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Advanced Ventilation Control: An Analysis of Innovation and Environmental Sustainability

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ABSTRACT

The current economic challenges faced by the mining industry of present led to a review of options for reducing the cost of Ventilation Control Devices (VCD's). The VCD's at the Mount Isa Mines (MIM) site operated by Glencore in Queensland typically experience significant damage on the operating levels and were requiring expensive replacements. Ventilation controls can become damaged by the effects of stope firings. This paper discusses the nature of blast wave effects, giving consideration to distance from the firing and changes in mine geometry. In addition, the time taken to adjust the airflow on the operating levels with the current VCD's resulted in the loss of productivity opportunities. The mine site engaged an equipment supplier and in collaboration developed a high strength regulator to control the required airflows within its underground workings.

The strengthened regulator proved to be cost effective whilst also providing additional benefits in the ease of use, simplicity of installation and speed of change in the control of available ventilating airflow. An added advantage of the re-engineered regulator over contemporary VCD's is its flexibility which includes the allowance for the movement of mobile equipment into different ventilation districts easily where required, without the need to remove the VCD from its location. This paper describes both the innovation and environmental sustainability approaches followed in developing the new regulator for its implementation at the site.

INTRODUCTION OF MOUNT ISA MINES GLENCORE OPERATION

In 1923, prospector John Campbell Miles discovered the lead-silver carbonate ore body known as Mount Isa Mines. In 1927 copper ore was discovered within the lease and production of the resource commenced in 1943. The lease is adjacent to Mount Isa City which is located 900 kilometres west of Townsville in Queensland Australia as shown in Figure 1.

The Mount Isa Mines underground operation today incorporates the Enterprise mine and the X41 mine within the lease. The mining of the reserve is carried out simultaneously with working depths ranging from approx. 500 – 1900 metres below surface (mbs) due to the complexity and orientation of the ore body as illustrated in Figure 2.

The operation employs the selective mining method of Sub-Level-Open-Stoping and produces approximately 6.3MTpa of hoisted material with combined throughput from the Enterprise and X41 mines. The development profile is in excess of 14 000 lineal metres annually. Broken ore is transported from the underground workings via ore passes, conveyors and hoisting shafts to the business unit's onsite copper concentrator. The operation employs cemented aggregate backfilling as part of its sustainable mining strategy from its onsite Paste and Wet fill plants.

The operation currently manages in excess of 2600m^3/s ventilating air to maintain a healthy sustainable atmosphere throughout its underground workings. The fans within the primary and secondary circuit system are monitored using the supervisory control and data acquisition (SCADA) computer system and programmed logic control (PLC) starter system. The SCADA system assists in the management of available air for workplaces, removal of heat and contaminates from throughout the mine. The structure of the operation is very complex and ranges from 1900mbs and four kilometres in longitude. Due to the topographical location of the mine site, the surface rock temperature is 28.5°C and the geothermal gradient increases at 19.8°C per 1000mbs. A total of 36MW of refrigeration for air cooling is utilised onsite to effectively manage inherent heat related issues including high surface intake air and underground wet bulb temperatures.

VENTILATION DESIGN AT MOUNT ISA MINES

The underground ventilation network employed at Mount Isa Mines utilises a negative pressure system driven by seven primary surface exhaust shafts with a combination of axial and centrifugal fans ranging from 250kW – 2000kW installed. The fresh air intake utilises nine primary shafts to provide sufficient ventilating air. A forced and flow-through ventilating system controls the distribution throughout the underground secondary ventilation zones / districts. The operations overall ventilating system is shown by the current ventilation software (Ventsim™ Visual) model in Figure 3.

The management of the underground zones / districts effectiveness and efficiency is directly controlled by the relationship between the primary and secondary ventilation systems. Primary ventilation circuits are directly interconnected to the underground infrastructure by dedicated ventilation manifolds, which are then distributed to/from the secondary circuits. The secondary systems are controlled via push (fresh air)/ pull (return air) fans with available ventilating air regulated utilising manually controlled ventilation control devices (VCD's) throughout the operation to form parallel circuits. Previous VCD's being employed onsite consisted of Drop board regulators (DBR's) and steel Blast flow louvres. The latter had become an ineffective device due to blast damage and this was creating ventilation air demand control issues within the working levels. Because blast damage of underground infrastructure including VCDs can contribute significantly to production downtime it is beneficial to consider the interaction between stope firings and infrastructure.

Effects of Stope Firing on VCDs

In many mining operations VCDs such as drop board regulators have to be dismantled before firings to avoid damage. This has an impact on production because of the recovery time required to clear the working areas from shot firing fumes, dust and to re-establish the ventilation controls. In order to understand the effect of a stope firing on surrounding infrastructure, the very nature of a blast must be understood, including how the blast energy dissipates with distance from the firing. There is little information available on the effects of stope firing blast waves on underground infrastructure influenced by multiple parameters, including blast design and mine geometry. *Smith and Sapko (2005)* used Sach's scaling laws to develop a relationship for both pressure rise and impulse which incorporated factors for intersections. Intersection geometry changes the peak pressure and the energy of the blast wave. *Silvestrini et al (2009)* developed the scaling laws with an energy concentration factor to predict blast propagation in partially confined geometries. *Lovitt (2014)* proposed equations for determining the peak side pressure and impulse from free to air explosions in a tunnel.

When a firing *(Silvestrini et al, 2009)* occurs a fraction of the available energy is converted into a blast-wave.

A typical firing produces high pressure pulses of short duration, typically 15 milliseconds. These two effects both have an impact on any infrastructure that is encountered including VCDs.

1. An overpressure wave *(Rigas et Al, 2005)* is generated that propagates in three dimensions (channelled by tunnel geometry) with velocity that exceeds the velocity of sound (supersonic flow) soon covering a large distance.
2. An expansion of air in the vicinity of the firing caused by a thousand fold volume increase in explosives from solid to gases and a 30-50% increase in rock volume as it is broken by explosive pressures generated in the boreholes (ranging from 3-8 GPa).

Another phenomenon called "channelling". *(Silvestrini et al, 2009*) is the enhancement, or increase, in the pressure and corresponding impulse of a blast wave, created by reflections from the drive. The enhancement of the wave allows it to sustain higher pressures and impulses farther away from the blast, causing damage at farther locations than would have been possible for a free-field blast. The amount by which a blast wave is enhanced by channelling is a function of the geometric confinement.

The more confined the geometry, or the smaller the volume for a blast wave to expand into, the more reflections will occur and the greater the overall enhancement of the wave. A dead-end stub heading, for example, has greater confinement (less volume) and provides greater enhancement of the wave than a more open geometry, such as an intersection.

As intersections are reached a portion of the blast wave 'turns the corner' and enters the adjoining drive instead of continuing forward along the drive the charge was detonated in. Since *(Smith and Sapko, 2005)* most ventilation controls in underground mines will be in crosscuts incident to the pressure wave, it is important to know the impulse (total energy) perpendicular to the primary detonation wave as it passes each intersection.

The outward travelling shockwave peak pressure causes the most damage to infrastructure and energy dissipation occurs through friction in the roadway and encountering of obstacles. The velocity from the expansion of air decreases in proportion to distance from the firing. A rigid structure such as a steel VCD which blocks a roadway will experience large forces from a reflected shockwave and it is likely that during a firing the high stiffness materials will exceed peak strain capability resulting in permanent deformation and loss of function. It is important when installing primary regulators and other infrastructure that they are sufficiently distanced from stope firings and positioned to lessen the potential likelihood of damage.

The Situation

In a challenging economic climate, the site Ventilation Advisor was considering various options for reducing the cost of VCD's within the mine. The currently installed VCD's were experiencing significant damage on the operating levels caused by normal mining activities and were requiring expensive replacements. In addition, the time taken to adjust the airflow quantities on the operating levels with the current VCD's was time consuming.

These flow-on effects caused restrictions to the business unit performance through lost opportunities including production delays. The single action louvre regulator was not a sustainable solution for the particular operation, based on the expected benefits the operation was endeavouring to achieve. With the rapid expansion and close proximity to the mines workings, user friendly devices that were easily managed, reduce delayed production and could be effective for the operations sustainability were required.

A solution was sought by engaging a product manufacturer to create supplier buy-in during the research and redesign phase. The overall mindset was to approach the project with the desire of a win-win outcome for all stakeholders by incorporating environmental sustainability and standardised site safety systems. Other underlying aspects considered were:

- Reduce production delays,
- Develop a modular VCD to provide flexibility and ease of use,
- Simple operating concept,
- Cost effectiveness,
- Value add to the business,
- Re-use existing structures i.e. previously constructed shotcrete surrounds,
- Recycle when possible.

Methodology

The operation required a step change in spending due to the current economic challenges being faced within the industry. With self-starting initiative and enthusiastic encouragement from management an investigation of innovative avenues to reduce per unit costs began. A financial analysis of the operations previous yearly budget spends undertook a comparison of new installation costs versus repair and replacement costs. The findings of the analysis confirmed that a significant portion of the ventilation budget was being consumed by the repair and replacement of the unsuitable VCD's.

An operational analysis was performed on the functionality of the ventilation system and identified critical opportunities to reduce delays in the mining cycle, maintain safe workplaces and maximise savings. With mines going deeper as the cost of power increases, approximately *(Mutton et al, 2009)* 30-50% of operating costs can be consumed by ventilation requirements. Therefore small changes in secondary ventilation efficiency would allow the business to increase its competitiveness in the market and improve the efficiency of the circuit. The intention of improvement was to maintain legislative / industry leading practice standards, whilst building in flexibility to sufficiently manage acceptable levels of heat and contaminants as per Queensland state regulatory legislation.

The blast louvres became ineffective controls due to the failing of components, constant rework due to damage, transport costs due to the remote location and costs associated with maintaining the units to provide an acceptable atmosphere at the operation. Damage sustained to the units from regular mining activities had introduced potential hazards. This was due to the steel structures of the blast louvres becoming loose which required removing personnel from the immediate area and the line-of-fire. The onsite ventilation department received communication from stakeholders regarding the issues being experienced due to the failures and delays occurring to the mining process. The feedback from stakeholders was considered and research into providing a workable solution was undertaken to provide an opportunity that could help to mitigate risks, improve safety and remove personnel from potential hazards whilst maintaining a 'Duty of Care'.

Investigation of ventilation circuit design

An initial task was to identify the current pressures being experienced across the existing regulators. The mines operation has approximately 80 working exhaust raises within its secondary circuits which are regulated separately with axial fans and VCD's. These circuits are then balanced throughout the entire network. The mines ventilation system was analysed using the available software model (Ventsim™ Visual) to identify sections with high pressure and resistance. The results from the modelling of the Enterprise mine were collated and identified that based on the available fan curves data and drivage resistance factors a regulator would need to be able to withstand a ventilation pressure of approximately 850 Pa during normal activities (without blasting) to sufficiently function. These measurements calculated from the modelling were then verified with onsite static pressure readings with only a maximum allowable variance of -/+ five percent.

A detailed look at the functional purpose served by a VCD was undertaken with the requirement to engineer out the human factor. The design needed to incorporate both strength and flexibility whilst ensuring that onsite construction methods could be easily adjusted without major changes.

Due to the remote location of Mount Isa, it was not a feasible option to ask suppliers to attend visits onsite to discuss potential products. With this predicament in hand it was decided that existing VCD concepts being utilised onsite could be investigated for a possible solution before engaging in new research and design.

Could the QBC be used as a regulator?

The Quality Brattice Control (QBC) as shown below in Figure 4 was identified as an access door for the purpose of segregating ventilating districts / zones where low pressure differentials were experienced. The QBC is not a new device and has a similar function to that of the Nixon flap which originated at Mount Isa Mines. The site had already been utilising (Orica) QBCs and these were generally being used as a temporary solution for site access whilst capital works were being completed.

The initial findings of the QBC identified that although it had an acceptable function, it would require some changes that would allow it to be a generic solution across the operation for the purpose of regulating airflow. After reverse engineering the components of the QBC including its winching system, feedback was sought from the workforce and other stakeholders on the unit's functionality and ease of use prior to any changes, or improvements to implement a stronger purpose-built design.

Due to the environmental characteristics of the mine and consensus from stakeholders, it was decided that the overriding components to provide the desired outcome included:

1. Cost effectiveness.
2. Able to retrofit to existing infrastructure.
3. Minimising any potential impact to operations during construction or repairs.
4. Factoring in some functional reserve to the design and value-add to the business.

The QBC was broken down into sections and analysed as separate components highlighting what significant properties affected the overall integrity of the QBC design including its function in the ventilation circuit.

Consultation with both the manufacturer and senior construction personnel onsite was sought after to enable a practical solution to be achieved. This also allowed stakeholders to take ownership in the outcome of the final product. The manufacturer was contacted, and with the proposed changes a technical drawing of the re-engineered QBC was provided to reflect initial mine guidelines, Features that required modification / improvement to enable a stronger and more efficient unit to be manufactured for trial were highlighted in this process.

Redesigning a QBC

Orica was contacted by mine-site to assist with developing a high strength, low cost and easy to use regulator to control the airflow on the mine's operating levels. In consultation with site personnel the current QBC design was modified to strengthen it for operations within working levels. The modifications undertaken included:

- Increasing the number of supporting dowels for stiffness to resist higher ventilation pressures;
- Reinforcement of the high tensile strength cloth where the QBC is attached to the bulkhead to minimize damage;
- Strengthening the hanging brackets so that they would not bend under high pressures.
- End brackets and steel backing plates to prevent slip of the cloth on the dowels and to resist abrasion against the shotcrete surround.
- A more robust winch with higher capacity was supplied so that the QBC Regulator could be adjusted at higher ventilation pressures.

Previous design considerations *(Mutton et al, 2009)* have been incorporated in the design and are listed as follows:

“The proposed QBC blind had to able to be operated comfortably by one person through its full operating range and be easily deployed and attached to a shotcrete surround”.

The materials constituting the QBC blind also have the following properties:

- Resistance to abrasion and impact.
- Struts have to be able to be pushed and bent through the shotcrete surround without breaking or becoming permanently deformed.
- The cloth must be tear resistant and not weakened by sewing.
- The cloth is fire retarded to avoid flame propagation.

In addition to the above in overpressure events it was hoped any new device would not suffer damage but purely bend through the opening and be able to be adjusted and reset rather than totally replaced. Minova (now owned by Orica) previously had sourced a woven cloth for explosion testing 5 psi *(Mutton et al, 2004)* over pressure rated stoppings at NIOSH’s Lake Lynn Experimental Mine, PA, for the underground coal industry. This cloth has a fire-resistant antistatic coating, having a tensile strength 125 kN/m. Its 2 mm thickness is beneficial for resisting abrasion.

It was determined that the only material with enough strength and flexibility *(Mutton et al, 2004)* for struts were pultruded composite glass reinforced dowels using a polyester resin matrix. Other types such as epoxy or carbon fibre were too brittle and cost prohibitive. The purpose of the rods (diameters of 32, 38 and 45 mm) is to stiffen the blind so that it will function at pressure differentials as high as 1000 Pa without being sucked through the opening.

Typically drive sizes are 4 to 6m in width and 4 to 5 m in height but this strengthened regulator has been designed for a 3 x 3 metre sized opening size providing sufficient aperture for the management of approximately 40m^3/s of airflow as per the onsite requirements within the working areas.

QBC regulator prototype trials

Redevelopment of the existing QBC in collaboration with the manufacturer by incorporating changes meant that the achievable requirements could assist the operation to gain maximum benefit from the exercise. The project prototype design was completed in approximately two months via electronic drawings passing back and forth until a viable option was agreed upon. This product was manufactured after the design phase due directly to the geographical location and distance based / logistical issues for items being transported to the mine site.

Preliminary Outcome

Figures 5 and 6 show a half opened strengthened QBC design and the winch assembled on a bracket respectively. The overall construction costing is detailed in Table 1 with comparison between one strengthened QBC and the blast louver regulator.

Once the prototype was delivered onsite, stakeholders were consulted to assist in providing a solution on the most effective method of installing the modified VCD. A set of schematic drawings were drafted to provide construction personnel with the relevant information, and changes were communicated to stakeholders. The new QBC was designed to be 3600mm high by 3600mm wide overall to provide strength and flexibility with new and existing ventilation infrastructure. The construction of the new bulkhead to support the QBC curtain was designed with an opening of 3000mm high by 3000mm wide and allow an overall 300mm overlap with the curtain which provides an effective air seal. During the construction phase of the new bulkhead, another safety device was incorporated into the design by implementing a 1200mm high stop log into the structure to act as a physical barrier on vertical openings to further protect personnel.

Incorporation of the new hanging system gave the modified QBC the ability to be easily fixed or removed due to the four steel pins installed into the bulkhead during the construction phase as shown in figure 5. The overlap of the curtain allows the unit to be rolled up completely when normal mining activities are present in the area. If damage renders them inoperable they can be very quickly replaced. The new QBC has the ability to be retrofitted over the existing opening left from the previously installed blast louvers which has provided a further cost saving to the business. The winching system has provided the flexibility of quick, easy and safe changes to the ventilation circuit when it is required. By providing a set opening within the bulkhead, it has become easier to have controls reset or sealed after firings and removes personnel from the line of fire.

The Result

Working with the customer, Orica were able to provide a customized solution for the control of airflow on the mines working levels. The strengthened QBC has been shown to be a cost effective method of installing ventilation regulators. In addition, benefits have been shown in the ease of use and speed of change in the airflow control. An added advantage of the strengthened QBC over contemporary ventilation devices is the allowance for the movement of vehicles into different ventilation districts easily, without the need to remove the VCD from its location. Before firings the QBC can be winched open to its fully open position and secured. Because the strengthened QBC is made from a cloth stiffened by fibreglass dowels, it is able to deform and dissipate energy from overpressure events. Steel backing flat bars bolted to the back of the fibreglass dowels provide some abrasion protection from movement against the shotcrete surround.

The strengthened QBC has been designed so that it could be retrofitted onto previously constructed ventilation bulkhead openings 3000mm high by 3000mm wide, reducing the time and cost to install the new VCD's. The final installed product can be shown in the following photo in Figure 7.

To date, the site has purchased almost 30 Strengthened QBC's as a cost effective replacement for the regulation of air flow on operating levels. At an approximate saving of $16,000 per installation this has resulted in a cost effective replacement product for the mine site.

CONCLUSION

The feedback provided by on-site stakeholders regarding the interactions and lost opportunities, allowed for the review of the effectiveness of existing VCD's. The collaboration with stakeholders during the research and design phase has allowed for a generic resource with functional reserve to be utilised across the site providing qualitative and quantitative results. As the existing VCD's become unusable, they can be retrofitted with the newly designed QBC to remain as an effective control and provide a safe work environment for personnel. The new regulator has allowed the mines ventilating system to be more consistent and effective which has seen a reduction in ventilation related interactions. This has provided a win-win outcome by increasing available operational time and providing cost reductions for the operation. The project provided the ability to reduce, re-use and recycle infrastructure, it was a sustainable decision to reduce our environmental footprint and maintain our social licence to operate within the community. Isn't today's innovation potentially tomorrows standard.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

TABLE CAPTIONS

FIGURES

FIG 1 - Location of Mount Isa and MIM (MIM, 2014)

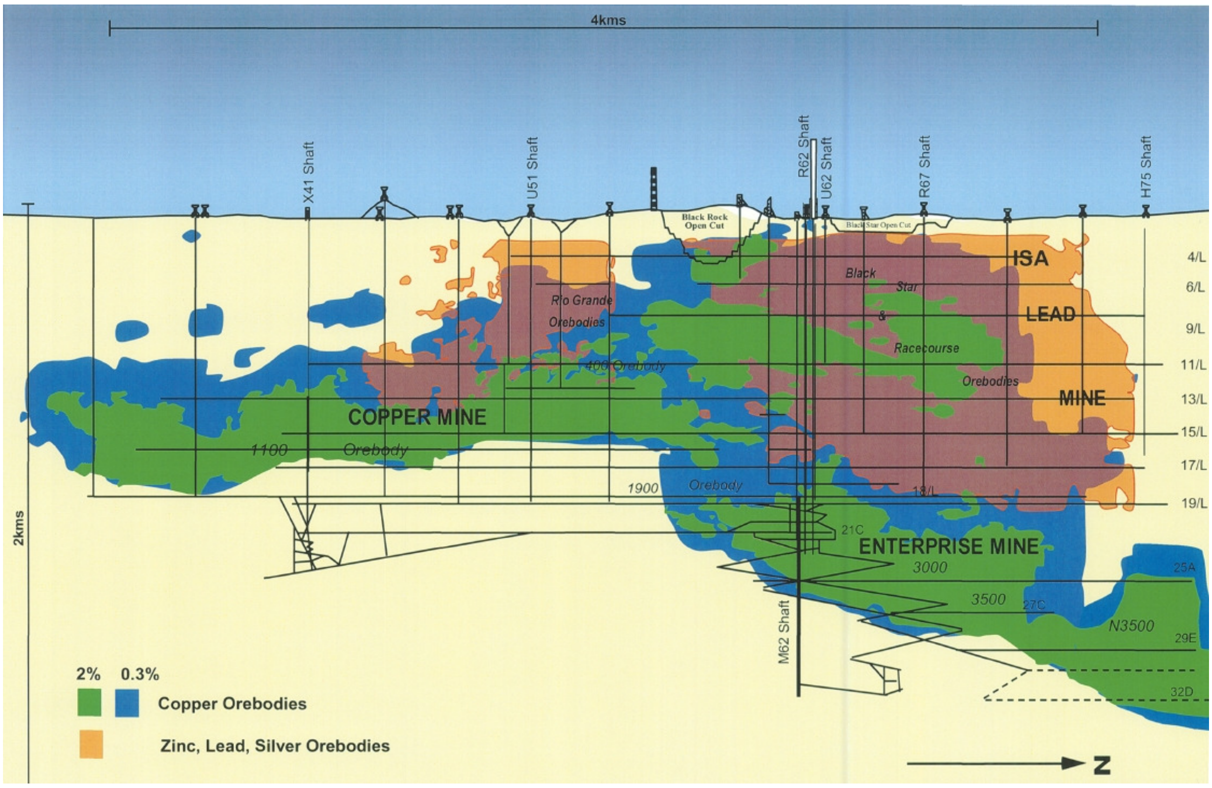

FIG 2 - Mount Isa mines longitudinal section indicating the underground resource (MIM, 2003)

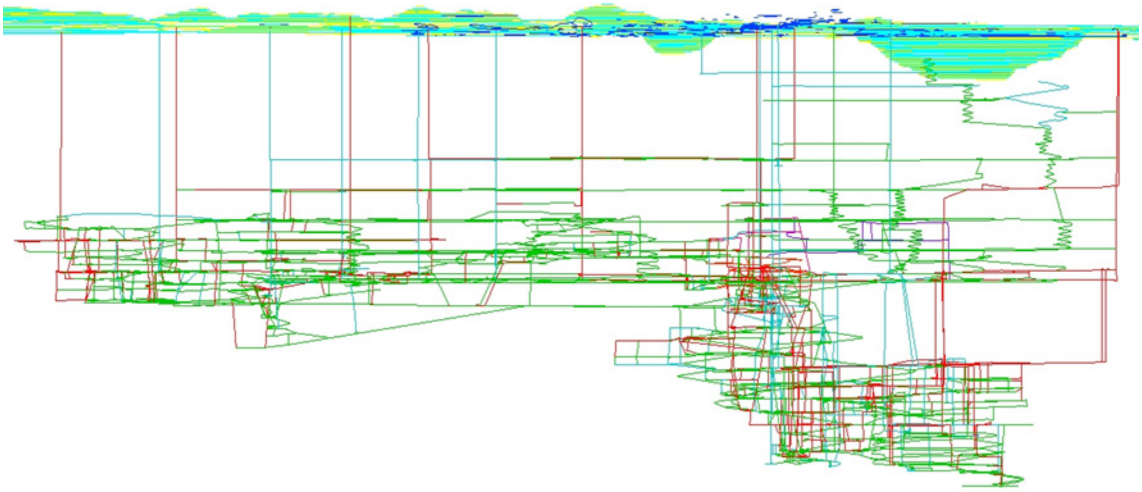

FIG 3 - Mount Isa Mines software modelling of the underground ventilation network (MIM, 2015)

FIG 4 - Original design of a QBC access curtain with chain hangers (MIM, 2013)

FIG 5 - Strengthened QBC Design (MIM, 2013)

FIG 6 - Winch and bracket on wall (MIM, 2013)

FIG 7 - An installed Strengthened QBC with the integrated stop log (MIM, 2014)

TABLES

TABLE 1

Ventilation Control Device construction costs (Shearer, M, 2013)

Redesign of current ventilation control device			
Redesigned QBC Curtain	Costs	Blast Louvers (double set)	Costs
Cost per unit excluding freight	$3,466	Cost per unit excluding freight	$20,062
Cost of parts per rebuild	$1,415	Cost of parts per rebuild	$8,162
Cost of construction (incl. shotcrete)	$20,460	Cost of construction (incl. shotcrete)	$19,870
Total Cost per Installation		Total Cost per Installation	
QBC + Construction	$23,926	Blast Louvers + Construction	$39,932