Updated Ventilation On Demand review: implementation and savings achieved

Conference Paper · October 2016

3 authors:

Enrique I. Acuña
Laurentian University

Roberto A Alvarez
BBE Group - Consulting Canada

Juan P Hurtado
University of Santiago, Chile

Updated Ventilation On Demand review: implementation and savings achieved

Enrique I. Acuña, School of Mines, Faculty of Engineering, Universidad del Desarrollo, Chile

Roberto A. Alvarez, Chuquicamata Underground Mine Project, Vicepresidencia de Proyectos, Codelco, Chile

Juan Pablo Hurtado, School of Mines, Faculty of Engineering, Universidad de Santiago de Chile, Chile

Abstract

Within the past years, the Ventilation On Demand concept has been implemented in several mines worldwide and seems to be spreading significantly as a result of the energy savings that it is achieving for the operations. More mines and projects are considering its implementation as a result of the limited access to energy and its cost, but also because of the potential to increase health and safety and the number of faces available at any given time with the same airflow volume boundary. Although the concept is simple—bringing the right quantity and quality of airflow where it is needed at the right time—the different components of the system and the implementation process necessitate additional work and increased maintenance compared to conventional systems. This paper presents the study developed, as an updated review of the Ventilation On Demand concept and implementation in different mines, the system components, software packages, level of implementation, strategies in place and energy savings achieved. The comparison is made in terms of the strategy implemented and the energy savings achieved. A discussion is also presented of the results obtained, and the implementation level according to each mine's requirements and reality.

1 Introduction

The concept Ventilation On Demand (VOD) has been spreading into the underground mining world at an intensified rate in the last few years as a result of the need to improve a healthy and safety environment, production and minimize the waste of energy dedicated to ventilation systems. Both the concept and the implementation of VOD are not new to mining or engineering, however only in the past 10 years have the economic conditions and the technological maturity of equipment and softwares been aligned to favor different phases of implementation across North America, South America, and Northern Europe. Nevertheless, as will be presented in the upcoming sections these softwares are not yet fully mature products and keep on evolving according to the different mines and user requirements and their level of implementation.

This paper introduces the general concept of Ventilation On Demand (VOD), propose an extended explanation to the different VOD strategies and relates each strategy to its conceptual background. Additional details are provided about the softwares origins, system components and the level of implementation that this technology has reached, with the reported savings when available.

2 Ventilation On Demand concept

As indicated by Tran-Valade and Allen (2013), ventilation on demand could be defined as follows "Ventilation On Demand (VOD) is the ability to direct air in an underground mine to the area that requires it, at the quantity needed for the local activities and ambient conditions at the time. In other words, it is the ability to provide the required air volume to where it is needed only when it is needed". Previously Lyle et al (2010) proposed a simplified version limited to the quantity needed. It could be argued that the definition provided is vague in terms of what are the components of the ventilation on demand system and that it is hard to understand what is required to actually have a VOD system for an underground mine, as the definition refers to the concept of how the airflow achieves the target but one must further study to understand what should be the components of such a ventilation system to be considered a ventilation on demand system. Based on the authors experiences this point turns to be one of the keys to understand what a VOD system really is, and that to achieve certain levels of VOD it is not necessary required having a fully implemented tag and tracking system in place or a fully deployed sensor network. As will be presented in the following section, it depends on what the site requires from a ventilation system, the control strategy or level considered for implementing the VOD going from manual to tagging and tracking.

According to Tran-Valade and Allen (2013), there are five control strategies that are considered for Ventilation On Demand:

- "User Control" also referred commonly as "manual control"
- "Time of Day Scheduling"
- "Event based"
- "Tagging"
- "Environmental"

These strategies are incremental in terms of the benefit that they can provide to the mine site, but also incremental in implementation and maintenance cost. However, it is mine site specific which control strategy will be applicable, the type of monitoring the site is comfortable with and of sufficient value when compared to the cost of implementation and maintenance. Additionally the technology cost and the capabilities of hardware and software components available in the market, has improved significantly in the past few year, making each one of the strategies worth considering if implemented properly from the project phase according to Flores and Acuña (2016).

The following section attempts to propose an explanation, to the different VOD strategies relating each strategy to its conceptual background. As per Tran-Valade & Allen (2013), the 5 identified strategies can be used singularly or in combination. In order to understand what is required to achieve each strategy, an attempt to describe the five different control strategies in details is performed in the following paragraphs.

2.1 User control or manual control

The first control strategy is "User control" also referred commonly as "manual control": is the first level that allows for manual control or setting of operational points for the different components of the ventilation system. Usually this can include (but is not limited):

- Main and secondary fans: whether they are direct online (on/off), or equipped with soft starters or variable frequency drives (VDF). It is more common to have auxiliary fans on/off especially with steel or flexible ducting, but soft starters should be considered for energy savings and safety when considering flexible tubing.
- Regulators and doors: both of these control devices can be used to adjust the opening orifice of a drift, enabling the regulation of the resistance and ultimately the airflow volume across the tunnel. However regulators and doors have fundamentally different expected applications as control devices, a regulator is built to operate at different openings and to be moving during the shift to modulate the airflow volume across the drift. In the other hand, the door is meant to open and close as equipment goes by to maintain ventilation circuits isolated and to avoid the mix of fresh and return air for example. The door could be open at a certain high (from 0% to 100%) to regulate the flow into the drift, but hopefully as a fix opening setting. The application where the door is expected to cycle as often as a regulator will increase the frequency of maintenance and most likely of failure forcing the door to be set manually anyways over time.

Manual operational point settings can be divided into two subcategories:

- Fixed setting: for fans this setting correspond to the on or off, or in case a VFD is available, to fix the operational rpm or frequency of the fan in an attempt to deliver just the airflow required. For regulators and doors the fix setting corresponds to a percentage of the opening from 0 to a 100%.
- Proportional Integral Derivative (PID) Control loop: in simple words is a feedback control loop to achieve a desire set point based on a measured process variable. In this case the set point is the opening of the regulator or door and the measured process variable is the airflow volume. Depending on the supplier of the VOD software this capacity would not be available at the manual or first level, but in the second or third level. More details on the software capabilities per level will be given in the upcoming paragraphs. Usually this feature is not available with the implementation of level 1 because the PID loop requires airflow sensors deployed through the mine to allow for the measurement of the airflow volumes in the tunnels. As an example Totten Mine has implemented this type of manual control with airflow sensors obtaining good results just using the manual control offered by the ABB 800xA system according to Flores and Acuña (2016).

2.2 Time of day scheduling

The second control strategy is “Time of day scheduling” which refers to the concept of triggering different set points of the fans, regulators and doors based on the time input to follow a certain schedule. Assuming that the sensor deployment in the mine is fairly limited or nonexistent as could be the case for this level, then the logical extension of the level 1 “user or manual control” is to couple it with a timer to trigger sequences of changes in the set point of the ventilation system as fans, doors and regulators in a semi-automated way. This application is actually a limited version of the main concept behind level 2, which from a broader point view should be called the “action trigger”. If the “action trigger” concept is constrained to act based on a timer only, the result is effectively the “Time of day scheduling”. If the “action trigger” could be coupled to use with other environmental variables or data as triggers the opportunity for different applications and savings could be even further enhanced. However this also requires a more extensive deployment of sensors underground.

2.3 Event based

The third control strategy is the "Event based", and as indicated by Tran-Valade and Allen (2013) it is the "automatic trigger of prescribed actions in reaction to configured events". Which can be summarize as the "action trigger" function based on alternative inputs other than the timer and the environmental variables, as each one of them has its one category. Just like the "Time of day scheduling", this control strategy uses the same principle of the "action trigger" but based on any variable available that could be conveyed to the software making the decision. In particular it could potentially be a combination of variables with certain logic. The potential for applications of this control strategy is significant, for example: optimize blast clearance and mine fire response. Additionally, the "Event based" can also be used to trigger cascade use of fans, for example turn a booster fan on if an auxiliary fan is turned on, to secure the supply of fresh air across the main drift.

2.4 Tagging

The fourth control strategy is the "Tagging" which represents a major step in both the capacity to understand where the people and equipment is, and also in terms of infrastructure required to locate them. This control strategy requires the implementation of a tag and tracking system, and its associated communication integrated with the ventilation software. The airflow distribution of the mine is generated based on the location of the personnel and equipment, and also based on rules to calculate the airflow that has to be assigned to each. The "Tagging" control strategy is commonly associated with the concept of ventilation on demand as the airflow volumes can be allocated across the mine according to the location real time data of both personnel and equipment. As a result of knowing where the airflow demand is located, then the ventilation system set points can be adjusted to provide the airflow required at minimum cost for both the auxiliary and main ventilation systems.

2.5 Environmental

The fifth control strategy is "Environmental" and considers the automatic control of the ventilation system based on real-time environmental data, which could be a number of sensor inputs as gas, dust, DPM, temperature (Heat Stress) for example, assuming that such sensors could work underground and provide real-time information. In that regard, the performance of dust and DPM online sensors is still work in progress, but with encouraging results in the past recent years. The environmental control can be used in two ways, as a failsafe in case of a gas exceedance or as the ultimate control strategy. Coupled with any of the control strategies the environmental strategy acts as a failsafe in case of an environmental variable going out of the preset boundaries, for example high CO or high temperature. This could be referred as the quantity and quality approach of the environmental control strategy. As a standalone strategy the environmental control strategy allows the ventilation system to distribute the airflow according to the environmental variables, for example the gas or dust concentration. This control strategy is expected to be the one that can provide the largest amount of savings.

Which one of the two environmental control strategy approaches can be implemented will depend on the regulations. For example in Chile (D.S. 132 and D.S. 594) and Canada (reg. 854 and reg. 833) it can only be used as a failsafe because the 100 cfm/BHP are a mandatory requirement as to be within the Threshold Limit Values (TLV) during the shift. At the conceptual level it could be argued that the environmental control strategy could be implemented before the tag and tracking is in place as a failsafe or as a standalone. In fact the implementation of the environmental strategy requires an extended network of underground sensor to properly monitor the "environmental variable" required, and as such does not necessarily requires a tag and tracking system in place to properly function, but could certainly benefit from having both in place when it comes down to troubleshooting.

The control strategies are usually referred as levels of implementation by the software packages available in the market. Table 1 presents the Author's interpretation of the different control strategies coupled with the levels of implementation according Tran-Valade and Allen (2013). Table 1 further expands in the concept of which of these control strategies could be considered "true" or fully automated VOD, the fan ventilation systems as main and principal, and the environmental approach: quantity or quality.

<table>
<tr><th colspan="6" rowspan="2"></th><th colspan="4">INFLUENCING MECHANISM IMPACTING SAVINGS</th></tr>
<tr><th colspan="2">Fans (on/off, SS, VFD)</th><th colspan="2">Environmental variable (Quantity or quality approach)</th></tr>
<tr><th>LEVEL</th><th>VOD</th><th>Personnel and vehicle information</th><th>Control strategy</th><th>Sub control strategy</th><th>Description</th><th>Auxiliary</th><th>Main</th><th>Quantity (airflow volume)</th><th>Quality (Contaminant)</th></tr>
<tr><td>1</td><td rowspan="3">VOD based on expected personnel and vehicle distribution</td><td rowspan="3">Expected distribution of personnel and vehicle</td><td>Manual</td><td>Manual or sensor loop set point</td><td>Local or remote manual start/stop, setting set points of devices</td><td>on/off</td><td>SS or VFD</td><td>Regulation (i.e. 100 cfm/BHP)</td><td>TLV</td></tr>
<tr><td>2</td><td>Time of day scheduling</td><td>Manual or sensor loop set point</td><td>Automatic execution of sequenced actions on devices at specific time windows</td><td>on/off</td><td>SS or VFD</td><td>Regulation (i.e. 100 cfm/BHP)</td><td>TLV</td></tr>
<tr><td>3</td><td>Event based</td><td>Manual or sensor loop set point</td><td>Automatic trigger of prescribed actions in reaction to configured events</td><td>on/off</td><td>SS or VFD</td><td>Regulation (i.e. 100 cfm/BHP)</td><td>TLV</td></tr>
<tr><td>4</td><td rowspan="2">VOD based on real-time personnel and vehicle distribution</td><td>Real-time Tagging data</td><td>Tagging</td><td>Auxiliary and/or Primary fans</td><td>Automatic adjustment in the ventilation system based on personnel and vehicle tag data</td><td>on/off or VFD</td><td>VFD</td><td>Regulation (i.e. 100 cfm/BHP)</td><td>Specified cfm/BHP based on exhaust test and dilution formula</td></tr>
<tr><td>5</td><td>Real-time sensor data</td><td>Environmental</td><td>Auxiliary and/or Primary fans</td><td>Automatic adjustment in the ventilation system based on real-time environmental data</td><td>on/off or VFD</td><td>VFD</td><td>Failsafe</td><td>TLV</td></tr>
</table>

Table 1 VOD levels of implementation based on Tran-Valade and Allen (2013) with additional variables.

TLVs represent the range of exposure to a certain concentration of a contaminant during a shift that is acceptable according to regulations. Auxiliary fans start is usually on/off in most common cases as they increasingly tend to be disposable, however they could be equipped with soft starters or VFD depending on the application. Main fans are more often equipped with VFD to allow for the modulation of the rpm and their power consumption according to the different mine requirements. Regulators are not incorporated in Table 1 as they are expected to be present in the system to regulate the airflow distribution unless only fans are considered for this purpose. This could prove to be far more challenging for a ventilation system.

As can be observed in Table 1 the set of alternatives available for the implementation and extension of a ventilation control system to achieve some form of ventilation on demand, is quite significant and as such each mine has to decide based on the local conditions and a solid business case which is the level of implementation that will be feasible to sustain over time and will be the most cost effective to achieve the desire savings.

3 Ventilation Control System components

This section details the main components that each ventilation control system level of implementation requires to achieve the control strategy desire. As indicated earlier each level requires software variations and hardware components which vary the cost.

3.1 Software and hardware requirement per levels of implementation

Due to the number of alternatives that can be considered for each level of implementation the following Table 2, outlines an attempt to summarize the general requirements for each level of implementation. PLC refers to Programmable Logic Controller. PLC is the unit that allows the communication from the main server on surface to each of the ventilation components in the levels. Instrumentation was divided in two main components: airflow and environmental sensors, the main reason is to split the quantity and quality approaches. Finally tag and tracking systems are included as a single package and it is only required for the "Tagging" control strategy. The "X" indicates the mandatory components, "Opt" the optional and blank means it is not required for that level of implementation.

LEVEL	Control strategy	Software package	PLC	Communications (main and auxiliary fans, doors and regulators)	Airflow sensor	Environmental sensors	Tag and tracking
1	Manual	L1	X	X	Opt.		
2	Time of day	L2	X	X	Opt.		
3	Event based	L3	X	X	Opt.	Opt.	
4	Tagging	L4	X	X	X	Opt.	X
5	Environmental	L5	X	X	Opt.	X	Opt.

Table 2 Software and hardware components required per level of implementation.

Based on the number of potential combinations that can be generated between the level and the optional (Opt.) alternatives for implementation, understanding exactly which one is the best solution for each mine site can turn into a challenging exercise. Even further when considering that it is a new technology and that it will require the work force to get used to the new concept of maintenance and monitoring, in particular for the "Tagging" level. The maintenance and acceptance of the "Tagging" system by the work force can be a challenge on itself.

3.2 Software origins

Three main software providers were researched for this paper, in alphabetical order: ABB, Bestech and Simsmart. Each supplier promotes its own software package, ABB – Smart Ventilation, Bestech – NRG1-ECO, Simsmart – SmartEXEC. This section outlines the origins of each of the three packages for the reader to better understand the context of their current development. Table 3 presents each of the three ventilation control softwares available considered in this paper and their origins grouped according to the design/origin and implementation stages.

Software provider	Software	Stage	Details
ABB	SmartVentilation	Design/Origin	Initial 800xA distributed control system (DCS), ABB solution for control, asset utilization and operator performance, adapted over time as per underground mine site requirements (Boliden mines, Sweden)
		Implementation	Boliden mines, Sweden
Bestech	NRG1-ECO	Design/Origin	NRG1-ECO designed through consortium for underground mining
		Implementation	CAF project, Coleman, Vale, Canada. Later implemented at Diavik Mine and Kidd Creek Mine. To be implemented at Totten Mine, all of them Canadian mines
Simsmart	SmartExec	Design/Origin	Initial control system designed for marine, submarin and fix facility, adapted for underground mining
		Implementation	CAF project, Nickel Rim South, Xtrata, Canada. Recently implemented at Eleonor Mine, both Canadian mines

Table 3 Ventilation control software origins.

As presented in Table 3 all three suppliers came from a control and engineering background to provide a solution for the underground mining challenge of managing the ventilation according to requirements. However Bestech – NRG1-ECO was the only solution benefiting from a consortium for its initial design that included seasoned senior ventilation experts as part of the design team and was specifically design for underground mine ventilation systems. Both ABB – Smart Ventilation and Simsmart – SmartEXEC were solid and proven solution for fix facilities adapted for underground mining environment. ABB and Simsmart had a partnership between 2009 and 2014, as a result the SmartExec software would be offered, if VOD was required, when the ABB DCS process was installed during that period of time.

3.3 Map of software features per level of implementation

As indicated in Table 2 the software packages for each level of implementation are different and equipped with various features. However these packages are not fully equivalent in terms of how their features are group per level of implementation.

Table 4 presents each of the three ventilation control softwares available considered in this paper, and their features grouped according to their definitions of levels. As presented in Table 4 all three suppliers consider level 1 as the manual control strategy, nevertheless the split for the remaining levels of implementation for each software can have some important differences and requires some details to be provided in order to fully understand that they are almost equivalent in terms of what they offer.

Both Bestech – NRG1-ECO and ABB – Smart Ventilation offer the capacity to control ventilation devices based on airflow volume PID control loops at the level 1, only Simsmart – SmartEXEC indicates that this features is only available at level 3. The authors did not find a reason for this particular arrangement of the “set point flow” feature, but suspect that Simsmart – SmartEXEC formulates level 1 as a pure manual mode, excluding any PID control loop from that level of control. To the end user this means that only at level 1 of implementation both Bestech – NRG1-ECO and ABB – Smart Ventilation will be able to deliver more savings.

Level 2, Bestech's "Time of day scheduling" commonly referred as just "Scheduling", is coupled with the "Event based" for Simsmart – SmartEXEC, and for ABB – Smart Ventilation "Scheduling" is coupled with "Event Based", "Environmental", and "Tagging". Level 3, Bestech's "Event Based", is already included in Level 2 of both Simsmart – SmartEXEC and ABB – Smart Ventilation. Level 4, Bestech's "Environmental", is included in level 3 of Simsmart – SmartEXEC, and level 2 of ABB – Smart Ventilation. Level 5, Bestech's "Tagging" is included in level 2 of ABB – Smart Ventilation, and level 4 of Simsmart – SmartEXEC.

<table>
<tr><th>LEVEL</th><th>ABB (Smart Ventilation)</th><th>Bestech (NRG1-ECO)</th><th>Simsmart (SmartEXEC)</th></tr>
<tr><td>Level 1</td><td>Manual (ABB 800xA)</td><td>Manual</td><td>Manual</td></tr>
<tr><td>Level 2</td><td rowspan="3">Level 2
Scheduling
Event based
Environmental
Tagging</td><td>Scheduling</td><td>Scheduling and Event based</td></tr>
<tr><td>Level 3</td><td>Event based</td><td>Set point flow and gas concentration control (Environmental)</td></tr>
<tr><td>Level 4</td><td>Environmental</td><td>Dynamic tracking (Tagging)</td></tr>
<tr><td rowspan="2">Level 5</td><td rowspan="2">Level 3
Energy optimization surface fans</td><td>Tagging (Auxiliary fans)</td><td rowspan="2">Energy optimization surface fans</td></tr>
<tr><td>-</td></tr>
</table>

Table 4 Ventilation control softwares and features grouped by levels.

An additional feature of the fifth level is offered by both ABB – Smart Ventilation and Simsmart – SmartEXEC, which is the Energy Optimization of main fans. This feature consists of modulating the main fans rpm to adjust the airflow volume provided to the mine according to the different levels aggregated demand. This is a very attractive feature conceptually, as it will allow reaching the ultimate level of savings through the main fans but both systems require the development and continuous update of a ventilation model of the mine for the feature to work.

4 Implementation

Considering that the implementation of these software packages is still fairly recent for mining applications, the amount of literature available describing the implementation is very limited, and most of it is concentrated in sales presentations from the different suppliers rather than formal conference and journal literature. The following Table 5 is a summary of the information gathered from literature search and discussion with suppliers. The authors did confirm verbally with most of the Canadian and Chilean mine sites that the information was accurate, but the Sweden sites were not reached and no formal information has been published in the related literature.

ABB reported three mines in Sweden that are using or implementing the Smart Ventilation, with no details of the level of implementation or savings achieved. For the rest of the Sweden mines reported by ABB using the 800xA control system, other than Malmberget Mine (Nensen and Lundkvist), it is assumed that only at level 1 "manual control" with no savings reported. On the Canadian side Totten Mine has fully implemented the ABB 800xA system for the ventilation control, using VFD on main surface fans, on/off auxiliary fans, regulators and doors with PID airflow control loop to generate the desire airflow distribution underground. The reported energy savings are about 25% using the manual control from the ABB system according to Flores and Acuña (2016). Totten mine has decided to move forward to a hybrid solution keeping the ABB 800xA control system, and implementing the Bestech – NRG1-ECO software to provide inputs and command the ABB 800xA control system. This implementation is scheduled for the third and fourth quarter of 2016 with an energy savings target of 50% of the overall energy consumption for main and auxiliary ventilation systems.

Software provider	Software	Mine	Company	Country	Level of implementation	Savings per year (CAD)	Estimated or Measured
ABB	800xA	Zinkgruvan	Lunding mining	Sweden		N/A	
ABB	800xA + Smart ventilation	Kristineberg	Boliden	Sweden		N/A	
ABB	800xA + Smart ventilation	Garpenberg	Boliden	Sweden		N/A	
ABB	800xA + Smart ventilation	Kankberg	Boliden	Sweden		N/A	
ABB	800xA	Malmberget	LKAB	Sweden		29%-40%	M
ABB	800xA	Kiruna	LKAB	Sweden		N/A	
ABB	800xA	Kittela	AngloEagle	Finland		N/A	
ABB	800xA	Totten	Vale	Canada	Manual	25%	M
ABB	800xA	Andina	Codelco	Chile	Manual	N/A	
Bestech	NRG1-ECO	Diavik	BHP	Canada	Manual, scheduling, environmental	600,000	E
Bestech	NRG1-ECO	Kidd Creek	Glencore	Canada	Manual and scheduling	N/A	
Bestech	NRG1-ECO	Coleman	Vale	Canada	Manual, scheduling, event based, environmental, tagging	N/A	
Bestech	NRG1-ECO	Fraser	Glencore	Canada	N/A	N/A	
Simsmart	SmartExec	Nickel Rim South	Glencore	Canada	Manual, scheduling, environmental, tagging	3,300,000	M
Simsmart	SmartExec	Eleonor	Goldcorp	Canada	Manual, scheduling, environmental, tagging	60%	

Table 5 Software implementation summary according to literature and providers.

On the Chilean side, Andina Mine is currently using the 800xA system and working on the implementation of the Smart Ventilation software. The authors could not find information available about the level of implementation targeted or savings.

Both Bestech – NRG1-ECO and Simsmart – SmartEXEC reported implementations are concentrated in Canada to-date of this paper. However, as per personal communication of the authors with the sales representatives, both companies reported that they are expanding across the world. Each mine site that has implemented the Bestech – NRG1-ECO solution has picked a different level of implementation starting at level 2 "Scheduling" at Kidd Creek Mine, level 4 "Environmental" at Diavik and level 5 "tagging" within a localized area of Coleman Mine.

Simsmart – SmartEXEC has reported good results in both of the Canadian implementations. Nickel Rim South Mine indicates 3,300,000 CAD savings per year, however from this amount only 2,000,000 CAD is direct savings from energy for fans and natural gas to warm up cold fresh air during winter time. There is no indication of the percentage of savings that this amount represents. The remaining 1,300,000 CAD is the result of provincial incentives. Nevertheless the complete amount was achieved due to the implementation of the ventilation on demand system. Eléonor Mine has reported impressive results but in terms of percentage only, 43% savings on natural gas consumption to warm up cold fresh air during winter time, 56% savings on auxiliary fans energy consumption and 73% on main fans energy consumption. In total this equates to 60% overall savings considering both energy and natural gas. However, the baseline considered was the design calculation and not the measurement of the system consumption at 100% capacity.

5 Discussions

5.1 Naming convention Ventilation On Demand (VOD) or Ventilation Control System (VCS)

Considering the first three control strategies it could be argued that there is no real time knowledge of where the personnel and equipment are. These three initial control strategies are based on the "expected" distribution and as such it could be misleading when using the concept of Ventilation On the Demand, as it is not based on the real time location of personnel and equipment but on the "expected" location of personnel and equipment. It also implies that mines executing these control strategies need to put procedures in place to control and guarantee that the allocated airflow per level and heading is not exceeded, which could be very challenging for a dynamic underground operation. Over 30 years ago (1980's) when the concept of VOD was being proposed, the idea was that the technology would go straight to the stage of controlling air volume based on the equipment in the area. As the technology evolved, it became evident that a more flexible approach was required to make a more practical solution.

As a result it could be deemed that the first three control strategies are not a "true VOD" and that only the last two would meet the original intent of VOD. Overall, when understanding the different control strategies or levels of implementation, referring to a ventilation control system (VCS) or ventilation management system (VMS), as initially proposed by Bestech, seems to be a more accurate naming convention to better define the concept that has been addressed over time as ventilation on demand (VOD). The two main reasons why the authors prefer to refer to the concept as a ventilation control system or ventilation management system, instead of ventilation on demand system, is because it is based on different levels of control strategies for the ventilation systems and also because for the first three control strategies, the concept of ventilation on demand can be misinterpreted and misleading to think about the real time location of personnel and equipment or contaminants distribution instead of the "expected" distribution.

5.2 Factors to consider when reviewing the software packages

ABB – Smart Ventilation will probably have to break down his approach of 3 levels into more levels as it gets implemented in more mines due to the extend cover only by level 2 and how that could affect the pricing offer to the potential customer that are not looking for the full blown implementation. As a result, for the levels from 2 to 4, Bestech – NRG1-ECO and Simsmart – SmartEXEC will allow the customer to choose only what it is required or needed to implement instead of buying a full package that is not necessary planned to be fully implemented. Bestech – NRG1-ECO will have to start developing "Energy Optimization of main fans" feature, in order to offer the possibility to achieve the last step in terms of savings at the main fans. Currently that can be somehow achieved through the supervised use of the level 2 "Scheduling" but not to the full extend. Hopefully this feature can be achieved without the need of a ventilation model which will then significantly reduce the hours of support required by the customer to keep the software running. Finally, Simsmart – SmartEXEC will probably have to consider making available at the level 1 of implementation the control of ventilation devices with the PID control loop based on airflow sensor readings which is referred as the "set point flow" in level 3 to match the current offer of both competitors. Overall, even considering the different background of the software packages, it is important to note that they have reached an important level of convergence in terms of the features they offer per level of implementation, and from the customer perspective it can be hard to differentiate without going through a detail technical and economic study which solution offers the best value over time for every specific mine site.

When considering remaining capacity at the main fans the implementation of the "Energy Optimization of main fans" can potentially offer important savings, however these do not come for free as for both ABB – Smart Ventilation and Simsmart – SmartEXEC. This requires the development, maintenance and accuracy of a ventilation model that reflect the airflow and pressure distribution of the mine. This ventilation model has to be updated on a regular basis, which in both cases might probably require the software supplier personnel to be supporting the mine site every time a change to the model is made like adding a mine level or connecting raises and ramps. According to the author's knowledge this is the case of the sites that have implemented the ABB – Smart Ventilation and Simsmart – SmartEXEC software package considering level 5 "Energy Optimization of main fans" (for ABB – Smart Ventilation that correspond to level 3). The "Energy Optimization of main fans" feature will only be useful if there is any remaining capacity at the main fan systems. In case the primary fan systems are running at their maximum capacity due to the diesel equipment that needs to operate at all times underground, then the application of this feature will not be able to offer any additional potential savings that cannot be achieved through the use of the level 2 "Scheduling". In many operations it is the case that the main fans are operating at full capacity, but the total HP underground does not require that amount of airflow at all times. In such case the implementation ventilation on demand through "Tagging" and the modulation of surface fans could offer the potential to reduce the airflow amount deliver to the mine. However it also opens the opportunity to target simultaneously another development or production area with the same airflow capacity, assuming the equipment could be available. In this case again the implementation of the "Energy Optimization of main fans" might not be of interest as the benefits of having an extra development or production area should be several times larger than the potential savings that could be achieved in terms of energy.

In terms of savings it is hard to compare as different methodologies were used to estimate these value and there not enough information available to standardize the values obtained to compare. Nevertheless, with energy savings being reported in the range of 25% to 60%, these numbers are very encouraging as they indicate that potentially half of the energy spent for ventilation could be saved. That is probably the most important result to report in this paper in terms of the application of ventilation control systems to deliver ventilation on demand. An important point that has to be considered but has not been given much attention is the definition of which solution is feasible for each mine site and what is the level of maintenance required to keep it running and achieve the expected savings. The deployment of this technology and its maintenance through time is not trivial and could cause the implementation to fail. However at this early stage of implementation the literature available is very limited.

6 Conclusions

This study presented the state of the art of the implementation of ventilation control system in North America and Sweden to deliver what is known as ventilation on demand. The paper outlines a detailed description of the different control strategies and levels of implementation to facilitate the reader understanding of what a ventilation control system can deliver and that ventilation on demand is only achieved coupled with a tag and tracking system or where fully deployed sensor system is in place and with the regulation permitting it. The different control strategies were mapped to the definitions of levels provided by each software supplier to show that they offer mostly the same capabilities. A detailed list of implementations and reported savings was provided also showing that in terms of number of sites implemented these softwares are still at an early stage of development considering that the softwares have been used for about 7 years so far. The discussion presented on the current state of the software development and also considerations in selecting a solution. Overall all of them seem equivalent in terms of the capability available and will depend on each mine site detailed evaluation which one will be the best solution for the extent of implementation that they are targeting. In terms of savings achieved the current implementation of the softwares has shown the potential to achieve 50% savings or more when considering energy for main and auxiliary fans and also natural gas.

References

Tran-Valade, T & Allen, C 2013, 'Ventilation-On-Demand key consideration for the business case', in Canadian Institute of Mining (CIM) Convention: proceedings of the Toronto 2013 CIM Conference, Toronto, Canada.

Lyle, G, Bullock, K, Dasys, A & Hardcastle, S 2010, 'Ventilation-On-Demand Project', in Mining Diesel Emissions Council (MDEC): proceedings of the Toronto 2010 Conference, Toronto, Canada.

Flores, O & Acuña, E 2016, 'Improving monitoring and control hardware cost at Totten Mine', in Canadian Institute of Mining (CIM): proceedings of the Maintenance, Engineering and Reliability / Mine Operators (MEMO) 2016 Conference, Sudbury, Canada.

Nensen, P & Lundkvist, A, 'From 167 GWH to 72 GWH – Ventilation On Demand in LKAB's Iron Ore Mine, Malmberget', Parallel session on innovative energy efficiency examples of different industrial sectors – energy efficiency in the cement, metal and petrochemical industry. n.d.

Sudbury Mining Solution Journal 2007, News. Available from: http://www.sudburyminingsolutions.com/bestech-celebrates-sale-to-barrick.html

Ontario Mineral Exploration Review 2011. Available from: http://www.bestech.com/wp-content/uploads/2015/03/Ontario-Mineral-Exploration-Review-2011.pdf

International Mining, October 2011. Available from: http://www.bestech.com/wp-content/uploads/2015/03/International-Mining-2011.pdf

Value Mine Research 2012, Ventilation On Demand – CAF (Community Adjustment Fund). Available from: https://www.miningexcellence.ca/?p=2577#

Pinssar's Ambient Air Monitoring Reader: Technical Specifications. Available from: http://pinssar.com.au/files/blog/pinssar_aams_reader_spec_sheet_aug14.pdf

DustMon. Available from: http://www.maestroventilation.com/products/dustmon-dust-monitor-for-underground-haulage-roads

Decreto Supremo (D.S.) 132. Available from: http://www.sernageomin.cl/pdf/mineria/seguridad/reglamentos_seguridad_minera/DS132_Reglamento_SEGMIN.pdf

Decreto Supremo (D.S.) 594. Available from: http://www.dt.gob.cl/1601/w3-article-59796.html