REFRIGERATION AND VENTILATION DESIGN FOR THE DEEPENING OF MINDOLA COPPER MINE

D. O. del Castillo (Hatch, South Africa),
M. Biffi (Prysm Resources, South Africa),
M. Dawborn (Hatch, South Africa),
D. Noort (Mopani Copper Mines plc, Zambia)

This paper was originally presented at the North American/9th US Ventilation Symposium, June 2002, Kingston, Ontario, Canada. Reprinted with permission of the publishers, A.A. Balkema Publishers, Rotterdam, Netherlands.

ABSTRACT: This paper is a study of the ventilation, cooling and refrigeration system design of the Mindola copper mine in Zambia. The challenges that were addressed varied from the restrictions imposed by an ageing infrastructure to the requirement for increasing the annual production rate, coupled to the introduction of a higher level of mechanization while maintaining acceptable conditions and limiting total ownership costs. A description of how the ventilation, refrigeration and cooling systems were modelled in order to obtain the projected heat loads associated with two different mining methods over the life of the project. The methodology included a number of iterations to optimise the design and include aspects such as the expected inrush of hot fissure water, the operation of diesel machinery at depths in excess of 1500m below surface, developing a cost-efficient cooling strategy and selection of the refrigeration machinery to meet the requirements imposed by the cooling strategy. This paper demonstrates the successful implementation of an integrated design approach.

1 INTRODUCTION

This paper describes the process followed and results obtained during the study of the ventilation cooling and refrigeration systems for the expansion of the Mindola Copper mine in the Kitwe District in Zambia. The Mindola Copper Mine is part of the Nkana Division of the Mopani Copper Mines plc. The mine has been in operation for over fifty years and presently produces approximately 1.8 Mt/year of copper ore from a depth of approximately 1300 m below surface. Production is to be increased within the next three years and expanded to the lower portion of the ore body. This implies a tonnage production increase to 2.5 Mt/year from a depth of 1 550 m below surface.

The mining method presently employed at Mindola consists of a down-dip vertical crater retreat method without the use of backfill. This mining method requires extensive haulage development consisting of a haulage used for transport, a drill drive, a ventilation drive and a crown drive per retreat. The study described in this paper was aimed at comparing a modified version of this mining method with an up-dip mining method using backfill.

A guiding criterion for the study was to minimise total ownership costs for this new venture termed the "Mindola at Depth" project. In order to achieve this, maximum utilization of the existing infrastructure would be considered desirable so as to reduce the capital expenditure. On the other hand, the operation of existing and outdated system components would have to be considered carefully so as not to penalise the overall operational costs of the project. In order to strike this balance, a careful assessment was made of the existing infrastructure though mine site visits, review of documents and plans and interviewing of mine personnel in the mining, engineering, ventilation, planning and survey disciplines. This was complemented with a detailed analysis of various ventilation, cooling and refrigeration system planning exercises that were conducted in the last decade. Finally, a new mine model was prepared and studied in terms of the various ventilation, cooling and refrigeration system requirements, performance parameters and corresponding ownership costs over the life of the project.

The main objective of the study was to design an optimised ventilation, cooling and refrigeration system for each mining method that would ensure that the proposed design targets would be met with the minimum capital and operating expenditure.

2 SYSTEM DESIGN PARAMETERS

The performance of the ventilation cooling and refrigeration systems would be regulated to generate an acceptable environment. A number of different aspects were considered in order to define acceptable design and performance criteria.

2.1 TEMPERATURE LIMITS

The guiding principle in defining the thermal operational parameters of a mine environmental control system is the wet-bulb temperature. An analysis of practices in Southern Africa indicated that a design maximum wet-bulb temperature of 29±1°C would be acceptable to minimise the statistical risk of heat stroke mortality within a screened and acclimatised workforce.

2.2 COOLING POWER

The concept of air-cooling power was considered as a pragmatic alternative to the wet-bulb temperature considering the very unforgiving margins offered by the temperature as the sole parameter. In particular, the effect of instantaneous conditions occurring in a freshly blasted end in the presence of fissure water and being occupied by a diesel-powered loader would result in instantaneous wet-bulb temperatures in excess of the design limit, but with acceptable air-cooling power as a result of the air velocity in the haulage. Having considered this, together with the need to limit cooling system expansion costs, it was decided to aim for a cooling power of 300 W/m² as a minimum environmental acceptance criterion. Table 1 below shows wet-bulb temperature and air velocity conditions equivalent to an air-cooling power of 300 W/m². The table is the A-scale cooling power version for acclimatised men.

Table 1. Conditions equivalent to an air-cooling power of 300 W/m² (A-scale)

Wet-bulb temperature (ºC)	Air speed (m/s)
28.0	0.77
28.5	0.95
29.0	1.18
29.5	1.50
30.0	1.99

2.3 AIR QUALITY CONSIDERATIONS

Another important aspect considered in the design of the ventilation system performance was the adequate dilution of dust and gas emissions from diesel equipment. For the Mindola at Depth project, a principle decision was made to continue using diesel-powered loaders and ancillary vehicles. This meant that the advantage of electrically powered equipment usage in terms of reduced heat energy emission and exhaust fume generation could not be exploited.

Historically Mindola has used a figure of 0.05 m³/s per kilowatt of rated power for the dilution of exhaust gases. This dilution factor has been found to be adequate to ensure that current legislated maximum levels of CO and NO_x concentrations are not exceeded in places where diesel units are operated and in the general atmosphere. It may be argued that in view of diesel particulate dilution requirements, this factor may have to be increased. However a detailed analysis of development end conditions in the interim phase from the present to the final commissioning of the refrigeration and cooling systems indicated that a minimum of 30 m³/s of air should be made available to each end to ensure adequate heat energy absorption within the proposed temperature parameters. Considering the proposed ventilation layout, the power rating of the equipment on any level and its utilization, the effective exhaust fume dilution factor for each end or stope would be of the order of 0.2 m³/s per kilowatt rated power.

2.4 WATER USAGE AND FISSURE WATER

The proposed mechanised mining methods will not lead to the extensive use of service water. Therefore, it will not have a marked benefit on conditions at the face. For this reason, the final design proposal for the refrigeration plants does not provide for the generation of chilled service water. In the modelling of the Mindola at Depth project, it was assumed that the service water would be distributed from surface and would reach the working places at an average temperature of 24°C.

The ingress of fissure water into the mine will have, however, a more marked effect. The fissure water is assumed to enter the mine at the virgin rock temperature (VRT) corresponding to the depth of the excavation below surface. Measurements of rock temperatures taken at Mindola over a number of years, and as recently as 1999, indicate that the rock temperature gradient is equivalent to:

$$T_y = 0.01673y + 26.4 \qquad (1)$$

where T_y = is the rock, and hence the fissure water, temperature (ºC) at a depth of y meters below surface.

The beneficial effect of backfill proposed in the new up-dip mining method is evident here. Presently, in the down-dip method, the deterioration of the hangingwall during stoping operations leads to the exposure of sizeable aquifers located in the hanging strata. This results in ingress of water at a rate of approximately 0.4 tons of fissure water per ton mined. This water invariably flows into the draw-points and into the transport haulages deteriorating environmental and road conditions. In the layout proposed for the up-dip mining method, the use of backfill would reduce the hangingwall damage and thus prevent exposure of the major water aquifers, thereby reducing the ingress of water from the worked-out stopes. The reduction in fissure water ingress has been included in the simulations by using a figure of 0.1 tons of water for each ton mined in the up-dip method. The estimated water ingress figures have been derived from separate geological reports commissioned by the mine.

3 ANALYSIS

In the first phase of the analysis, information was gathered, surface and underground infrastructure were visited and interviews were held with mine staff directly involved in this project.

Presently, mining operations extend between 3920 and 4440 levels. The mine is faced with a number of options to increase tonnage production from the deeper parts of the ore body. One option would be to continue with the present down-dip method with slight modifications. This would require mining the ore body from 4440 level, the upper horizon of the new section, downwards towards 5220 level that delineates the lower limit of this extension. This implies that mining would start form the upper section of the un-mined ore body downwards.
The alternative to this would be the up-dip mining of the lower levels first gradually moving upwards from 5220 level towards the 4440 level. In order to accomplish this, the use of backfill would be necessary to fill the lower, mined-out cavities and thus form a platform for the upward mining of the rest of the ore body.

3.1 METEOROLOGICAL CONDITIONS

Climatic data spanning from May 2000 to April 2001 was obtained from the Ndola Airport Meteorological Department about 65km from the mine. It was noted that the maximum daily temperature occurs between 14:00 and 15:00 and the minimum between 04:00 and 05:00. These conditions were used in the design of the surface refrigeration plant's condenser cooling towers and in considering the feasibility of cold water storage during the off-shift period to reduce operational costs.

The analysis of this data showed that the daily variation in relative humidity and dry-bulb temperature precluded the use of this strategy for cold-water thermal storage.

3.2 VENTILATION SYSTEM - FANS

Presently, the mine is ventilated through the action of three surface fans namely V5, V9 and V10. Fan V5 is located roughly in the centre of the mine and handles about 220 m^3/s of air. The fan has an axial flow configuration with a bifurcated discharge. Fan V9 is also an axial flow unit with bifurcated discharge. It handles about 200 m^3/s of air mainly from the northern areas of the mine. Fan V10 is a centrifugal fan that handles about 150 m^3/s of air from the southern areas of the mine. In total, the upcast quantity is presently in the region of 570 m^3/s.

Studies performed in recent years have indicated that the deepening of this operation would require the replacement of fans V5 and V9 since they have come to the end of their economic life, require extensive refurbishment and cannot deliver the required air power necessary for the envisaged extension. Fan V10 will require a new motor in order to improve its performance to the required levels.

In terms of the ventilation analysis of this work, the operating points for these fans were to be established in terms of the latest expansion plans.

3.3 VENTILATION SYSTEM - AIRWAYS

The air is drawn into the mine through two downcast shafts in close proximity to each other. No. 1 shaft is a rectangular shaft 4.2 m x 6.1 m and is used to convey men and materials between surface and 2880 level, which is the main platform level connecting the surface shaft complex with the sub-vertical shaft. A shaft station on 2630 level is also available to convey air to the sub-vertical shaft. The No.2 shaft is a circular shaft 7.3 m in diameter used for the hoisting of rock by means of skips travelling along rope guides. An air duct has been provided on surface at No.2 shaft, which could be utilised in the installation of a bulk air cooler.

The air in the two downcast shafts is drawn to the No. 1 sub-vertical shaft in parallel along 2630 and 2880 levels. The hoist chamber for the Koepe winder unit at the top of the sub-vertical shaft is located on 2630 level. A two-stage spray chamber is located in the drive connecting No.2 shaft and the sub-vertical shaft on 2630 level. Inter-connecting haulages link this to the drive between No.1 shaft and the sub-vertical shaft on this level.

A refrigeration plant located on 2880 level generates chilled water for the 2630 level spray chamber. This plant consists of five centrifugal water chillers with an installed cooling capacity of about 7 MW of refrigeration.

Air flows into the sub-vertical shaft on 2630 and 2880 levels. The shaft has a diameter of 7.8 m and extends to 5720 level, about 1 740 m below surface, where the VRT is in excess of 55°C.

The air in the sub-vertical shaft is drawn along each level and though ramps, travelling ways and boreholes to the working places. Once utilised, the air returns through a network of boreholes to the V5, V9 and V10 return airway systems, which are linked on the lower levels. The air in the V5 return airway system is coursed through a vertical cooling tower serving the 2880 level refrigeration plant, where the heat energy absorbed by the condensers of the underground refrigeration plant is rejected.

3.4 SOLUTION METHODOLOGY

In the second phase of the analysis, the information gathered was elaborated, models were designed and structured and solutions optimised.

After having fixed the target design parameters, and performed an analysis of the present situation, it was decided to look at a number of options in terms of feasible cooling strategies that could be adopted in the final design. Each option had to be replicated for the two mining methods. To accomplish this, simulation models were constructed and various runs were performed using the Environ 2.5 steady-state computer program. These yielded a series of solutions that outlined the different heat loads, cooling loads and air power requirements.

This was followed by a detailed equipment selection and costing of both the capital and operational costs for each alternative.

The guiding principles used in proposing each option were:

- *Maximising the use of the existing infrastructure.*
- *Minimising capital requirements for new equipment.*
- *Ensuring that plant equipment would be compatible with standard units commercially available.*
- *Ensuring that different types of equipment would be able to operate within the parameters generated by the computer simulations and that these would meet the standard operational specifications.*

4 FINDINGS

4.1 AIRWAYS

The simulations indicated that the amount of downcast air required would be in the region of 820 m³/s. This compared favourably with studies performed in the past. However, the capacity of the airway systems would have to be increased to reduce the air frictional resistance.

The first restriction occurs in the upper portion of the sub-vertical shaft. One of the underlying principles to the proposed cooling strategy was to maximise the air quantity reaching the working faces (see below). In order to achieve this, all available air must be drawn from surface into the sub-vertical shaft from No.1 and No.2 shafts. Additional downcast airways are required from 2880 level to 4440 level. Enlarging the cross-sectional area of existing raise boreholes between these two levels would be sufficient to reduce the resistance adequately.

Another problematic area identified was the integrity of the return airways on the abandoned upper levels. These need to be accessed and maintained on a regular basis to ensure that deterioration does not affect the capacity of the airway network.
In addition in order to maximise the airflow below the 2880 level, leakages in airways in the No.1 and No.2 shaft systems must be eliminated.

In order to maximise the benefit of surface bulk air-cooling, together with the use of an upgraded underground two-stage spray chamber on 2630 level (see below), the downcast air stream in the No.1 and No.2 shaft should be isolated from each other. The surface infrastructure allows for the construction of a bulk air cooler at the entrance to the No.2 shaft's air duct. This means that a large proportion of the downcast air would reach 2630 level at a temperature close to 19°C as opposed to 24°C (without cooling). Environ simulations showed that separating the two streams and cooling the air drawn through the No.1 Shaft in the 2630 spray chamber would maximise the heat absorption capacity of the downcast.

4.2 HEAT LOAD CONSIDERATIONS

The heat load variations were analysed for each simulated option. The major heat load contributors were found to be haulages and the production areas.

The heat energy absorption in the haulages is typical for operations where the temperature difference between the rock and the air is considerable. Where conditions in the haulages reach extreme temperatures, this may be offset by the installation of localised coolers that are expensive and require continual maintenance. In the case of Mindola, simulations using centralised cooling on surface and on 2630 level yielded acceptable wet-bulb temperature profiles throughout. The option of using localised coolers was therefore discarded.

In the production areas, the temperature increase was found to be more problematic. The operation of diesel-powered equipment, the emission of hot fissure water and the handling of freshly blasted ore at a temperature often exceeding 50°C resulted in rapid heat energy absorption, both in terms of sensible and latent heat. This resulted in the wet-bulb temperature exceeding the 29°C target. The use of localised cooling coils was considered but given the logistics, costs and practical considerations, this approach was found not to be suited for these conditions. As an alternative, the amount of air used in each production section was maximised and the concept of cooling power used as an alternative target condition. The advantage of using this parameter is that consideration is made of the heat absorption capacity of cold air moving at a high velocity over the human body. Figure 1 below shows the heat load components for selected options.

4.3 COOLING STRATEGIES

Presently some of the air downcasting through No.1 and No.2 shafts and moving along the 2630 haulage is cooled as it passes though the two-stage spray chamber. The amount of cooling is dependant on the air quantity though the chamber and the temperature and amount of water available from the refrigeration plant on 2880 level. As mentioned above, in order to make use of all of the available cooling power in the system, the use of the 2630 level spray chamber in conjunction with the underground refrigeration plant on 2880 level was considered to be a valuable starting point, particularly if the positional efficiency of coolers was to be maximised. A number of possible cooling strategies were considered.

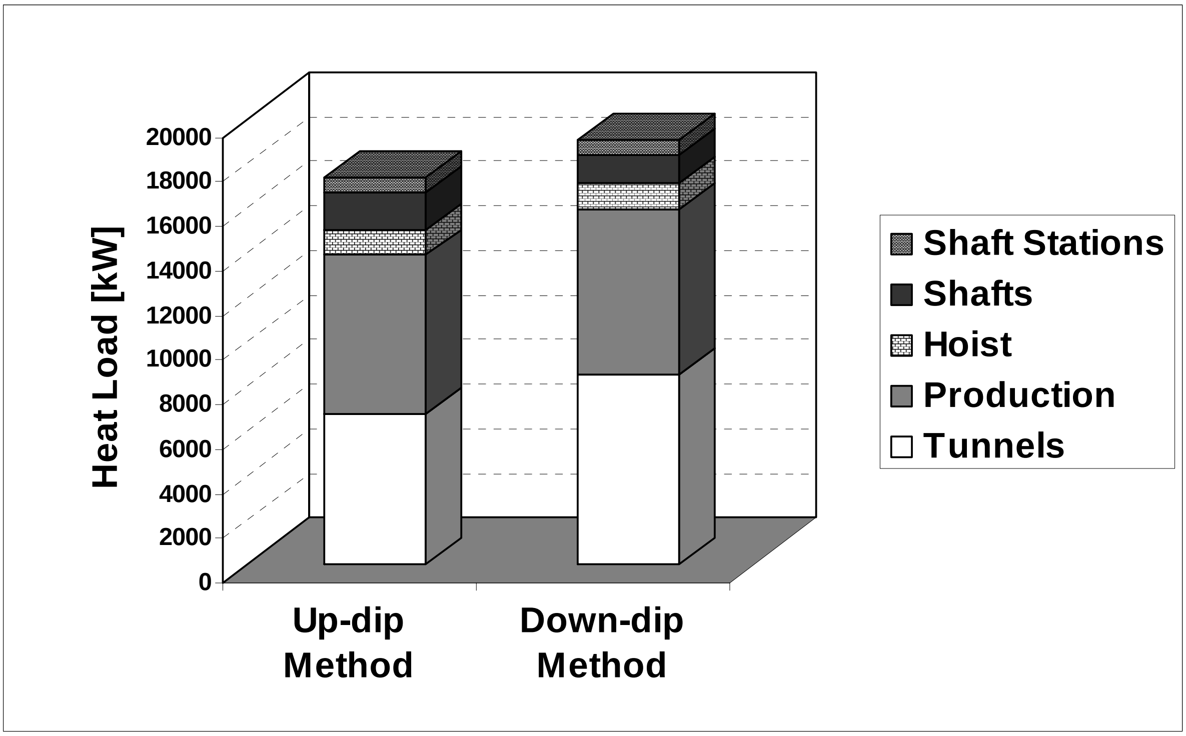

Figure 1. Heat load components for up-dip and down-dip options.

Details of the cooling strategies considered in this study are presented in Table 2, which indicates the cooling loads that may be absorbed using three different cooling strategies and various combinations of these.

The first and most obvious option (option A) consists in using the underground refrigeration plant on 2880 level to provide cooling to the spray chamber on 2630 level. A second alternative considered (option B) was to increase the capacity of the 2880 level refrigeration plant and distribute the additional cooling power in a closed-loop fashion to coils located in the main crosscut to lode on each level just prior to these splitting into the north and south haulages. The third basic option (option C) would be to augment the cooling load by adding a surface bulk air cooler linked to a dedicated surface refrigeration plant. The remaining options are variations obtained by altering the capacities of the coolers.

The application of these cooling strategies had an effect on the air distribution model in that the various air densities would be affected and would alter the overall air power in a small measure. However, the most significant links between the cooling strategies and the airflow were:

– *The availability of heat rejection capacity in the V5 return airway system. It was assumed initially that the extension of this would not be feasible in terms of infrastructure and cost.*
– *The enthalpy difference between the air entering the air coolers and the water should be large enough to promote the heat energy exchange mechanism effectively.*

Table 2. Summary of cooling strategies considered *

Option	From 2880 level refrigeration plant		From surface refrigeration plant	Total air-cooling capacity
	2630 Level spray chambers	Cooling coils		
	(kW)	(kW)	(kW)	(kW)
A	3 200	0	0	3 200
B	3 200	4 000	0	7 200
D	3 200	4 000	15 360	22 560
D	0	0	30 000	30 000
E	3 200	1 500	15 360	20 060
F	3 200	1 500	16 250	20 950
G	4 800	0	15 360	20 160
H	4 800	0	16 250	21 050
I	6 300	0	15 360	21 660
J	6 300	0	16 250	22 250
K	6 300	1 500	15 360	23 160
K1	3 800	4 000	15 360	23 160

** Capacities shown in the table are not refrigeration machine duties but represent net air-cooling duties.*

Figure 2 shows the results of the various runs in terms of the cooling power ranges calculated for each development drive and stope.

A selection process followed whereby each of the above options was analysed and a first order of magnitude cost assigned. Issues regarding equipment suitability, additional infrastructure requirements and various risk aspects were also considered to arrive at a final selection.

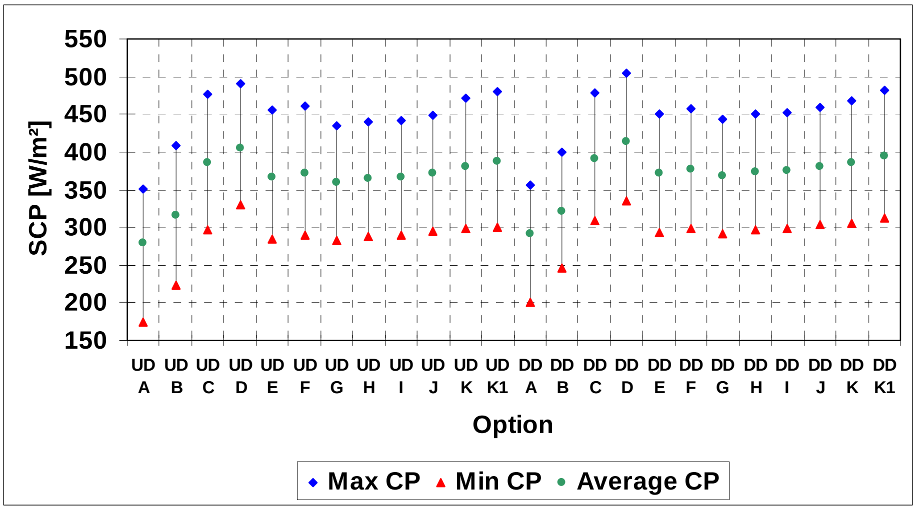

Figure 2. Air-cooling power ranges.

The final cooling strategy selection indicated that options G, H, I and J would be best suited for both the up-dip and down-dip scenarios. Details of the simulated wet-bulb temperature ranges for the development ends and stoping sites are shown in Figure 3.

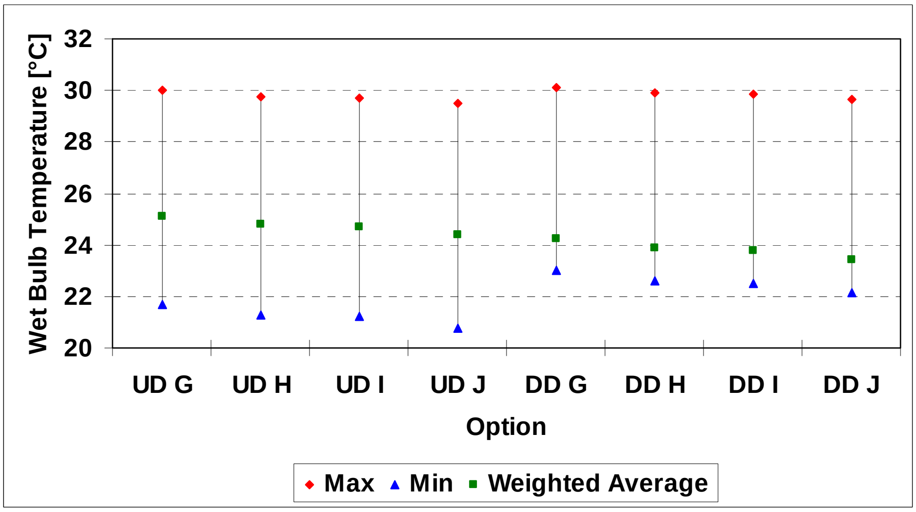

Figure 3. Wet-bulb temperature variations for options G, H, I and J.

4.4 REFRIGERATION AND COOLING OPTIMISATION

It became clear from the onset of this investigation that it was best not to install all the cooling on surface given the fact that some infrastructure already existed underground, though some of it would become redundant because of ageing (like the refrigeration machines) and some upgrading of equipment would be required (like the existing condenser cooling tower).

The size of the existing air duct at No.2 shaft is such that a maximum air mass flow of 350 kg/s can be introduced via a bulk air cooler without having to break into the existing shaft by enlarging the duct. It was felt that, due to the prevalent soil conditions and the cost associated with the enlargement, it was best to limit the air capacity of the surface bulk air cooler to 350 kg/s.

The duty selection of the refrigeration machines is higher than the duty of the coolers themselves. This is to allow for 5% accuracy in the supplier's prediction of the compressors' thermal capacities (which is the normal tolerance specified by most suppliers), wear and tear and to allow for losses in the water circuits.

Once all the options shown in Table 2 were assigned a first order of magnitude cost and it became apparent which options were the ones that required further investigation, options G, H, I and J were priced in detail for both capital and operating costs. A 15% (or better) level of confidence was achieved in the costing exercise.

Given the level of accuracy in pricing the infrastructure, the difference in cost of ownership between options H and I was negligible, whereas option G was the cheapest overall and option J the most expensive. The recommended option in the end was option I because it would make full use of the existing underground spray chamber and would give some extra spare cooling capacity. The difference in ownership cost between the cheapest option (G) and the most expensive one (J) was about 5%. The life of the project is 15 years.

4.5 COOLING EQUIPMENT (OPTION I)

4.5.1 Surface Cooling Plant at No.2 Shaft

It was proposed to have a surface refrigeration plant, with a capacity of 17 080 kW of refrigeration, to feed a two-cell bulk air cooler in a closed circuit.

The bulk air cooler conditions 350 kg/s of air from 22ºC to 8.1ºC wet-bulb temperature, with a cooling duty of 15 360 kW. The mixed temperature in the shaft is 16.7ºC.

Two ammonia refrigeration machines were proposed, operating in parallel on the chilled water side. Each machine would consist of two screw compressors operating in parallel, but drawing and delivering the ammonia refrigerant to single evaporator and condenser plate heat exchangers. Each individual compressor would be equipped with its own dedicated oil separator, which will greatly improve the part-load operation of the machines.

4.5.2 Underground Cooling Plant on 2880 Level

It was proposed that the five existing refrigeration machines be replaced due to ageing. The replacement would be two new 3 800 kW centrifugal refrigeration machines. The machines would be single-stage taking advantage of the reasonably low wet-bulb temperature of the air available for heat rejection. The new machines would operate with refrigerant R-134a, which is an ozone friendly refrigerant.

The existing condenser cooling tower is big enough for the proposed duty and would only require a fill and nozzles change.

The two-stage spray chamber on 2630 level would be re-used, delivering its full nominal design capacity of 6 300 kW of cooling. The spray chamber would operate in a closed loop with the refrigeration machines. It is expected that under certain conditions the design duty of the cooler could be exceeded, which explains the relatively high specified duty of the refrigeration machines.

The two existing hot and cold storage dams on 2880 level would also be re-used. The hot dam collects the water that gravitates via two boreholes from the spray chamber. The cold dam stores the cold water from the refrigeration machines, from where it is pumped to the spray chamber by high-lift pumps.

4.6 MAIN FAN ANALYSIS

Once the cooling strategy and system performance were narrowed-down to a small number of possibilities for each method, the main fan selection was made. The design, age and conditions of the fans is such that two new units would have to be purchased while the motor of the third unit would be up-rated. The replacement option was viewed favourably in view of a planned mine life of at least fifteen years.

It was proposed that each fan (V5 and V9) be replaced by two centrifugal fans operating in parallel. This decision was made considering the principle that the movement of air through the mine would maintain conditions within acceptable limits and the loss of a whole fan unit over extended periods of time could have serious repercussions on production. By using two fans in parallel the failure of one would result in the loss of less than half of the total upcast quantity for that fan station, thus allowing for some degree of redundancy. In particular, fan V5 has is the only means providing heat energy rejection capacity for the 2880 level refrigeration plant. It is therefore crucial to keep this unit running at all times during mining operations. Table 3 details the main fan selection for the down-dip method.

Table 3. Main fan duty points

Fan	No. Off	Air Quantity (m^3/s)	Pressure (Pa)	Density (kg/m^3)
V5	2	135	6400	0.99
V9	2	150	4000	0.95
V10	1	250	6200	0.96

4.7 RISK ANALYSIS

In view of the high VRT gradient, a short analysis was performed to establish the effect of stopping one of the surface fans. This analysis was carried out by monitoring the wet-bulb temperature and air-cooling power variations using the Environ 2.5 models. The study, performed for peak summer weather conditions, indicated that the operation of the V5 surface fan is most critical as it affects the operation of the underground bulk air cooler directly. The stoppage of the other two fans results in less severe conditions as long as all the bulk air-cooling is available. Table 4 below shows the effect that the stoppage of each fan on conditions. In the event of multiple surface fan failure, the evacuation of the mine of parts of it is recommended until mine management performs a proper and suitable risk assessment.

In addition, the risk of operating a surface ammonia refrigeration plant was also assessed. In the final proposal, possible sites for this plant were suggested and due cognisance was taken of prevailing wind directions in consultation with the Ndola airport weather office. Also the location of formal and informal settlements in the close proximity of the mine was considered to limit the risk to the public.

4.8 SCHEDULE OF WORK

The final stage of the study was the production of a cost schedule for Mindola in order to guide the capital expenditure programme. This was achieved with due consideration of the simulated heat load increase in the period leading up to full production and ensuring that sections of the ventilation cooling and refrigeration systems are commissioned in time to meet the rising heat load demand. Figure 4 below shows the heat load profile superimposed on the cooling capacity available. The heat load profile follows the tonnage build-up very closely. In the "plateau' zones the heat load increases or decreases slightly depending on whether the down-dip or the up-dip method is considered respectively. The figure also indicates that long production tails can be wasteful as the maximum cooling demand ultimately dictates the capital cost of this aspect of the project. Once the information regarding production is finalised, the effect of high peaks and long tails should be analysed and smoothed-out in an effort to reduce overall ownership costs.

Table 4. Comparison of environmental conditions resulting from fan failure

Event	Down-dip method		Up-dip method	
	Highest wet-bulb temperature (°C)	Lowest air-cooling power (W/m²)	Highest wet-bulb temperature (°C)	Lowest air-cooling power (W/m²)
Normal Operation	30.2	292.2	30.0	282.9
V9 Stop	30.7	267.4	32.3	185.5
V10 Stop	32.2	212.1	30.5	261.0
V5 Stop	33.0	172.8	32.1	201.6

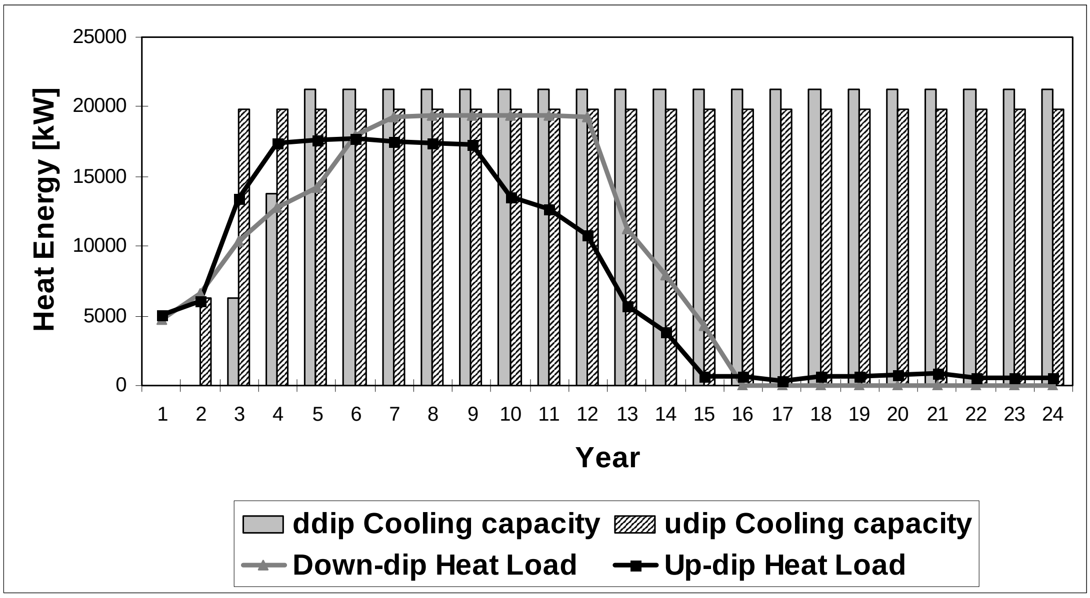

Figure 4. Heat load and cooling capacity profiles.

5 CONCLUSIONS

The analysis of the ventilation, cooling and refrigeration systems proposed for the expansion at the Mindola copper mine was performed using the Environ 2.5 software to establish airflow requirements and heat loads. The resulting models were compared and assessed in terms of a set of pre-defined acceptance criteria that included the definition of a maximum wet-bulb temperature of 29°C or a minimum cooling power of 300 W/m² (A-scale).

A number of cooling strategies were proposed and analysed for both up-dip and down-dip variations of the mining method. The size and type of refrigeration plants required were specified and selected.

The performance of the integrated system depends primarily on the availability of sufficient air to absorb the heat energy generated by mining operations and environmental conditions while maintaining adequate wet-bulb temperatures and levels of air-cooling power. To this end, the main fans and airway systems require upgrading and adequate maintenance.

As a result of these efforts, the capacity of the underground spray chamber and refrigeration plant may be maximised. This will result in a higher positional efficiency and in the reduction in the capacity of the surface refrigeration plant and bulk-air coolers.

Although risk certain hazards were investigated, more extensive analyses are required regarding the identification of hyper-heat intolerant workers, the risks and measures required in the event of malfunctions involving the surface ammonia plant and the protective measures designed to counter the effects of prolonged and extensive power failures.

The integration of the ventilation, cooling and refrigeration designs shown in this paper has resulted in a 40% reduction in effective capital expenditure from previous designs, even though the surface design wet-bulb temperature was increased from the original 21ºC to 22ºC.

This exercise has also shown the value of using an integrated approach in ensuring the completion of a comprehensive analysis of this design and in optimising the proposed solution.

ACKNOWLEDGEMENTS

The authors acknowledge the assistance of the management of Mindola mine and Mopani Copper plc in preparing this paper and express their gratitude for consenting to publish aspects of this study.

REFERENCES

Biffi, M. 2001. The Design of the Ventilation and Cooling Systems for the Mindola at Depth project. CSIR-Miningtek consultancy report EC 2001-0485.

Dawborn, M., Biffi, M. 2001. Ventilation and cooling options for the 5220 level development. Addendum to Hatch consultancy report project M0092.

Del Castillo, D., Dawborn, M., Biffi, M., 2001. Mindola at Depth: Ventilation & Refrigeration Study. Hatch consultancy report project M0092.