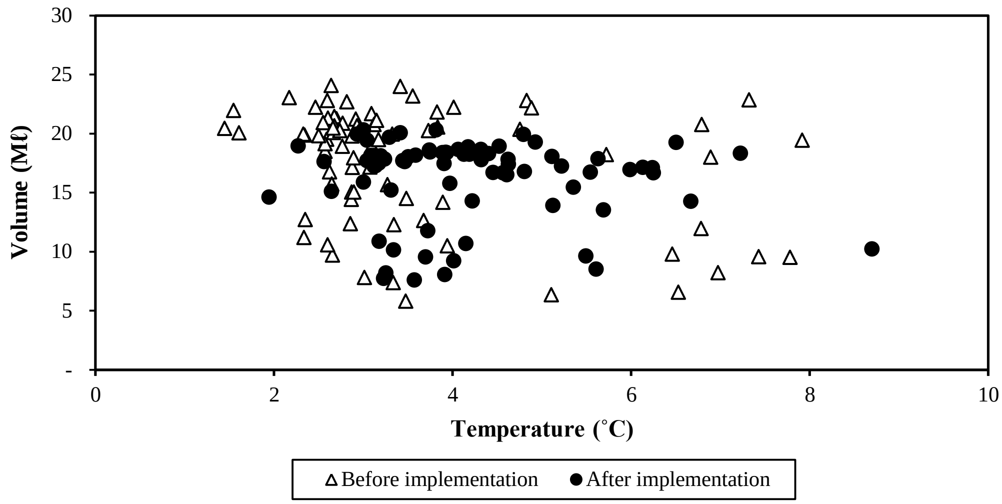

Figure 115 Daily average chilled water temperature and water volume sent underground (Kopanang)

It was found that an average chilled water volume of 17.5 Mℓ/day was sent underground during similar conditions before implementation. This was reduced by 6.9% after implementation. However, the lowest daily flow before implementation was 5.8 Mℓ/day, while after implementation it was 7.6 Mℓ/day. This means that, even though the average flow was reduced somewhat, the availability of chilled water to underground end-users did not decrease.

The daily average chilled water temperature increased from 3.8 ºC to 4.3 ºC after implementation. This is possibly a result of the variations in chilled and cooling water flow rates influencing the performance of individual chiller capacity control. However, Kopanang specifies that the water temperature must ideally remain below 5 ºC. The small increase in chilled water temperature is still below the maximum temperature specified.

Economic viability

Table 31 shows the main economic factors applicable to implementation at Kopanang, calculated analogously to the methods in Chapter 6.

Table 31 Cost savings, implementation costs and payback period (Kopanang)

Annual cost savings (R)	6 919 997
Implementation costs (R)	5 536 000
New equipment	2 920 996
Integration, installation, commissioning	2 615 003
Simple payback period (months)	10

For this site, new equipment costs were comparable to the integration costs. Only VSDs and a psychrometer were newly installed, while significant amounts of integration and installation work were required. It is shown that the annualised cost saving (using 2012/2013 tariffs) of R6 919 997 and total cost of R5 536 000 realised an effective payback period of 10 months. This indicates cost-effectiveness since it is less than two years, the suggested benchmark discussed in Chapter 3. It is also similar to the seven months realised for Kusasalethu, indicating general consistent performance when the DSM strategy is applied to cooling systems of similar specification.

9.3 South Deep South Shaft

System layout

The variable-flow strategy was also extended to the surface cooling system of the South Deep gold mine's South Shaft near Randfontein, South Africa. Figure 116 shows the layout of the cooling system, including the control equipment added to enable REMS-CA^{TM} to implement the variable-flow strategy.

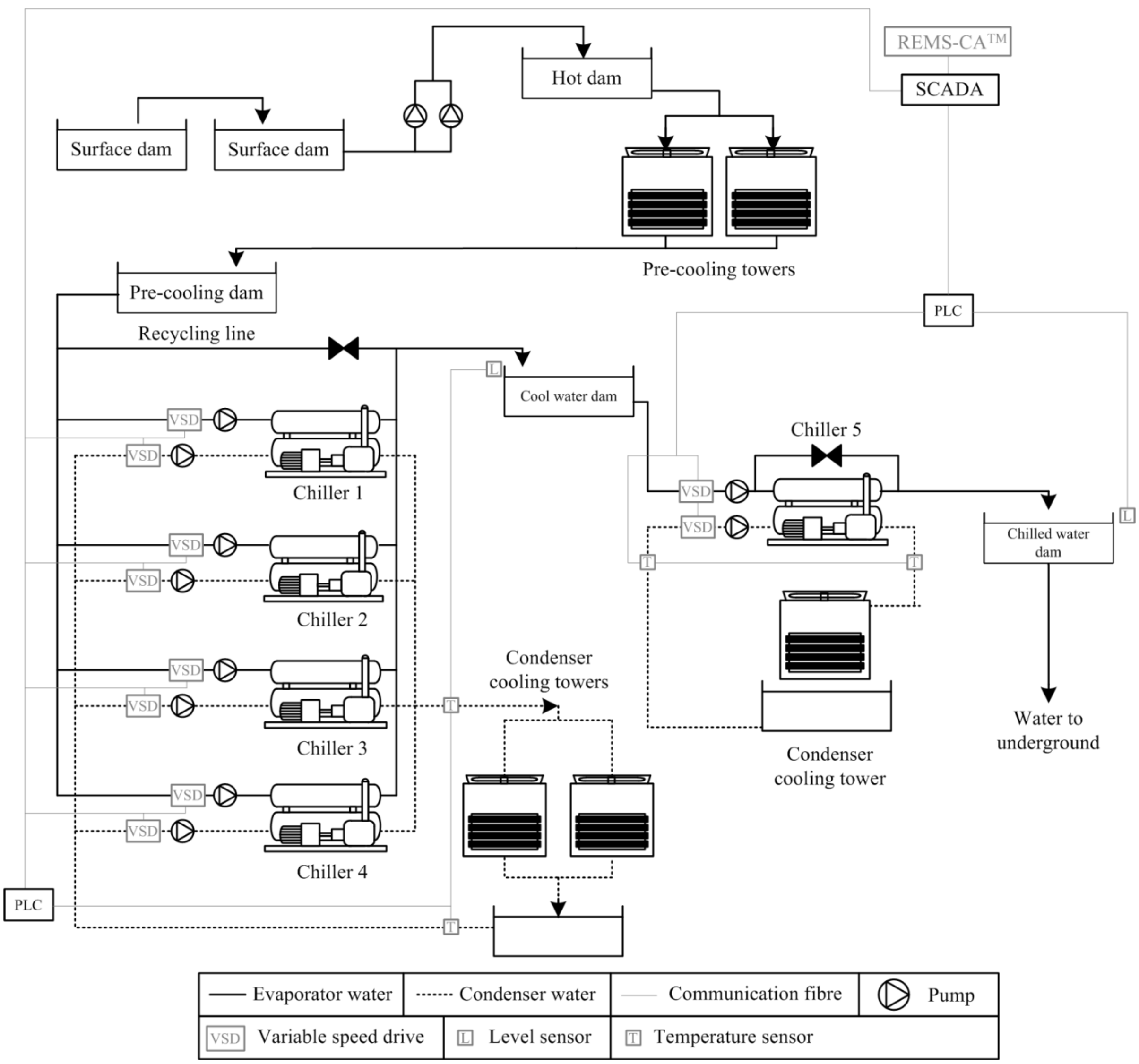

Figure 116 South Deep South Shaft surface cooling system layout

Figure 116 shows that the South Deep South Shaft system features a cascaded dam arrangement. Four parallel chillers feed into an intermediate cool water dam which is cascaded with another chiller that feeds into the final chilled water dam. The cascaded dam layout allows more flexibility in terms of thermal storage and chiller scheduling since more water storage is available. Each chiller has its own dedicated evaporator and condenser pump. This system only supplies chilled water underground, with no surface BAC present. It also features a recycling chilled water line as in the other systems. The system specifications and details are given in Table 32.

Table 32 South Deep South Shaft surface cooling system specifications

Combined plant		
Hot water dam temperature (ºC)	26	
Chilled water dam temperature (ºC)	2.5	
Volume of water sent underground (Mℓ/day)	19	
Combined COP	6	
Combined cooling capacity (kW)	26 000	
Individual chillers	**Chillers 1-4**	**Chiller 5**
Cooling capacity (kW)	5 000	6 000
Evaporator outlet temperature (ºC)	6.5	3
Condenser inlet temperature (ºC)	22	22
Evaporator water flow rate (ℓ/s)	115	300
Condenser water flow rate (ℓ/s)	300	380
COP	6	5
Refrigerant	R134a	Ammonia
Compressor type	Centrifugal	Screw
Water pumps	**Chillers 1-4**	**Chiller 5**
Evaporator pump motor rating (kW)	55	183
Number of evaporator pumps	4	1
Condenser pump motor rating (kW)	132	183
Number of condenser pumps	4	1
Pre-cooling pump motor rating (kW)	70	
Number of pre-cooling pumps	2	
Cooling towers		
Pre-cooling towers		
Number	2	
Water outlet temperature (ºC)	14	
Air inlet wet-bulb temperature (ºC)	22	
Condenser cooling towers		
Number	3	
Water outlet temperature (ºC)	27.5	
Air inlet wet-bulb temperature (ºC)	22	

Implemented strategies

Table 33 gives a summary of how the strategies were adapted and what equipment was installed during implementation at South Deep South Shaft.

Table 33 Variable water flow strategies implemented at South Deep South Shaft

Strategy	Set point	Equipment installed
1. Evaporator flow control		
- Install a VSD on each evaporator pump	-	4 x 55 kW Danfoss VLT HVAC VSDs (525 V/78 A, including line choke) 1 x 200 kW Danfoss VLT HVAC VSD (525 V/78 A, including line choke)
- Maintain constant cool and chilled water dam levels	90%	-
2. Condenser flow control		
- Install a VSD on each condenser pump	-	4 x 132 kW Danfoss VLT HVAC VSDs (525 V/78 A, including line choke) 1 x 200 kW Danfoss VLT HVAC VSD (525 V/78 A, including line choke)
- Maintain a constant water temperature rise over each condenser	5 ºC	-

It is shown in Table 33 that only the evaporator and condenser flow control strategies were applied since there is no BAC. In addition to its basic hierarchical control functionalities, REMS-CA™ was adapted to take into account schedules of underground mine operations and thereby make recommendations concerning the operation times and duration of the two chiller sets, incorporating the lead and lag of the cascaded dams.

A typical daily power profile of this system is shown and discussed in Annexure C.1 (Du Plessis et al. 2013b), illustrating the typical daily operation and chiller scheduling.

Realised savings

The power usage of individual pumps is well monitored at South Deep. This made it possible to investigate pump-specific energy savings. Figure 117 shows the average evaporator water flow rate and electrical power input for full-load conditions of the evaporator water pumps of chiller 3. This shows the effect of replacing valve control with VSD control, even before any flow modulation takes place. While the design flow rate remained relatively constant, the electrical input power was reduced by 54%. Although the extent of this reduction depends on the extent of pump motor over-specification, the benefit of VSD control is clear.

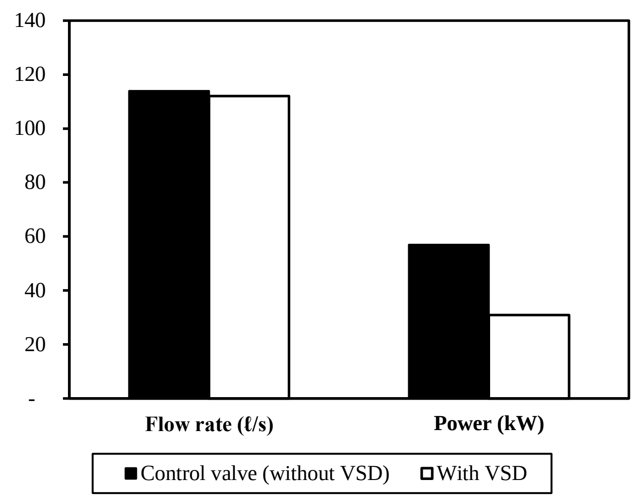

Figure 117 Chilled water flow rate and pumping power when controlling flow with a control valve (without VSD) or with a VSD (South Deep South Shaft)

The average speeds and electrical power consumed by the pump motors at South Shaft are shown as percentages in Figure 118. It can be seen that the speed mostly varied between 75% and 95%. The general trend of the profile corresponds very well to that shown in Figure 4, emphasising the benefits of VSDs and validating that they were suitably implemented and controlled at this site.

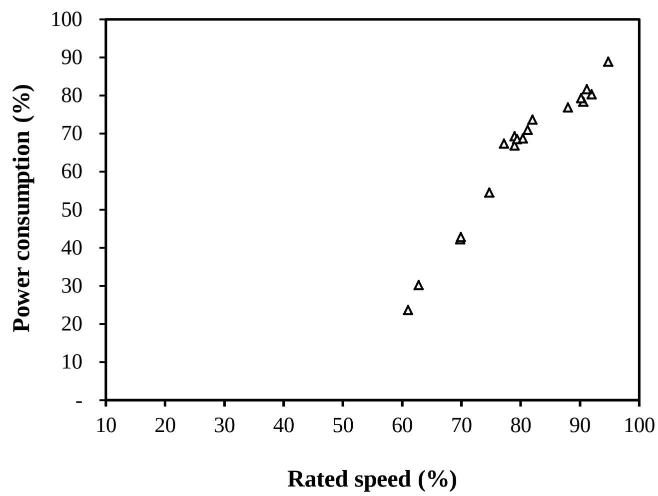

Figure 118 Relationship between average motor power reduction and rated speed after VSD implementation (South Deep South Shaft)

Figure 119 shows the average daily power baseline and post-implementation power usage of the combined cooling system. The period under consideration included two summer months in 2012. It can be seen that, although the savings fluctuated somewhat, positive savings were realised.

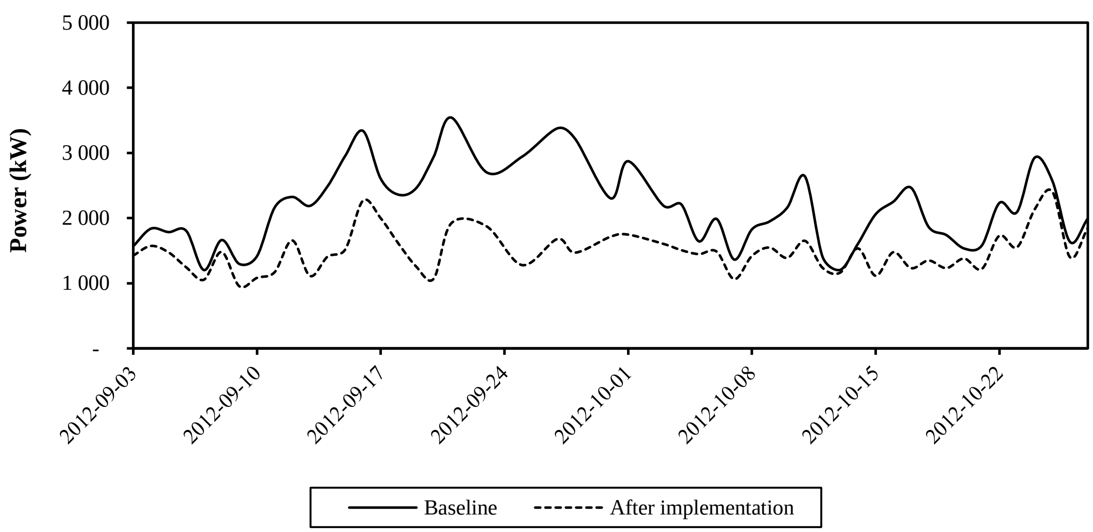

Figure 119 Daily average power input of combined cooling system (South Deep South Shaft)

Figure 120 shows the average daily power profiles for the two assessment months. It can be seen that the post-implementation profile shows clear troughs during times of low demand and when electricity tariffs are higher. This is because the system recommended chiller shutdowns during these times, given that there was sufficient chilled water in the storage dams. The full-load offset is the result of valve control elimination, back-passing elimination and constant part-load modulation of VSDs, as previously discussed.

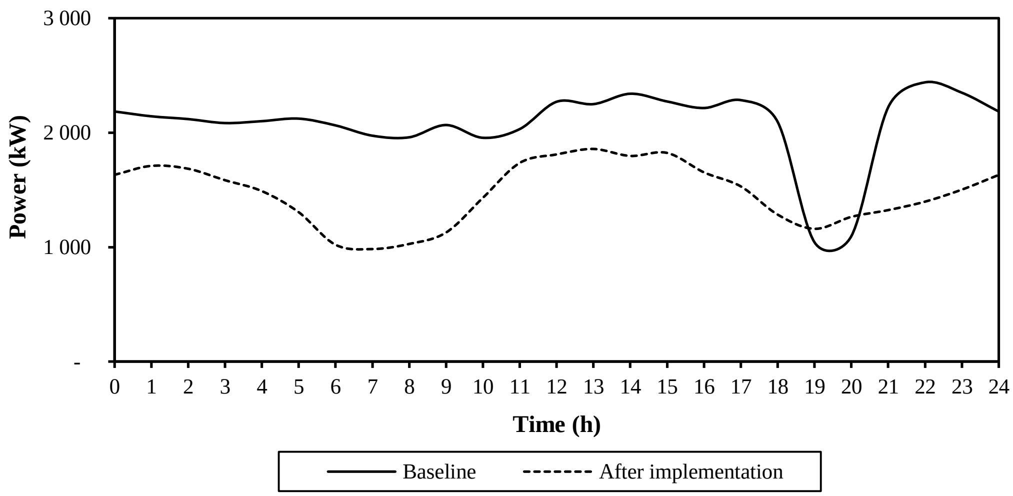

Figure 120 Average daily profile of combined cooling system power input (South Deep South Shaft)

Table 34 gives a summary of the savings realised at South Deep South Shaft. It is shown that the average saving is 606 kW, or 29.3%. This corresponds relatively well with Kopanang's 31.7% and Kusasalethu's 35.4%. It can thus be said that large energy savings were also realised on a large cooling system that does not have a BAC and that features cascaded storage dams.

Table 34 Combined cooling system energy saving summary (South Deep South Shaft)

	Baseline power (kW)	**Actual power (kW)**	**Power saving (kW)**	**Measured saving (% of baseline)**	**Simulated saving (% of baseline)**
September 2012	2 207	1 436	772	35.0	
October 2012	1 965	1 485	480	24.4	
Average	**2 070**	**1 464**	**606**	**29.3**	**18**

Effects on cooling system

Figure 121 shows daily average chilled water volumes sent underground and average chilled water temperatures.

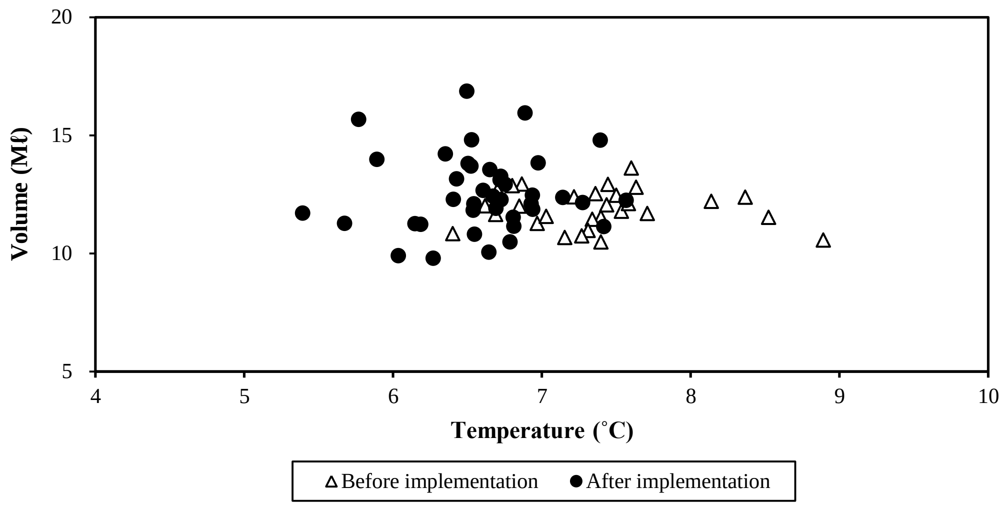

Figure 121 Daily average chilled water temperature and water volume sent underground (South Deep South Shaft)

It can be seen in Figure 121 that the service delivery requirements of this cooling system were improved after implementation of the strategy as managed by REMS-CA^{TM}. The daily water volume sent underground increased by 5.7% to 12.58 Mℓ/day, while the average chilled water temperature decreased by 10.3% to 6.6 ºC. It is therefore apparent that the energy management of cascade chillers based on a systems approach not only improves its energy efficiency, but also its output requirements.

Economic viability

Table 35 shows the main economic factors applicable to implementation at South Deep South Shaft, calculated analogously to the methods in Chapter 6.

Table 35 Cost savings, implementation costs and payback period (South Deep South Shaft)

Annual cost savings (R)	2 250 000
Implementation costs (R)	3 193 838
New equipment	1 231 835
Integration, installation, commissioning	1 962 003
Simple payback period (months)	17

For this site, new equipment costs were less than integration costs. Only VSDs were newly installed, while significant amounts of integration and installation work were required. It is shown that the annualised cost saving (using 2012/13 tariffs) of R2 250 000 and total cost of R3 193 838 realised an effective payback period of 17 months. This exceeds Kusasalethu's seven months and Kopanang's 10 months because this system's installed capacity and thus the absolute savings are lower, even though the savings percentage is comparable to the other sites. The implementation cost is also similar due to similar equipment requirements. However, feasibility is still apparent since the payback is less than two years.

9.4 South Deep Twin Shaft

System layout

Finally, the variable-flow strategy was implemented at the surface cooling system of the South Deep gold mine's Twin Shaft. Figure 122 shows the layout of the cooling system, including the control equipment added to enable REMS-CA™ to implement the variable-flow strategy.

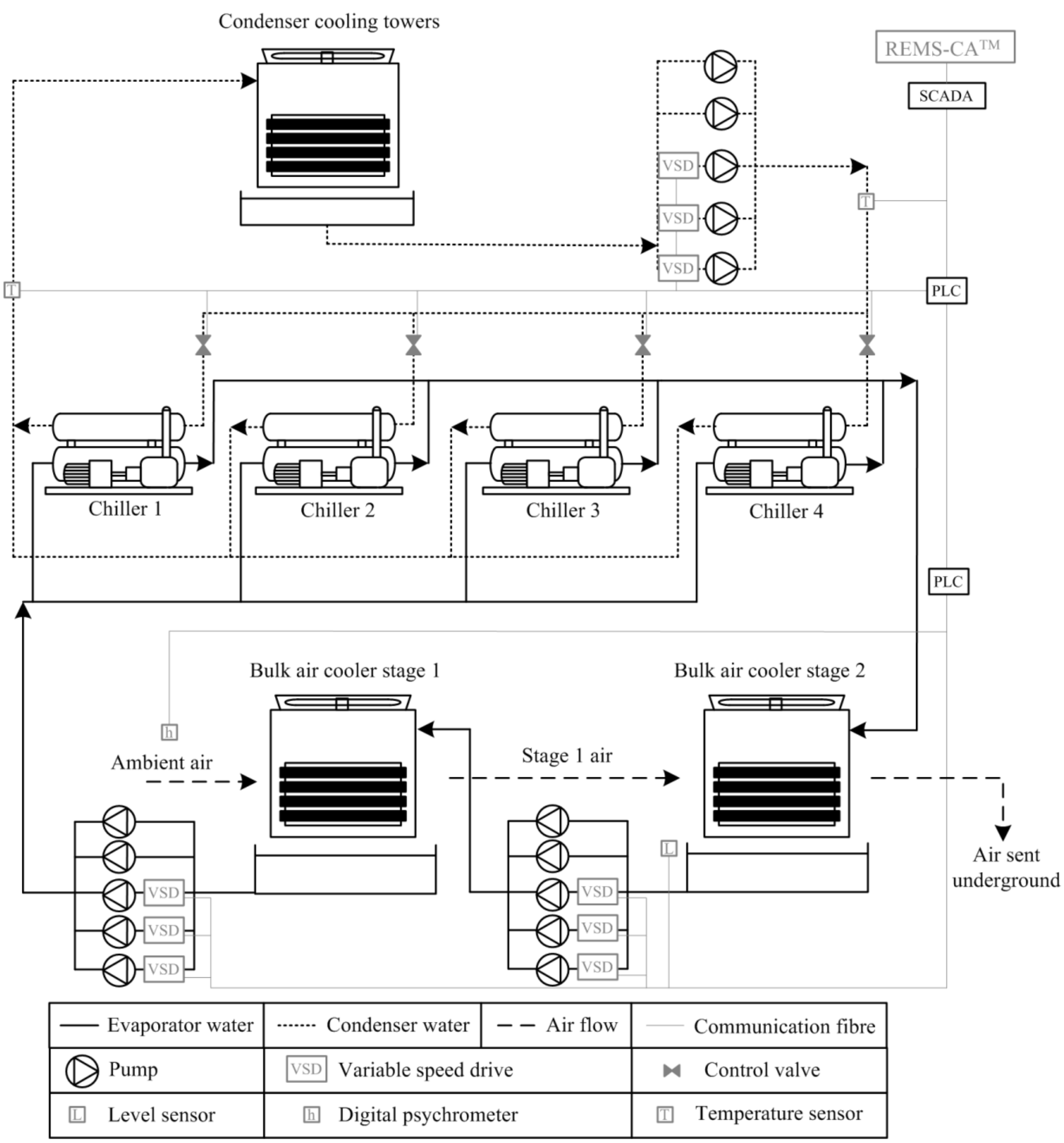

Figure 122 South Deep Twin Shaft surface cooling system layout

It can be seen in Figure 122 that the South Deep Twin Shaft system features a closed-loop BAC system. Four parallel chillers supply chilled water to the BAC second stage. Transfer pumps transfer the second stage outlet water to the first stage, after which it is pumped back to the chillers. No water is therefore sent underground in this system. The system specifications and details are given in Table 36.

Table 36 South Deep Twin Shaft surface cooling system specifications

Combined plant	
Chilled water temperature (ºC)	2.5
Combined COP	5.5
Combined cooling capacity (kW)	24 000
Individual chillers	
Cooling capacity (kW)	6 000
Evaporator outlet temperature (ºC)	2
Condenser inlet temperature (ºC)	21.4
Evaporator water flow rate (ℓ/s)	140
Condenser water flow rate (ℓ/s)	210
COP	5.5
Refrigerant	Ammonia
Compressor type	Screw
Water pumps	
BAC supply (evaporator) pump motor rating (kW)	132
Number of evaporator pumps	5
Condenser pump motor rating (kW)	110
Number of condenser pumps	5
BAC transfer pump motor rating (kW)	75
Number of BAC transfer pumps	5
Cooling towers	
BAC	
Number	1 (2 stages)
Water outlet temperature (ºC)	11
Air outlet wet-bulb temperature (ºC)	8
Condenser cooling towers	
Number	4
Water outlet temperature (ºC)	22.5
Air inlet wet-bulb temperature (ºC)	18

Implemented strategies

Table 37 gives a summary of how the strategies were adapted and what equipment was installed during implementation at South Deep Twin Shaft.

Table 37 Variable water flow strategies implemented at South Deep Twin Shaft

Strategy	Set point	Equipment installed
1. BAC flow control		
- Install a VSD on three BAC supply (evaporator) pumps	-	3 x 132 kW Danfoss VLT HVAC VSDs (525 V/78 A, including line choke)
- Modulate the VSDs in proportion to ambient enthalpy	25-60 kJ/kg	1 x Testo 6 681 humidity transmitter including Testo 6610 probes
- Install a VSD on three BAC stage 1 transfer pumps	-	3 x 75 kW Danfoss VLT HVAC VSDs (525 V/78 A, including line choke)
- Maintain a constant BAC stage 2 drainage dam level	85%	-
2. Condenser flow control		
- Install a VSD on three condenser pumps	-	3 x 110 kW Danfoss VLT HVAC VSDs (525 V/78 A, including line choke)
- Maintain a constant water temperature rise over each condenser	5 °C	-
- Install open-close valves on each condenser line to isolate non-operational chillers		

It is shown in Table 37 that the BAC supply flow control forms the basis of the strategy since this will ensure that only enough water is pumped and chilled to supply the BAC cooling demand. The transfer pumps retain system equilibrium by ensuring that the BAC stage 2 drainage dam level is maintained. The condenser flow control strategy remained unchanged, except that isolation valves were added to ensure that water is only pumped through the operational condensers. This ensures that only sufficient condenser water is pumped, which was not the case before.

Realised savings

Figure 123 shows the average daily power baseline and post-implementation power usage of the combined cooling system. The period under consideration included two summer months in 2012. It can be seen that positive savings were realised for most days. The days indicating lower savings corresponded to days when the average ambient enthalpy was high and therefore the potential to modulate the flows at partial loads was reduced.

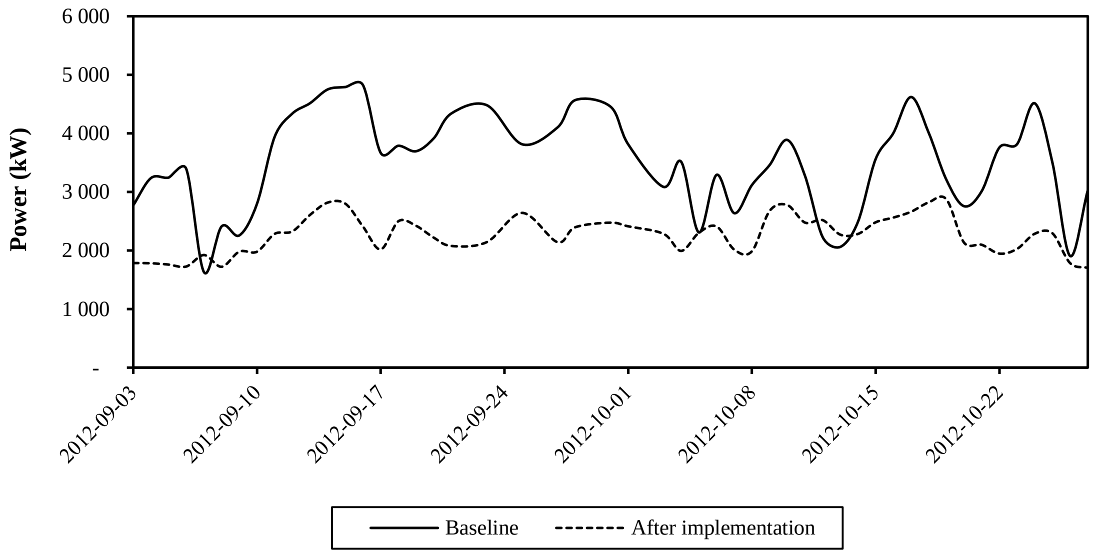

Figure 123 Daily average power input of combined cooling system (South Deep Twin Shaft)

Figure 124 shows the average daily power profiles for the two assessment months. The post-implementation profile clearly peaks during hotter periods of the average day, indicating that the new control method followed the ambient conditions as specified. The full-load saving is attributed to the elimination of valve control and the part-load savings shows the extent to which chilled water flow had been oversupplied previously.

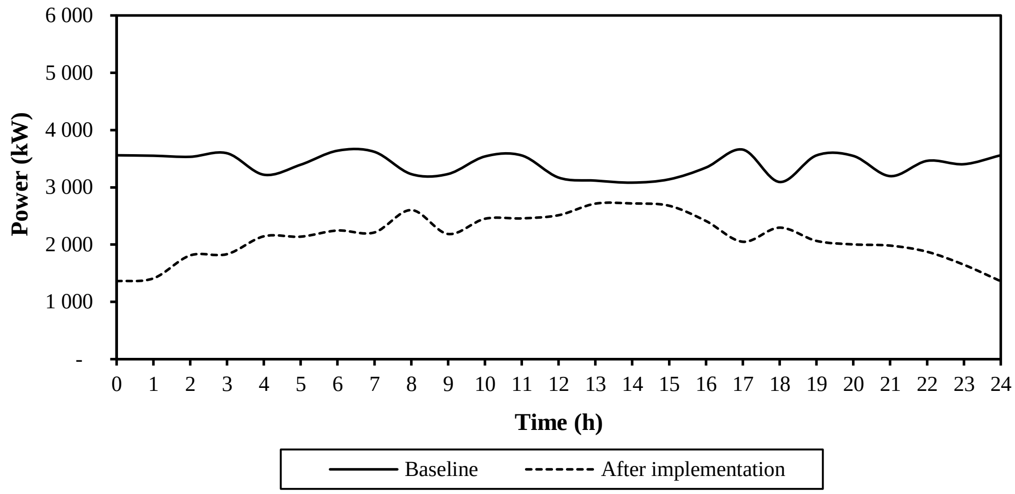

Figure 124 Average daily profile of combined cooling system power input (South Deep Twin Shaft)

Table 38 gives a summary of the savings realised at South Deep Twin Shaft. It is shown that the average saving is 1 149 kW, or 33.8%. Once again this corresponds relatively well with Kusasalethu's 35.4%, Kopanang's 31.7% and South Shaft's 29.3%. It can thus be concluded that large energy savings can also be realised on large cooling systems that supply water to a BAC in a closed-loop system.

Table 38 Combined cooling system energy saving summary (South Deep Twin Shaft)

	Baseline power (kW)	**Actual power (kW)**	**Power saving (kW)**	**Measured saving (% of baseline)**	**Simulated saving (% of baseline)**
September 2012	3 595	2 165	1 430	39.8	
October 2012	3 242	2 307	936	28.9	
Average	**3 394**	**2 245**	**1 149**	**33.8**	**21**

Pump savings at South Deep

It has been mentioned that pump-specific power usage is well monitored at South Deep. The electrical energy consumption of the various pumps was monitored over a period of one month after implementation, in addition to the combined cooling system power input. These results were then compared to the electrical energy consumption of the same pumps, over the same number of running hours, before VSD installation. As commonly done during measurement and verification, only running hours were compared for which operating conditions such as ambient conditions and service requirements were comparable. The results for the different pumps motor sizes found on South Deep South and Twin Shafts combined are shown in Figure 125.

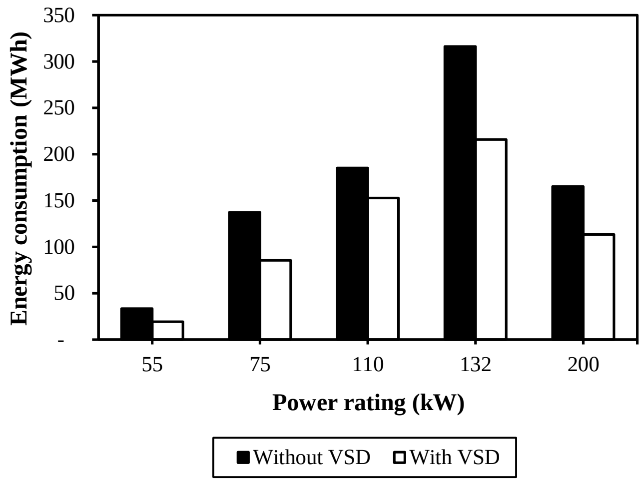

Figure 125 Energy consumption of pump motor groups with different power ratings (South Deep)

Figure 125 shows that there was a clear reduction in energy consumption of all the pump motors. The 132 kW motors showed the greatest reduction in energy consumption, because the largest number of VSDs was installed on these motors. The realised energy savings of the various types of pumps are shown in Figure 126.

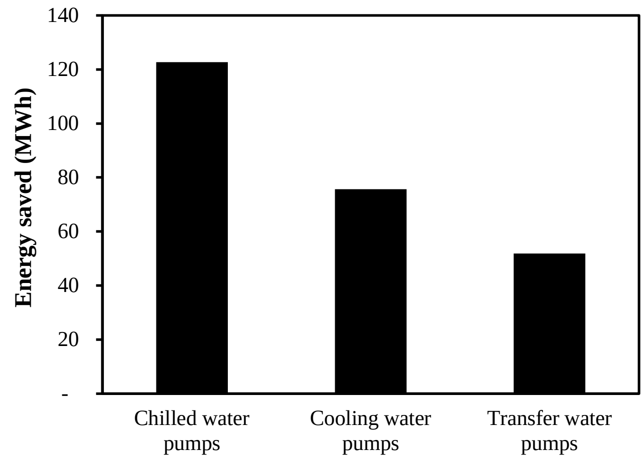

Figure 126 Energy savings of chilled, cooling and transfer water pump motors (South Deep)

It can be seen in Figure 126 that the largest contribution to the savings was made by the chilled (evaporator) water pumps, realising 49% of the total pump savings. This was followed by the cooling (condenser) and transfer water pumps with 30% and 21%, respectively. The major share of the chilled water pumps can be attributed to the drives that modulated the primary water flow rates in quick response to part-load conditions and to the fact that the chilled water lines were throttled significantly by control valves before implementation. Cooling water VSDs were generally less sensitive to part-load changes and these water supply lines were not throttled as much by valves before implementation.

Effects on cooling system

At South Deep Twin Shaft the shaft wet-bulb temperature was measured before and after implementation for days with comparable ambient conditions using a portable sensor. Figure 127 (Du Plessis et al. 2013b) shows the daily average shaft wet-bulb temperature and the average cooling system power input before and after implementation.

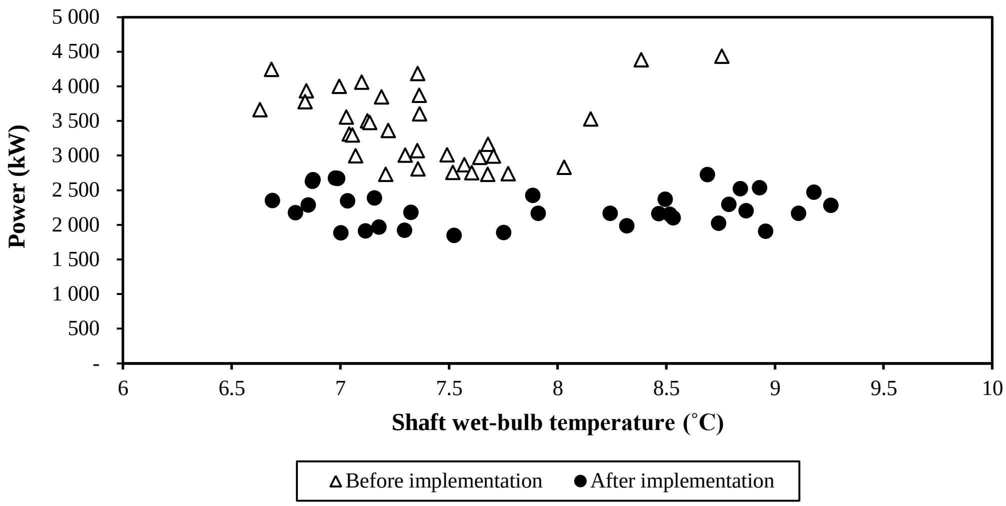

Figure 127 Daily average shaft wet-bulb temperature and cooling system power input (South Deep Twin Shaft) (Reprinted from *A versatile energy management system for large integrated cooling systems*, Du Plessis G.E., Liebenberg L., Mathews E.H., Du Plessis J.N., Energy Conversion and Management, 66, 312-325, Copyright (2013), with permission from Elsevier)

Figure 127 shows that the average wet-bulb temperature of the air entering the shaft increased from 7.4 ºC to 7.9 ºC, or by 7.1%. This is not a large increase considering the significant electrical power savings that were realised as shown. The temperature restriction at this mine states that the shaft inlet wet-bulb air temperature must not exceed 10 ºC. It is thus apparent that the ventilation air was significantly overcooled before implementation. It is therefore possible to realise large electrical energy savings on a closed loop BAC system, while maintaining service delivery requirements, by considering the optimal management of subsystem energy usage.

Economic viability

Table 39 shows the main economic factors applicable to implementation at South Deep Twin Shaft.

Table 39 Cost savings, implementation costs and payback period (South Deep Twin Shaft)

Annual cost savings (R)	4 259 998
Implementation costs (R)	1 927 837
New equipment	1 047 837
Integration, installation, commissioning	880 000
Simple payback period (months)	5

It is shown that the annualised cost saving (using 2012/13 tariffs) of R4 259 998 and total cost of R1 927 837 realised an effective payback period of five months. This is in accordance with Kusasalethu and Kopanang because the savings value and incurred costs are comparable. The payback period is the shortest of all the case studies considered, indicating definite viability.

9.5 Further application potential

It has been shown that the developed variable water flow strategy and energy management system can be feasibly applied to a variety of large cooling systems. *In situ* implementation has only been considered on mine cooling systems as case studies. However, the DSM strategy has the potential to be adapted and expanded to other industrial cooling systems as well. Two typical examples of such cooling systems are industrial air-cooled heat exchanger systems and industrial wet cooling tower systems.

Customisation and application of the strategy to an air-cooled heat exchanger system at the Saldanha Steel works near Vredenburg, South Africa, was briefly investigated. A detailed case study cannot be presented because no implementation has been done. However, simulation results are shown to quantify the potential for potential expansion.

System layout

An industrial air-cooled or dry heat exchanger system involves a closed-loop water circuit. The water is pumped through a heat load where it is heated before being pumped through banks of finned tubes that are air-cooled by axial fans. Such systems are typically found where large volumes of demineralised water need to be cooled without coming into contact with the environment. Common examples can be found on power plant subsystems, iron and steel furnace systems and applications that are sensitive to water quality (GEA 2012).

The investigated cooling system at Saldanha Steel, including the proposed alterations, is shown in Figure 128.

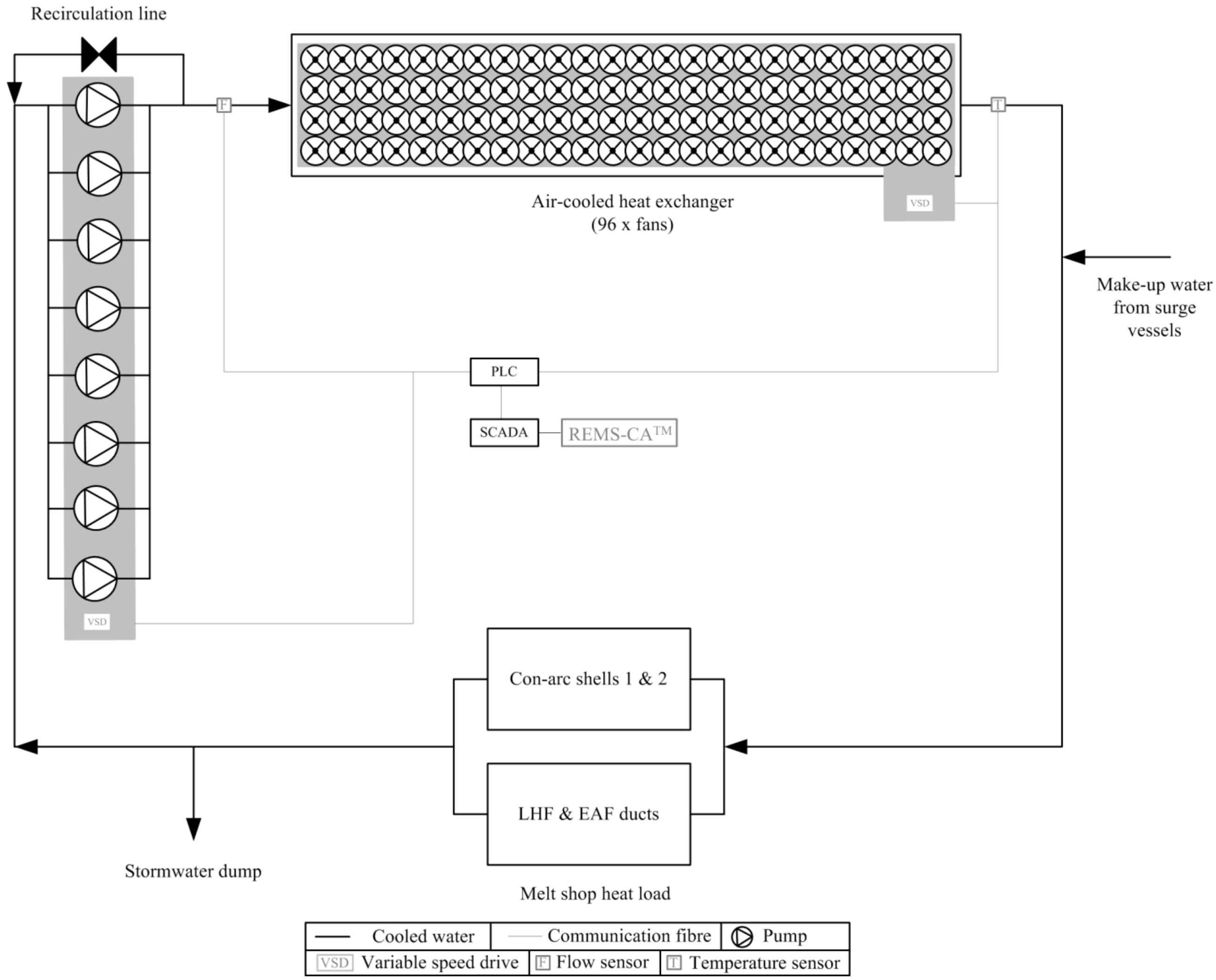

Figure 128 Saldanha Steel cooling system layout

Figure 128 shows that the system consists of eight water pumps and an air-cooled heat exchanger (ACHE) with 96 fans. Demineralised water is pumped through the dry cooling tower system to supply cold water to the melt shop at a constant pressure. The cold water is distributed through various manifolds to cooling jackets of the continuous arc furnace (con-arc), ladle heat furnace (LHF) and electric arc furnace (EAF). The hot water is returned directly to the cooling tower system in a closed-loop configuration.

The present system specifications and set points are outlined in Table 40.

Table 40 Saldanha Steel cooling system specifications

Water flow rate (ℓ/s)	2 000
Water temperature at ACHE inlet (ºC)	43-50
Water temperature at ACHE outlet (ºC)	37-44
Water temperature rise across heat load (ºC)	6
Average thermal load (kW)	50 000
Water temperature limit at heat load (ºC)	50
Water pressure set point before heat load (kPa)	750
Number of pumps	8
Pump power rating (kW)	285
Number of ACHE fans	96
ACHE fan power rating (kW)	37

Proposed strategies

The heat load from the melt shop is constant and there are no working shifts that cause part-load conditions. There is a limit on the water temperature in the con-arc shells of about 50 ºC. This is because higher temperatures cause hot spots in certain parts of the shell, which leads to the furnace tripping. The water flow rate required currently is therefore constant. There is also significant recirculation of water to achieve the required flow rate. The fans are controlled in groups of four and are constantly running throughout the day. The pump system continually consumes 1 425 kW (30% of the total system) and the fans 3 404 kW (70% of the total system).

It is proposed that the developed DSM strategy be adapted as shown in Table 41.

Table 41 Variable-flow strategies proposed for Saldanha Steel

Strategy	Set point
1. Water flow control	
- Install a VSD on each water supply pump	-
- Close the recirculation valve and modulate flows to maintain the specified water flow rate required at the melt shop	2 000 ℓ/s
2. Air flow control	
- Install a VSD on each group of four ACHE fans.	-
- Modulate the air flow of the ACHE to maintain the required ACHE outlet water temperature at all times.	45 ºC

Pump energy savings will be realised by eliminating valve control as suggested. Fan energy savings will be realised by making use of ambient condition partial loads to reduce power input at times when ambient dry-bulb temperatures are low. The present method of constantly running fans and an outlet water temperature varying according to the ambient profile will be changed to one in which the water temperature stays constantly but acceptably high while the fan speeds modulate.

VSDs will need to be installed on the fans and pumps, indicating that similar equipment will be required as for the mine systems. The monitoring and reporting functionality will remain the same since the steel plant uses the same network principles as found on mines. The hierarchical control principles will also remain unchanged since the PLC network is integrated similarly to that in the mine. REMS-CA™ can also be adapted to optimally change set points while taking into account relevant influencing factors such as furnace operation times, wind speed and wind direction.

Potential savings

Figure 129 shows the average daily power profiles of the Saldanha Steel cooling system. The baseline represents the present system operation, while the proposed profile was obtained from simulation results using the adapted simulation model used in this study, customised to include an ACHE.

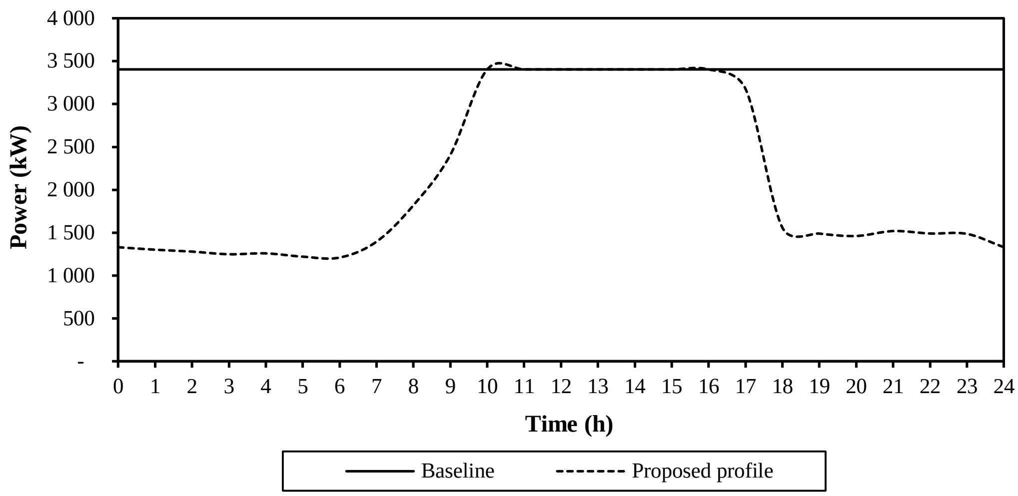

Figure 129 Potential average daily power profile of the Saldanha Steel cooling system

Figure 129 clearly indicates the proposed profile following the average ambient temperature profile, effectively realising part-load savings. The savings is season-dependent and higher savings can be expected in winter, given that the set point of 45 ºC is maintained. The average annual saving predicted is 1 300 kW, or 38.2% of the baseline power usage.

It is estimated that the installation costs will be around R4 000 000. The annualised energy costs will be R4 069 180, resulting in a simple payback period of one year. This indicates economic viability as before.

It is thus concluded that it should be viable to extend the developed strategy and energy management to large cooling systems outside the mining industry. The benefits of VSD installations, partial load flow control and centralised energy management have been proven on the mine cooling systems and also show potential for the investigated Saldanha Steel cooling system.

Industrial open-circuit wet cooling tower systems are commonly found where it is less critical to maintain high water quality and make-up water is readily available. Examples are found in electricity generation, petroleum, chemical and most manufacturing environments (BAC 2012). The expansion of the developed energy management system to these systems will be similar to the adaptation described for air-cooled heat exchangers. Additional optimisation parameters might include the cooling tower supply-water pressure and process-dependent requirements. Further customisations will depend on site-specific control network structures. These are not expected to be significant because most industrial plants operate with SCADA and PLC networks similar to those found on mines (Control Systems Integration 2012).

9.6 Conclusion

The variable water flow strategy and energy management system that was developed and validated on the Kusasalethu surface cooling system was also implemented on the cooling systems of Kopanang, South Deep South Shaft and South Deep Twin Shaft. Further potential application to the Saldanha Steel cooling system was also considered. The key results were discussed and are summarised in Table 42.

Table 42 Summary of key results of variable-flow strategy application

Case study	Kusasalethu	Kopanang	South Deep South Shaft	South Deep Twin Shaft	Saldanha Steel (simulated)
Baseline power (kW)	7 361	5 877	2 070	3 394	3 404
Power after implementation (kW)	4 752	4 012	1 464	2 245	2 104
Average power saving (kW)	2 609	1 865	606	1 149	1 300
Average power saving (%)	35.4	31.7	29.3	33.8	38.2
Payback period (months)	7	10	17	5	12

It can be seen from Table 42 that significant savings were realised on all case study large cooling systems. On average, a saving of **33.3%** was realised for the four case study systems. This shows that the developed variable-flow strategy and energy management system can effectively be customised for a variety of cooling systems and realise cost-effective energy savings. The potential application on Saldanha Steel also showed that the strategy could be extended to realise energy savings on other industrial cooling systems.

For all the case studies considered, it was shown that the critical service delivery requirements such as chilled water temperature, water volumes and shaft wet-bulb temperatures remained within specified limits.

It can be concluded that the versatility of the newly developed variable water flow strategy and the energy management system to implement it was shown in a large context. The *in situ* implementation results of three cooling system case studies with different layouts were considered in addition to the primary case study of this thesis. The potential to extend the strategy to non-mining large cooling systems was also shown.