# VUMA MINE VENTILATION SOFTWARE

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## Introduction

Technological advances during the past few decades have brought new challenges to the international mining industry.  Research organisations worldwide are searching for new technologies to assist the mining industry to mine more safely and productively and to ensure high standards of worker health.  A world trend is the change from Contract Research Organisations [CRO] to Knowledge Intensive Technology Organisations [KITO], where industry becomes a research partner and where the focus is on, firstly, finding real life solutions and secondly, the transfer and implementation of technology.

An example of new technology developed to assist the mining industry is the VUMA suite of mine ventilation and cooling software, developed as a joint initiative by the Mining Technology Division [Miningtek], of the Council for Scientific and Industrial Research [CSIR] and Bluhm Burton Engineering [BBE].  This paper is an extended and updated version of a paper titled "VUMA - a mine ventilation and cooling network simulation tool" which was presented at the Seventh International Mine Ventilation Congress held in Poland during June 2001[1].  The current paper describes the need for such software, provides a brief overview of two programs in the suite and highlights the application and benefits of the VUMA software.  The two programs discussed are VUMA-network[®] and VUMA-transient[®].

## Need for Network Simulation Software

One of the disciplines that affects the well-being and profitability of the modern mining industry is that of mine underground ventilation control.  It is not surprising therefore that it has become essential for ventilation practitioners to plan and design ventilation and cooling systems to a high degree of accuracy.  These systems need to take modern mining methodologies into account as well as the costly infrastructures needed for future ventilation and cooling requirements.  To enable the practical and economical design of mine ventilation and cooling systems, ventilation practitioners need effective and modern tools.

Increasingly stringent standards are being set with regard to occupational health and safety.  In the mining industry, maximum allowable pollutant levels are being reduced, medical compensation levels have been increased, medical surveillance requirements are increasing, and standards regarding escape and rescue equipment are more stringent.  Furthermore, production rates have increased, mining depths are greater, mines are more mechanised and the network of excavations more extensive.  On the other hand, the majority of commodity prices are low and the mining of coal, gold, platinum, gemstones and base metals has become an extremely competitive business worldwide.

Given that the planning and design of underground ventilation control systems for future mines will require extensive optimisation, it will be necessary to evaluate a number of options and scenarios, not only for the ventilation systems, but also for overall design of mines.  Due to the

integrated and extended nature of high production mines, seemingly small changes in its design could have significant global effects on the underground ventilation control system.

Accordingly, the effects of any changes being considered would have to be evaluated in terms of the entire system, including both the mine layout and the design of its underground ventilation control system. Firstly, the mine layout must be conceptualised before the underground ventilation control system is designed to be appropriate and compatible with the mine layout. Subsequent refinements to the mine layout and the underground ventilation control system must be accurately simulated to ensure that the latter is efficient, safe and cost-effective.

Such a process would require numerous predictions for network conditions, system design and performance. It would be virtually impossible to make such predictions without simulation tools that are accurate and flexible enough to evaluate rapidly all possible options and scenarios.

The general practice in underground ventilation systems is to ventilate and cool 'all-mine-all-of-time'. Recent studies have shown that cyclical operation of cooling systems can benefit power management programmes. Stopping fans and pumps during the late afternoon coincides with the period for peak energy costs. In general, it was observed that this type of cyclical global air conditioning control would be feasible and economically justified, but for each specific site, there would be many details and specific risk assessments that would require attention. Another important transient scenario, which affects both fans and air coolers, is an emergency loss of power. In such an event, the mine will have areas where air temperatures or gas concentrations may be dangerously high. From a safety perspective, it is essential for mine management to be aware of such areas to enable the successful implementation of safety precautions. Another important eventuality to consider is the risk of underground fires. This requires that designs for escape and rescue systems should incorporate the findings of 'what-if' studies that use simulation software to enable the formulation of appropriate procedures and action plans. There is a need to simulate such variations in the airflow and temperature within the mine ventilation system.

# VUMA-Network: A new mine ventilation and cooling network simulation tool

The previous section discussed the challenges faced by mine ventilation control personnel and the need for an accurate network simulation tool. The VUMA-Network simulation program is specifically designed to assist underground ventilation control engineers and practitioners to plan, design and operate mine ventilation systems. VUMA-Network is an interactive 'Windows' program that allows for the simultaneous steady-state simulation of air flow, air thermodynamic behaviour and gas and dust emissions in an underground mine. The program caters for a wide variety of mining methods. A fundamental feature of VUMA-Network is the incorporation of user-friendly interfaces that allow simulation networks to be constructed and viewed graphically and what-if studies to be rapidly performed to determine optimal designs and system requirements.

Some of the other principles of operation are:

❑ Network consists of branches, starting and ending with nodes, and depicting network components such as shafts, tunnels, etc.

- ❑ Input data for branches is used to calculate the air pressure drop and air thermodynamic and contaminant level changes in a specific component of a network.
- ❑ Input data for nodes consists of the X, Y and Z co-ordinates, Barometric pressure [BP], Virgin Rock Temperature [VRT], and air temperatures. The BP, VRT and wet-bulb and dry-bulb temperatures only need to be set for the start-node as these parameters are calculated for other nodes throughout the rest of the network.
- ❑ Simulation networks are constructed in a two-dimensional [2-D] graphical editor on a level-by-level basis. Different levels are then interconnected, typically by shafts or declines.
- ❑ Network is viewed in 2-D format in either geometric, strike, or section view.
- ❑ Input data for each branch is entered in a specific input screen for that branch-type before a solution is obtained for airflow, contaminants and air thermodynamic properties.
- ❑ If only an airflow solution is required, only information relating to the geometry and air resistance characteristics of the branches need to be entered.
- ❑ Iterative network solution algorithms are used to solve for airflow, and updated heat flow models are used to calculate the air thermodynamic changes in each branch.
- ❑ VUMA-Network contains an extensive help function to assist with the development of a simulation model.
- ❑ Three-dimensional [3-D] graphical viewer is used to view the network in 3-D.
- ❑ In addition to the 2-D and 3-D graphics output display, results may be viewed in a tabular format.

The solver around which VUMA-Network is designed is the result of the development of both theoretical and empirical models that have been developed and verified by engineers and scientists at both BBE and CSIR Miningtek over a number of year's involvement in consultancy and research projects.

The VUMA 2-D Editor
The 2-D editor is used to construct and edit a network and to enter all the relevant data required to obtain a solution for the simulation. Figure 1 shows a geometric view of a level [top] and a section view of two levels of a small network [bottom].
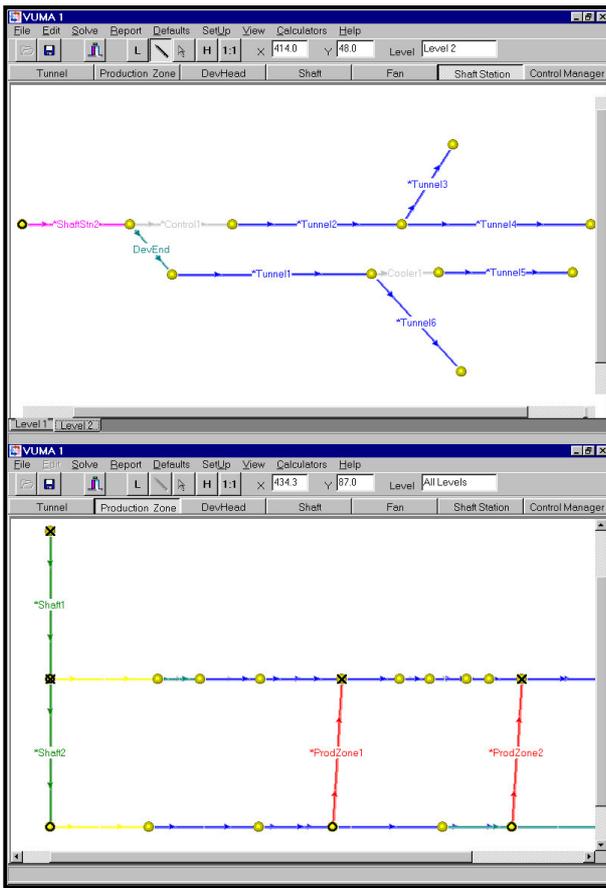
*Figure 1. VUMA-Network 2-D Editor*

From Figure 1 it can be seen that branches connecting two levels can only be seen in the section view and therefore both views are necessary to enter branch data.  A panning and zooming facility makes it easy to view large networks that span across multiple screens.

Libraries
Libraries are 'dynamic' catalogues, data tables and other information built into VUMA-Network. Libraries are designed to transfer information directly to the input forms and solver routines.  The program provides basic or typical data in each library but the user can add to or delete information from each library.  Libraries include:

❑   Rock property data
❑   Fan catalogues
❑   Mining equipment catalogues

Information contained in the mining equipment catalogue is shown in the Figure below.
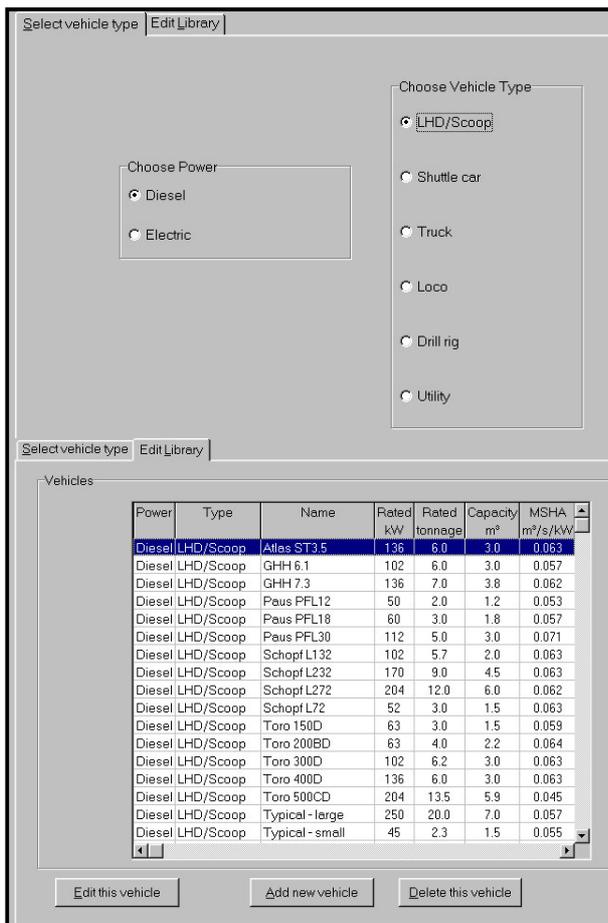
*Figure 2. VUMA Equipment Catalogue*

Rating Categories

The nature of mining is such that it is often impractical to define parameters in a fully quantitative manner. For these situations, VUMA has developed rating categories that allow for a consistent qualitative approach. Users are called to select from sets of VUMA rating categories at various points within the program.

For example, work cycles, load ratings, and/or utilisation descriptions of some elements of mining equipment are often difficult to quantify. The workloads of dump trucks, loaders, roadheaders, tunnel boring machines, continuous miners, locomotives, utility vehicles, winches, etc, vary significantly from operation to operation. The amount of heat and contaminants generated depend strongly on the load cycle of the machine [varying from idling to motor operating at the full rated capacity].

Because of the many different possible degrees of utilisation, the machine work cycles are qualified using VUMA rating categories ranging from heavy machine utilisation to idling. These are described below:

❑ Very heavy - machine working on heavy continuous full load rating, maximum inclines.
❑ Heavy - machine on heavy load, moderate inclines, regular use, carrying medium load.

- ❑ Typical - machine working on average load, moderate inclines, regular use, carrying medium load.
- ❑ Moderate - machine working on moderate load, gentle inclines, occasional use, carrying minimal load.
- ❑ Light - machine working on very light load, flat ground, infrequent use, carrying virtually no load.

Another factor, which has a significant influence on both the heat transfer and moisture transfer within a mine, is the amount of moisture present on rock surfaces. In VUMA-Network rock surface wetness, ratings give a qualitative measure of moisture distributed over the excavation surface. Because of the many different possible wetness scenarios and the difficulty of an accurate definition, rock surface wetness conditions are qualified using VUMA rating categories ranging from very dry to very wet. These are described below.

- ❑ Very dry - Surfaces very dry with no moisture at all.
- ❑ Dry - Surfaces generally dry but with very moderate moisture: generally about 5% to 15% of available perimeter moist.
- ❑ Moist - Surfaces generally moist with moisture clearly visible: generally about 15% to 40% of available perimeter moist.
- ❑ Wet - Surfaces generally wet with water in patches and moisture clearly visible: generally about 40% to 70% of available perimeter wet.
- ❑ Very wet - Surfaces very wet with water covering entire perimeter in shafts and lower part of perimeter in tunnels: about 70% to 100% of available perimeter fully wet.

Rating categories are also defined for:

- ❑ heat-moisture ratings
- ❑ duct leakage ratings
- ❑ rock cover [insulation] ratings
- ❑ ventilation bends and junction ratings
- ❑ pipe insulation ratings.
- ❑ inclination of development heading ratings

The 'help' function gives guidance to users on the selection of the applicable rating category in each of the above.

Calculators
There are currently two calculators available in the 2-D editor. They are a psychrometric calculator and an air cooler calculator. The following figure shows a view of both these calculators.
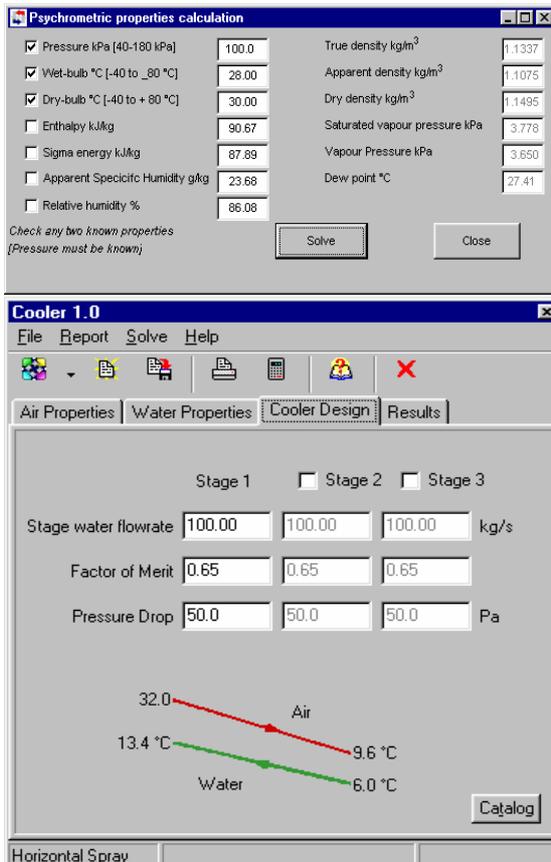
*Figure 3 - VUMA calculators*

These calculators can be activated at any stage during the construction or editing of a network and allow the user to determine various psychrometric properties [in the range -40 °C to 80 °C and 40 kPa to 180 kPa], and to determine the cooling duty of different air cooler configurations [direct or indirect contact, horizontal or vertical, spray or packing] under certain airflow and water flow conditions.

VUMA Branch-Types
The program includes branch-types representing all components making up an underground mine ventilation circuit. Input fields for branches are divided into Aero, Thermo and Contaminant categories as described below:

❑ **Aero** - aerodynamics and other parameters influencing air flow in a branch, such as shape, physical dimension [length, cross-section, and perimeter], and surface frictional resistance characteristic

❑ **Thermo** - thermodynamics and other parameters influencing heat flow in a branch, such as, the surrounding rock and equipment/activities within the branch. Factors influencing heat flow from the surrounding rock are the rock properties [density, conductivity, and specific heat capacity], age of the excavation, rock surface covering [shotcrete or insulation], and the surrounding VRT. Heat, or cooling, sources inside a branch are vehicles, equipment, drains, pipes, ducts, etc.

❑ **Contaminant** - parameters describing contaminant sources or sinks in the branch, such as filters or scrubbers.

As noted earlier, if the user is not interested in Thermo or contaminant solutions, only relevant Aero information need to be entered.

The following is a list of the branch-types in VUMA followed by a short description of each.

❑   Tunnel
❑   Production Zone
❑   Development Heading
❑   Shaft
❑   Fan
❑   Shaft Station
❑   Control Manager [all components not described by the above]

Tunnel

A tunnel or airway is the most commonly used branch in VUMA.  The following figure shows an input screen for a tunnel branch.
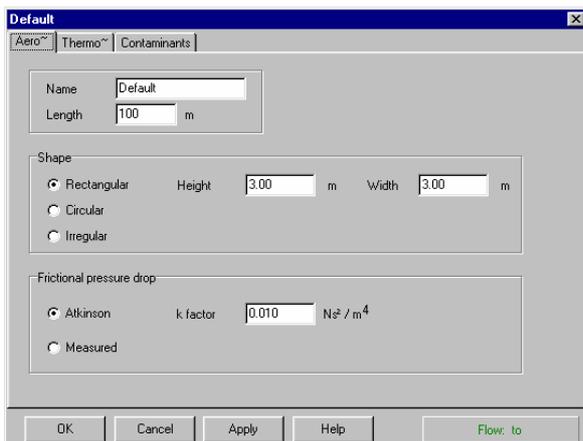


*Figure 4 – Tunnel input screen*

Production Zones

The production zone branch caters for the majority of mining types found in underground mining. Each of the mining types can be either a drill and blast operation or continuous mining.  Different variations of a broader mining type can also be selected.  The following mining types, with their derivatives, are available in VUMA[21]:

❑   Drift [and Fill]
❑   Benching/cutting [and Fill]
❑   Open Stoping
❑   Stope Shrinkage
❑   Vertical Crater Retreat
❑   Room and Pillar
❑   Colliery Longwall

□ Narrow Reef Stoping
   □ Single Sided Breast
   □ Double Sided Breast
   □ Updip
   □ Downdip

The input form for production zones includes a graphical representation of the specific zone. Figure 5 shows the input screen and corresponding production zone representation for a narrow reef-stoping configuration.
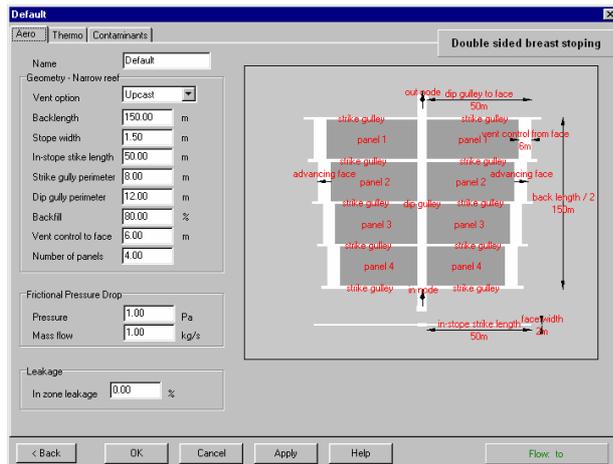


*Figure 5 – Narrow reef stoping input form*

Development Headings

As with production zones, the user has the option of simulating different heading types, based on the mining methods and/or machinery used. These are:

□ Drill & Blast
□ Road Header
□ Continuous Miner
□ Tunnel Boring Machine

Shafts

The input data for a shaft is similar to that of a tunnel.

Fans

Fan branches require the input of a fan curve. A fan catalogue is used to define or select fan curves for specific fans in VUMA. The solution engine takes the effects of a fan on both airflow and heat increase into account.

Shaft Stations

Due to the complexity of a shaft station area and the numerous excavations associated with the shaft area, a shaft station branch is used to simplify the total airflow, contaminant and heat flow effect on a network. The total length of excavation and major contaminant sources and heat loads such as pump chambers and workshops are simulated in this type of branch.

Control Manager

The control manager branch is used to simulate a host of air control, heat/cooling load and contaminant components. The following is a list of Aero options that can be selected in the VUMA control manager list:

- Leakage Paths
  - Specified Flow
  - Percentage of Flow
  - Fixed Resistance
  - Measured Flow & Pressure
- Regulators
  - User Defined Resistance
  - Fixed Flow
  - Fixed Pressure Difference
  - Measured Flow & Pressure
  - One way Flow [Door]
  - Duct Piece through Wall
  - Tunnel Reduced Area
- Bends
- Air Crossings
- Abrupt Contraction Losses
- Abrupt Enlargement Losses

Thermo options for a control manager branch are the following:

- Coolers
  - Fixed Duty
  - Fixed Outlet Condition
- Heaters
  - User Defined
  - General Equipment
  - Pump Station
  - Refrigeration Station
  - Hoists & Winders
  - Crushers
  - Auxiliary Fans
  - Substations

Contaminant options for a control manager branch are the following:

- Gas
  - Source
  - Sink [scrubber or filter]
- Dust
  - Source
  - Sink [scrubber or filter]

The input form for a dust scrubber is shown below.



*Figure 6 –Input form for a dust scrubber*

The regulator fixed flow branch may be used in place of a fan when building a new network. The resulting branch pressure increase and volume flow will specify the required fan's operating point.

Reporter
The report facility is used to view input and output data in tabular format. Data is sorted either for nodes and branches, or for different branch types. Reports can be printed or exported to a spreadsheet format. Once data tables are exported to a spreadsheet, the spreadsheet software can be used to manipulate the data.

Solver
Once a network is completed and all input data is entered, one of four solution methods can be selected. These are:

- Aero – Network airflow will be simulated.
- Aero & Thermo – Both airflow and heat flow will be simulated.
- Aero & Contaminants – Both airflow and contaminant concentrations will be simulated.
- Full Solution – Aero, Thermo and contaminants will be simulated.

In the case where a solution is not obtained, the program will highlight the branches and/or nodes where errors were found.

3-D Viewer

The 3-D viewer has two main functions, firstly to display graphically an entire network in 3-D format, and secondly to view results graphically. Several view options such as plan view, section/strike view, geometrical and diagrammatic can be selected. The geometric view is based on real co-ordinates whereas the diagrammatic view introduces an artificial level spacing to enhance visibility of levels.

When solved networks are viewed, results are displayed graphically by colouring nodes and/or branches in correspondence with a colour bar graph. The colour bar graph indicates the full range of values from minimum to maximum of the parameter being displayed at that stage.
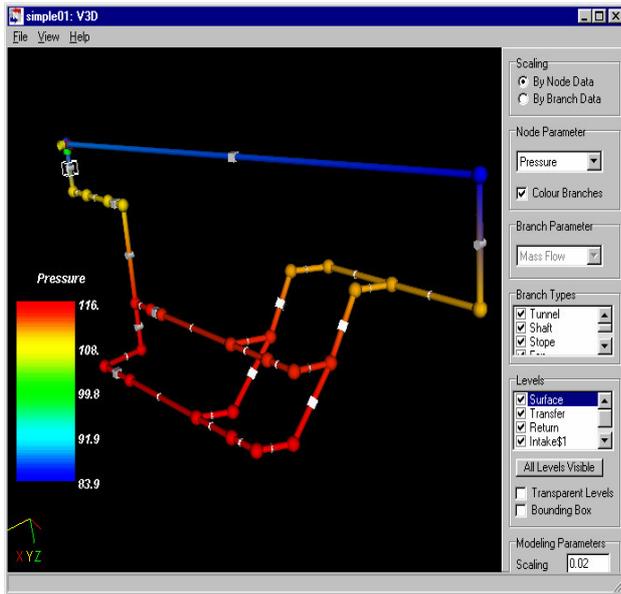


*Figure 7  - 3-D View of solved network*

Figure 7 shows the 3-D view of a solved network including the colour-coded bar graph on the left depicting the selected parameter [in this case barometric pressure] represented by the coloured codes. Different branch-types and levels can be switched on and off and the network on screen can be zoomed in and out, rotated and panned.

# VUMA-Transient

The general practice in underground ventilation systems is to ventilate and cool 'all-mine-all-of-time'. This is a brute force approach to the process and herein lie many opportunities for improvement. This is a particularly fertile area for creative and inventive input by mine ventilation engineers as illustrated below.

Recent studies[3] carried out under the Deepmine Research Programme have shown that cyclical operation of cooling and ventilation systems can lead to significant cost savings. The work first established the optimum approach to steady state ventilation tactics. The work then concentrated on the possibilities of introducing a cyclical air conditioning approach and evaluating the benefits.

For the base case mine considered in the study the total refrigeration requirement was of the order of 115 MW [including losses]. The cost of the capital infrastructure for ventilation, refrigeration and cooling was about R1 000 m. The total power consumption was 70 MW with a life-of-mine

power operating cost of R700 m. The steady state examination showed that the variation in total ownership cost for the complete ventilation, refrigeration and cooling system, from best to worst practice, was R750m [which relates to 44% of the capital and running costs].

Many different theoretical possibilities of cycling air conditioning to match mining activities were considered conceptually. However, the only real practical opportunity, on a global scale, was identified as follows: a 6-hour off-shift period during which all recirculation and all secondary and tertiary cooling would be stopped. During this period there would be a significant saving in power and reduction in heat load.

The equivalent heat load of the off-shift period was found to be about 80 MW, compared to 100 MW for the on-shift period and the power consumption drops to 26 MW from 57 MW. The enormous power savings during the off-shift period and the reduction in overall heat load more than compensate for the capital and operating costs of the larger cooling components.

Cyclical operation of cooling systems can benefit power management programmes. Stopping fans and pumps during the late afternoon coincides with the period for peak energy costs.

The overall reduced heat load translated to an effective reduction in required refrigeration capacity but slightly larger cooling coils would be required during the 18-hour on-shift period. It was also observed that cyclical operation provides ideal circumstances to maximise benefits from increased recirculation during the on-shift period.

The overall power savings from stopping of major items of equipment would be significant. The combined effect of this cyclical approach would be a further reduction of R185 m [11% of the total base case capital and running costs] over and above that achievable by optimising steady-state approach. In general, it was observed that this type of cyclical global air conditioning control would be feasible and economically justified, but for each specific site, there would be many details and specific risk assessments that would require examination.

As shown above, variations in the inlet flow or temperature, which may be as a result of a planned or an emergency loss of power, result in variations in the heat entering a mine and there is a need to simulate these variations within the mine ventilation system. VUMA-Transient is a tool that has been designed to examine these variations. The time-varying concentrations of dust and gas contaminants can also be examined.

A number of programs that predict 'steady-state' or average conditions in mine networks have been verified against measurements of average conditions in gold and platinum mines[4,5]. Improvements to the basic methods have been implemented in VUMA-Network. In developing the fundamental algorithms used in VUMA-Transient, use was made of the superposition principle [in which a varying temperature is approximated as a series of steps of constant temperature] and the improved steady-state methodology to determine the heat flow in each step. The approach was verified in an underground field trial [carried out as part of the Deepmine programme[65]] and the results were also compared with previous field trials. The figure below shows a comparison of predicted and measured temperatures over a 30-hour period during which bulk air coolers [BAC] and fans were switched off to simulate a power failure.

**Measured and modelled temperatures in stope**
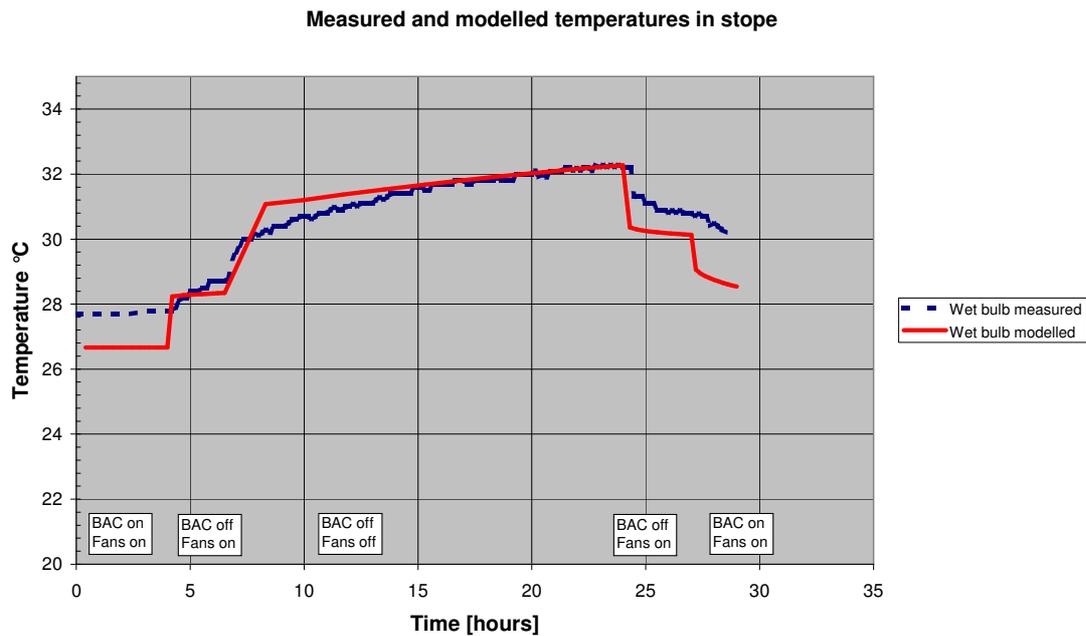


*Figure 8 Comparison of predicted and measured temperatures*

In VUMA-Transient a single path of air flow in a mine ventilation circuit [which may previously have been entered into VUMA-Network] is identified. [Because of the dynamic complexities within an overall mine ventilation circuit, the software may not be used to examine variations within a complete network]. Time varying inlet conditions [temperature, flow, gas or dust] are also defined. Once a solution has been obtained the variation of the flow, temperature and contaminant concentrations can be displayed graphically or in tables. The user-interface of VUMA-Transient is the same as those of VUMA-Network and the same library, rating category and other facilities are included.

## CONCLUSION

The VUMA simulation programs are essential tools at the disposal of underground ventilation control engineers and mine planners to facilitate system design and verification of operational parameters. The constraints of finer technical tolerances and narrower financial margins result in a limited viability of existing and future mining ventures against the background of increasingly expensive capital equipment. It is therefore imperative that accurate advanced system planning and design tools be at the disposal of decision makers. In particular, considering the holistic approach required for modern mine planning and design and ever increasing demands for quick, accurate and reliable answers, VUMA-Network provides an effective solution to the problem of simulating complex and interactive ventilation and cooling networks. VUMA-Transient allows the examination of emergency and planned cost saving variations in air flow and inlet air temperature. The VUMA suite of software is continually being upgraded and new tools will be added to the suite. An example of this is the facility to import mine network data and layouts previously captured in mine planning software.

The viability of future mining prospects will be determined by the ability to provide a safe and acceptable working environment at a cost that is not disproportionate with the anticipated returns. The use of precise and reliable simulation and planning tools is a vital component of this process.

Accurate simulation tools as described in this paper will facilitate and enhance mine planning and system operational monitoring and will assist in moving the science of mine environmental control up yet another notch.

## Acknowledgements

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