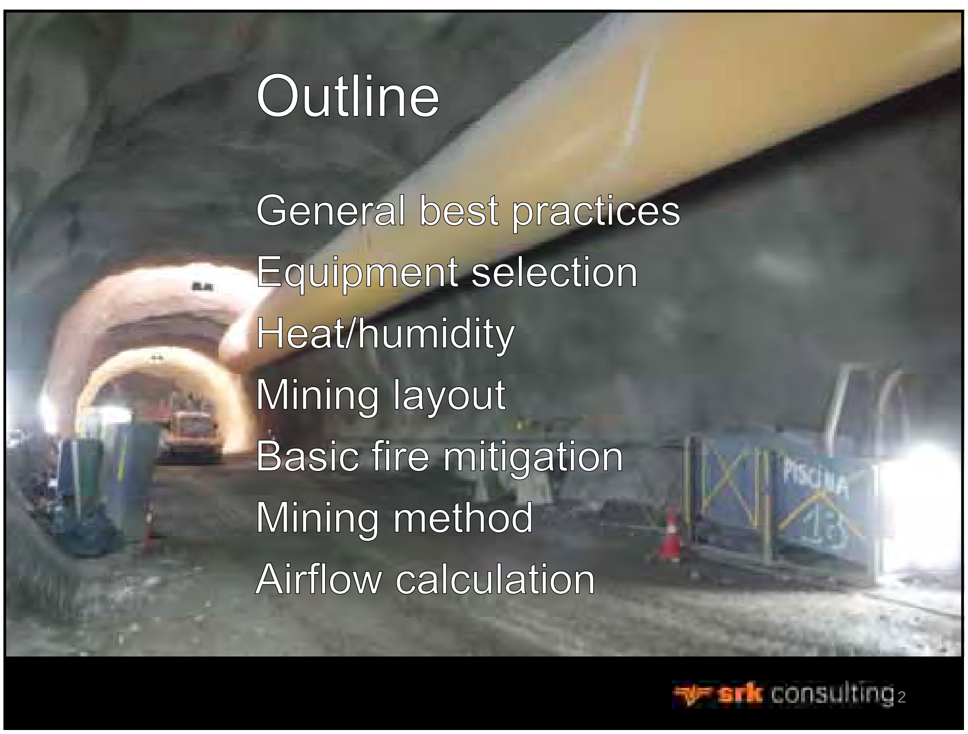

Ventilation Design Process
Brian Prosser, PE
Principal Consultant
Mine Ventilation Services/SRK
srk consulting
1


Outline
General best practices
Equipment selection
Heat/humidity
Mining layout
Basic fire mitigation
Mining method
Airflow calculation
PISCINA
18
srk consulting
2

General Best Practices

Why do we ventilate mines?

The objective of underground ventilation is to provide airflows in sufficient quantity and quality to dilute contaminants to safe concentrations in all parts of the facility where personnel are required to work or travel. (McPherson)

We design ventilation systems to ensure health and safety, not just to meet minimum legislative requirements.

srk consulting 3

General Best Practices

What is "best" in a hot mine may not be "best" in a cold mine, what is "best" in potash may not be "best" in a stope mine, etc.

- Design and operating procedures and practices that are described as being correct and effective.
- Best practices are not the end all – be all of design development, but represent a good place to start.
- Each mine, mining method, location, and ore type requires different approaches and consideration.
- "Best Practices" will change from person to person, and/or place to place.

srk consulting 4

Best Practices and Regulations

Regulations should follow along the lines of "best practices" however, this is not always the case.

Meeting the regulatory requirements should represent a "minimum" design.

Following best practices will often create a design that is more robust than the regulatory requirements.

General Examples

Air supplied to a working area can come from a haulage ramp (legally ok)

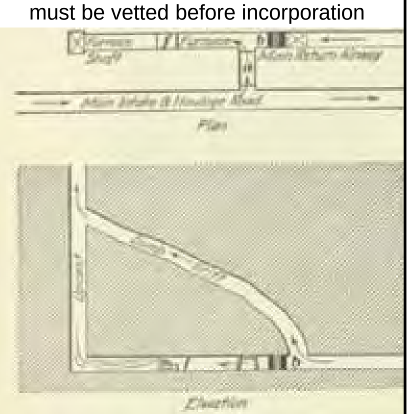
- *Best practice would be to supply air from an alternate source (risk avoidance, air quality)*

Emergency egress can be through an exhaust route (legally ok)

- *Best practice would be to egress through fresh air*

Best Practices Will Change Over Time

- What was "state of the art" in the past will be superseded as new technology is developed.
- But as with any new technology it must be vetted before incorporation



ICS Reference Library, Volume 145, 1907, Fig 15 & 16

srk consulting 7

Literature

This is a starting point, not an exhaustive list

Its always good to start with what other people have already done;

Ventilation Symposium
Published/Peer Reviewed Papers and Designs
Well Ventilated Operating Mines (Similar Designs)
NIOSH
  Chekan
Mine Design Wiki
  Hardcastle and Kocsis
Mine Ventilation Australia
  Brake
Mine Ventilation Services/SRK
  Prosser & Wallace
HSE Occupational Health in Mines Committee
  Gilmour et al.
Pittsburgh Safety and Health Technology Center
  Schultz
Minerals, Metals and Materials Technology Centre
  Kurnia and Mujumdar

srk consulting 8

Realize that mitigation strategies for individual hazards will provide a load on the ventilation system

NIOSH - Chekan

Dust Control in Metal/Nonmetal Underground Mining

Crushers and Truck Dumps

- Isolate dust sources from ventilation system
- Airflow to direct dust directly to the exhaust
- Localized Fans installed as close to the dump as possible
- Operators booth should be equipped with filtration systems

srk consulting 9

Redundant systems will increase the airflow requirement above what is required for simple overall dilution

Mine Ventilation Australia - *Brake*

- One pass ventilation system with dedicated fresh air supply to each mining area.
- Haulage ramps developed as neutral intake.

srk consulting 10

General Comments

- Although with enough design and engineering almost anything can be justified.
- What happens if “engineered” solutions fail?
- How can the ventilation systems be designed to promote success?
- What basic design parameters can be adjusted to provide a basic level of coverage?
- These would be considered “<u>best practices</u>”.

Design Criteria
Equipment Airflow Requirement

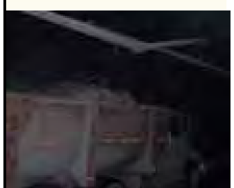
Airflow quantity evaluation is a multi-faceted problem, simple justification by a single parameter is not sufficient

Airflow requirement cannot be based on a single parameter. Multiple parameters need to be met:

- Gas Dilution
- Diesel Particulate
- Heat
- Minimum Velocity

Design Criteria - Diesel

Examples;
0.08 m^3/s per kW for general use in the US
0.06 m^3/s per kW for general use in Ontario or Chile
0.05 m^3/s per kW for general use in Western Australia



- For general ventilation planning a fixed value of cfm/bhp (m^3/s per kW) provides for basic airflow allocations and different engine manufacturers/emissions controls.
- Dilution values for specific equipment based on NIOSH and CANMET testing is also useful as a minimum but may restrict the versatility of the system.

srk consulting 3

Design Criteria - Diesel

- Lower values can be used based on tested dilution factors but they must be balanced with other parameters (minimum air velocity, and heat).
- Remember that not all equipment in use in the mine will be maintained in an “as new” manner.
- Availability of ultra low sulfur fuel may not be sufficient.

srk consulting 4

Design Criteria – Air Velocity

Minimum Velocity
- Dust, safety, heat

Maximum Velocity
- Dust, visibility, safety, comfort

srk consulting 5

Design Criteria – Air Velocity

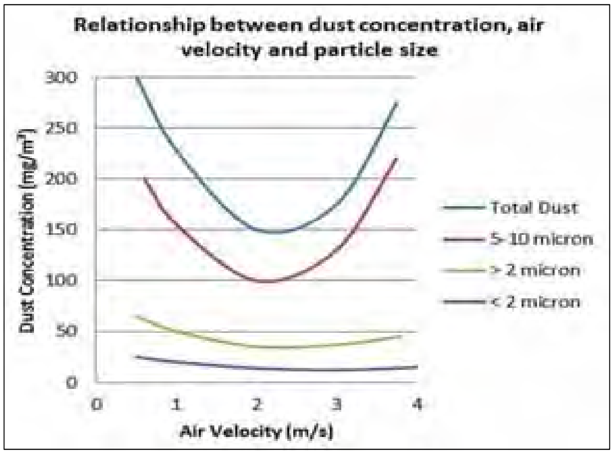
<u>Minimum</u>

- Perceptible movement as a minimum for general areas.
- Perceptible movement is generally between 60 ft/min and 80 ft/min. However, for planning purposes we suggest a slightly higher value 100 ft/min.
- Entrainment of dust, 1.5 m/s to 2.5 m/s.

(Vutukuri)

srk consulting 6

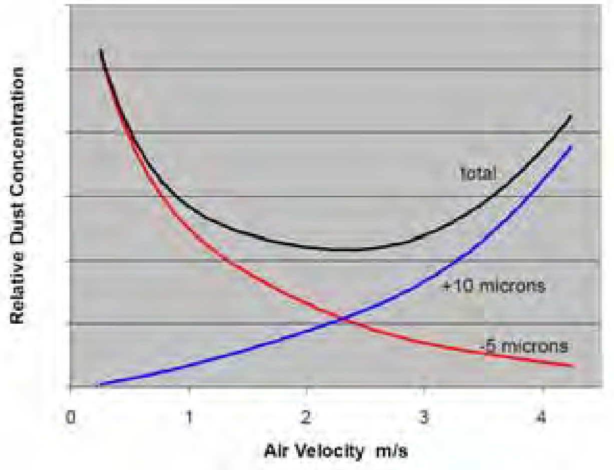
Design Criteria – Air Velocity



(Vutukuri)

srk consulting 7

Design Criteria – Air Velocity



After McPherson and Vutukuri

srk consulting 8

Design Criteria – Air Velocity

Maximum

- Visibility – dust
- Comfort (not more than 4 m/s)
- Economics (should be evaluated for each region location)
- Safety – Skip/Cage Stability (10 m/s rope guides, 20 m/s for engineered systems with high capital costs)
- Water Blanketing (not between 7 m/s to 12 m/s)

Area	Velocity (m/s)
Working faces	4
Conveyor drifts	5
Main haulage routes	6
Smooth lined main airways	8
Hoisting shafts	10
Ventilation shafts	20

(McPherson)

Design Criteria – Air Velocity

Conveyors generally move ore out of the mine, which means that the air source for the conveyor is additive to the overall ventilation load, unless exhaust air is used

Conveyors

- Airflow should move in the same direction as the conveyor belt (homotropal).
- Antitropal flow can be achieved but it should be designed to minimize dust (water, moisture content, covered conveyor, dedicated conveyor exhaust).
- As we move away from homotropal flow additional features must be designed into the system.

Design Criteria - Heat

Just because a mine is not "deep" does not mean heat will not be a factor. Influx of hot/warm water, surface conditions, equipment load, and airflow quantity all contribute to heating issues

- Flow through ventilation system
- Fans should be exhausting, heat loads should be placed near exhaust routes, fresh air routs should be clear of fixed equipment.

Design Criteria - Heat

- The ACGIH (among others) chooses to utilize wet-bulb globe temperature (WBGT) as the basis for establishing TLVs, or other action levels based upon heat stress.
- In addition to the ACGIH, WBGT has been recommended for use as an index of heat stress by NIOSH (NIOSH, 1986) and is also specified in the International Standard (ISO, 1982).
- However useful WBGT is for evaluating conditions in existing mining environments it is not easy to measure. This makes it necessary to rely on more traditional (if less telling) indicators of climate (e.g., wet-bulb temperature, dry-bulb temperature, humidity, effective temperature) (McPherson, 2009).
- Cognitive processing and the ability to perform even routine manual tasks is also impaired by heat stress under some environmental conditions (Hardcastle, 2012).

Design Criteria - Heat

TLV and Action Limit for Heat Stress Exposure (ACGIH, 2007).

Allocation of Work in a Cycle of Work and Recovery	TLV (WBGT values in °C) Light	Moderate	Heavy	Very Heavy	Action Limit (WBGT values in °C) Light	Moderate	Heavy	Very Heavy
75% to 100%	31.0	28.0	N/A	N/A	28.0	25.0	N/A	N/A
50% to 75%	31.0	29.0	27.5	N/A	28.5	26.0	24	N/A
25% to 50%	32.0	30.0	29.0	28.0	29.5	27.0	25.5	24.5
0% to 25%	32.5	31.5	30.5	30	30.0	29.0	28.0	27.0

- Some companies use a reject wet bulb temperature of 26.5°C
- Some companies use a reject wet bulb temperature of 28°C

srk consulting 23

Mine Layout - Auxiliary Ventilation Systems

Fundamentally, subsurface ventilation systems are designed to remove the contaminants of dust, gases and heat from the underground environment. This is accomplished by dilution of the contaminant(s) in question, removal from the affected area, or both.

Dilution of dust and gaseous contaminants involves a relatively simple calculation directly proportional to the relative volumes of air and the contaminant.

The removal on contaminants is dependent upon the velocity of the ventilating airstream, along with the fundamental design of the ventilation infrastructure, e.g. the location of intake/return airways, raises, etc.

srk consulting 24

Mine Layout - Auxiliary Ventilation Systems

The choice of a blowing (forcing) system of ventilation versus an exhausting system will also have an impact not only on the ventilation system design, but also may impact the tunnel design itself (such as the locations of various connections or fixed facilities, or the need and location(s) of ventilation controls such as doors and regulators.

Each of these types of systems has its own properties and thus its own benefits and drawbacks, they can be more suited to certain types of designs than others.

This process is often iterative; a design is selected, its benefits and consequences examined, and then if necessary an alternative is implemented.

srk consulting 25

Mine Layout - Auxiliary Ventilation Systems

Long or extended auxiliary ventilation systems often require "booster" fans to be installed.

- The installation of these fans needs to be "engineered".
- Often gaps are left between the discharge of the duct and the next fan. (not a best practice).
- Sometimes the duct will discharge into a closed alcove where the booster will draw air from (not a best practice)
- Upstream duct and booster fan need to be joined.
- Hardline duct, pressure relief dampers, proper fan spacing can all be used.

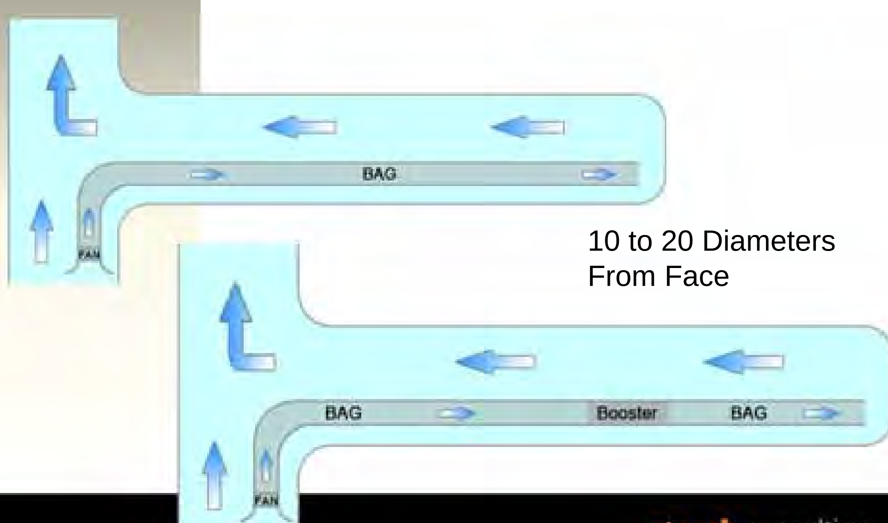
srk consulting 26

Mine Layout - Auxiliary Ventilation Systems

Planning for Duct Booster Fans

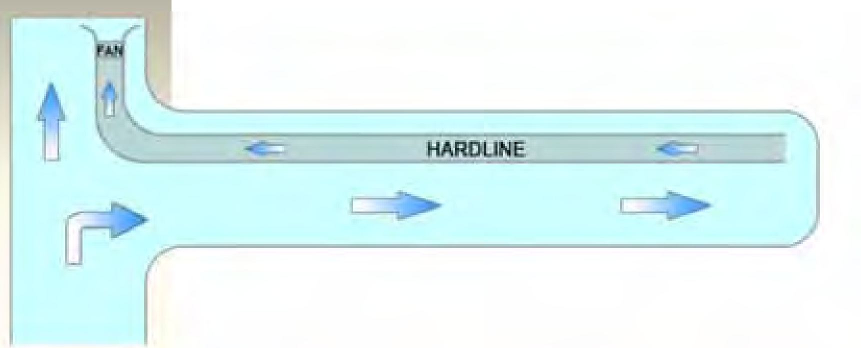
srk consulting 27

Mine Layout - Auxiliary Ventilation Systems

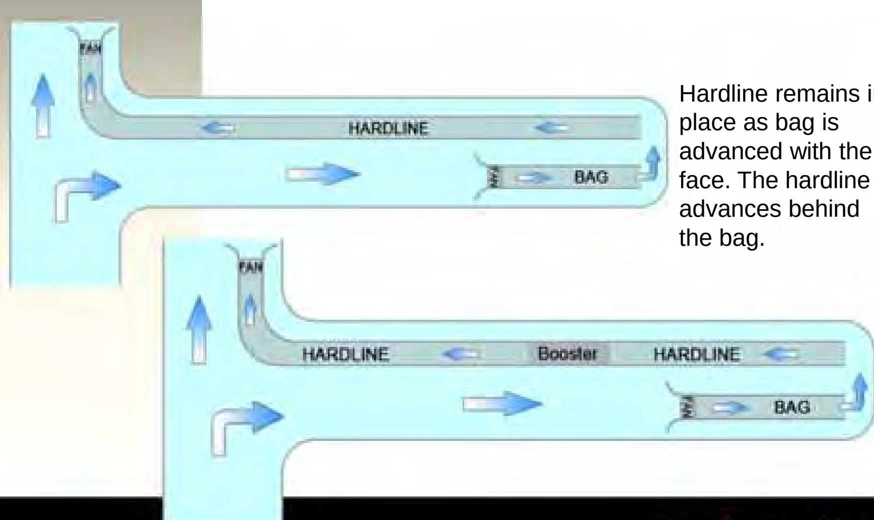


srk consulting 28

Mine Layout - Auxiliary Ventilation Systems

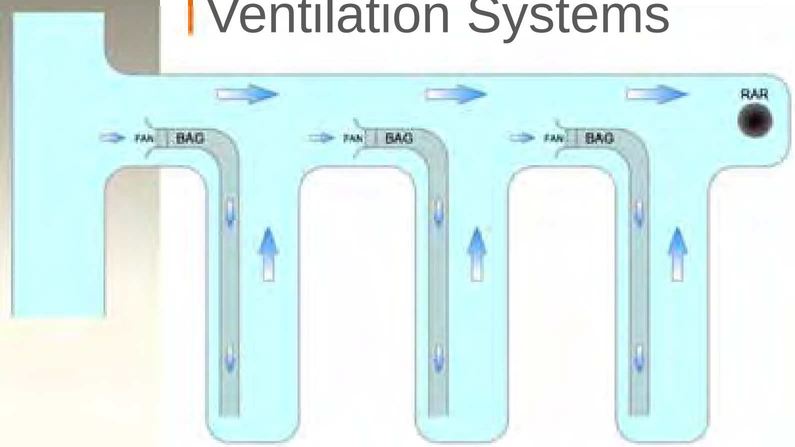


Mine Layout - Auxiliary Ventilation Systems



Hardline remains in place as bag is advanced with the face. The hardline advances behind the bag.

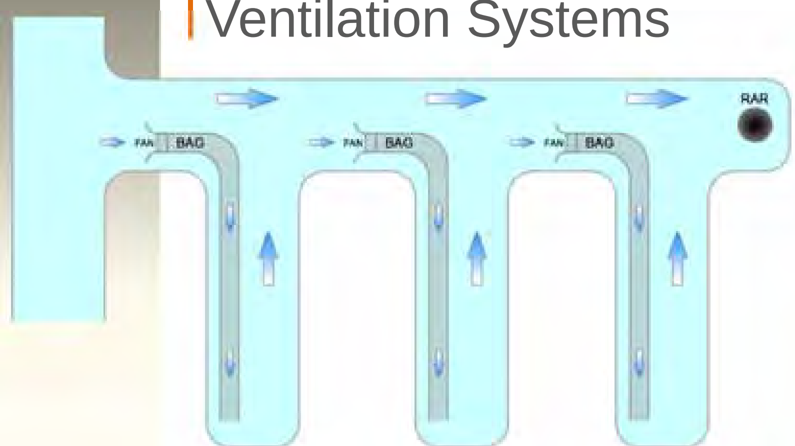
Mine Layout - Auxiliary Ventilation Systems



- Each mining area receives adequate airflow, but the air supplied to the downstream face will receive partially contaminated air.
- Airflow gets progressively more contaminated the further along the level it travels.

srk consulting 31

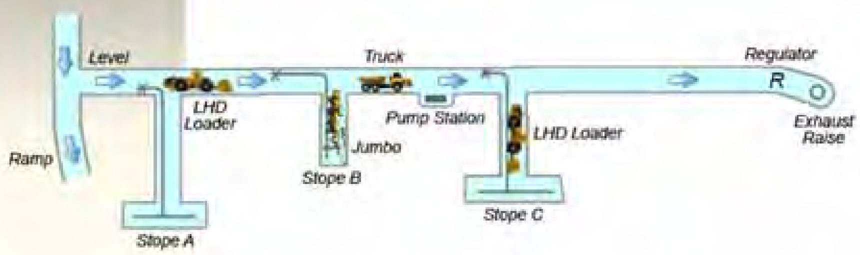
Mine Layout - Auxiliary Ventilation Systems



- Fresh air is supplied directly to the mining areas
- Minimum airflow quantities and velocities need to be examined for the main level access
- Duct integrity needs to be managed closely

srk consulting 32

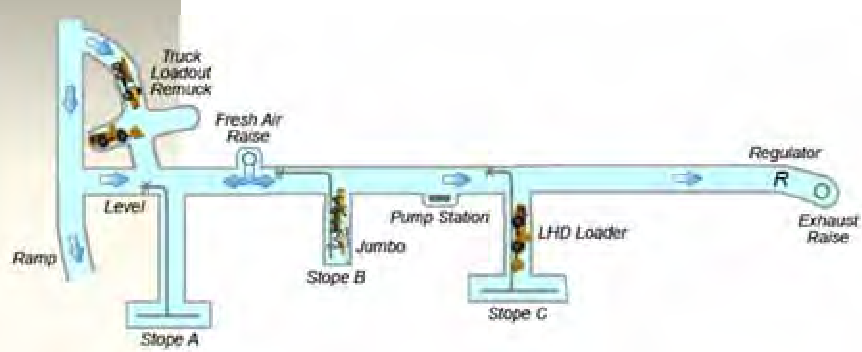
Level - Truck Loading



Loading trucks on the level greatly increase the airflow requirement on the level and diminishes the air quality.

srk consulting 33

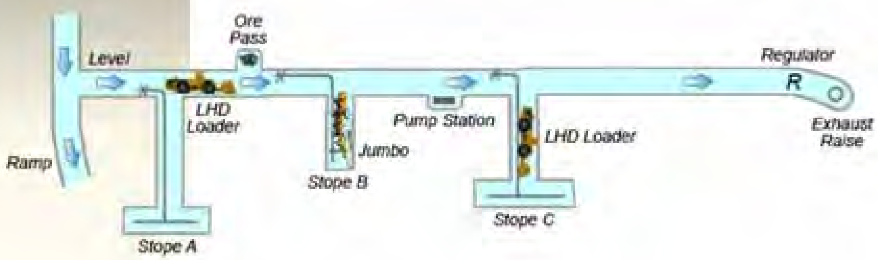
Level - Truck Loading



Loading trucks in the ramp or in a ramp “bypass” keeps the truck airflow requirement off the level.

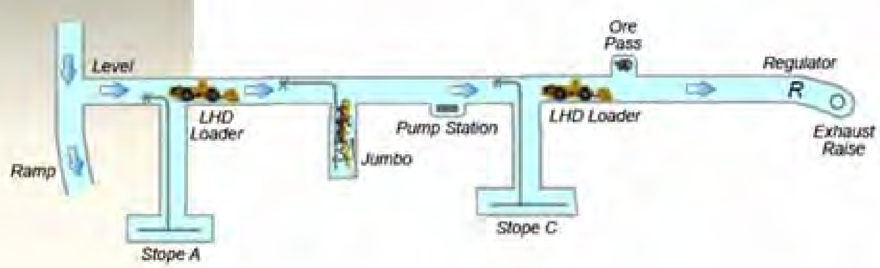
srk consulting 34

Level - Ore Passes



If an ore pass is located in the airstream feeding the stopes then there will be an increased risk of dust contamination.

Level - Ore Passes



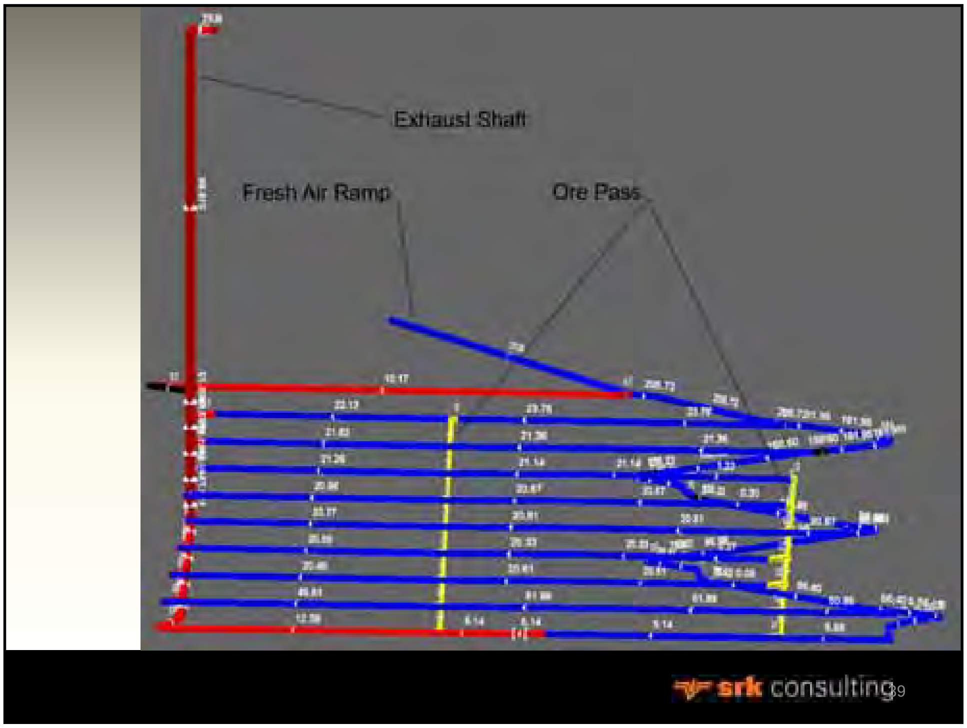
Ore passes should be located such that their impact on the level can be minimized.

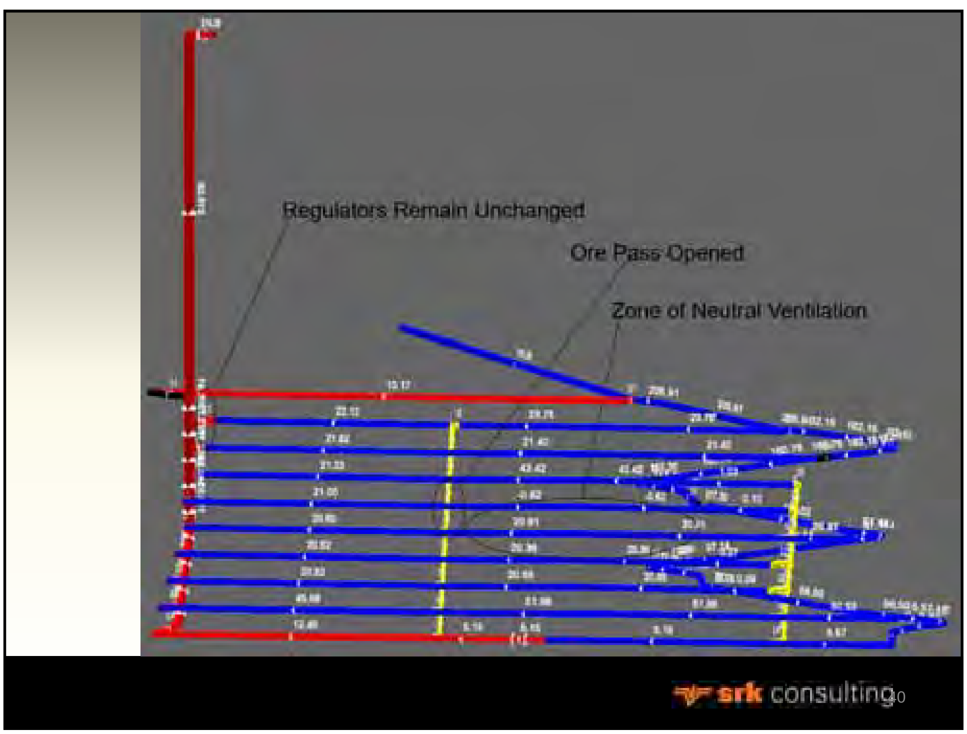
Ore Pass Issues

- Ore passes are frequently used in multi-level metal mines.
- Much of the time the ore passes are modeled with either a high resistance or are omitted from the model.
- Is this really the case?
- What happens when an ore pass is opened?

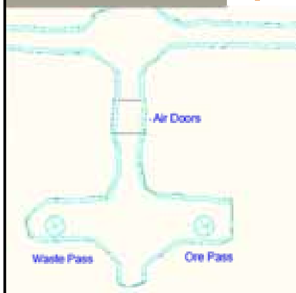
Ore Pass Issues - Continued

- Short circuiting of air from one level to the next.
- Injection of dusty air onto the level.
- Uncontrolled disruption in the ventilation system.
- Improper location of Ore Pass accesses


Exhaust Shaft
Fresh Air Ramp
Ore Pass
srk consulting 39


Regulators Remain Unchanged
Ore Pass Opened
Zone of Neutral Ventilation
srk consulting 40

Ore Pass Control



Isolated "Alcoves"

LHD Plugs/ Covers

Conveyor Belt Flaps

Automatic Lifters

Ore Pass Modeling - Strategy

- Ensure the control technique in the model matches the technique to be used in the mine.
- Conduct a sensitivity analysis to determine the effect of the leakage route.

Ventilation System Design with Respect to Minimization of DPM

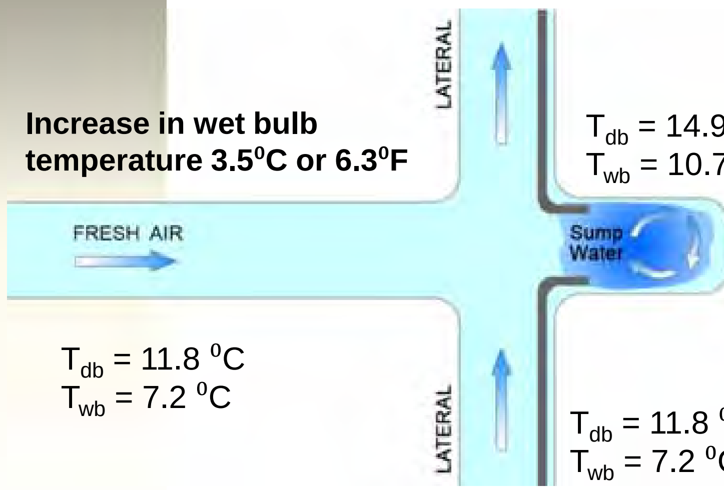
- One pass ventilation circuit minimizes DPM concentrations.
- Full airflow allocation required for dilution – previous 100% (dilution for largest piece of equipment), 75% (second largest), 50% (all other equipment) rule should not be used.

Ventilation Design with Respect to Minimization of Heat Loads

- Differences between electric equipment and diesel equipment.
- Forcing and exhausting duct systems, temperature increases across auxiliary fans.
- Keep auxiliary duct systems to a minimum and keep duct lengths short.
- Keep water away from the air splits.

Consequences of Not Covering Sumps – Real Life Example

Increase in wet bulb temperature 3.5^{0}C or 6.3^{0}F



T_{db} = 14.9 ^{0}C
T_{wb} = 10.7 ^{0}C

T_{db} = 11.8 ^{0}C
T_{wb} = 7.2 ^{0}C

T_{db} = 11.8 ^{0}C
T_{wb} = 7.2 ^{0}C

Shop, Fuel Bay, and Garage Ventilation

- Establish Minimum Velocities
- Use air changes for airflow evaluation
- Air change rationale
- Discharge or exhaust location
- Isolation doors
- Fire suppression

Shop, Fuel Bay, and Garage Ventilation

- Example Air Change Rates
- Assumptions are built into rates like welding fume hoods, hookups for diesel exhaust extraction at tailpipe.

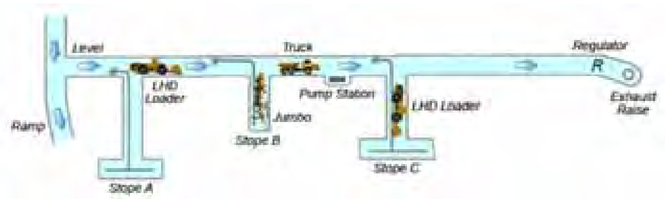
Location	Minutes per Air Change
Training Room	6
Offices	5
Warehouse Areas	7
Electrical Room	6
Service Bay	3
Sanitary Facilities	5
Lunchroom	5

Airflow Calculation Based on Air Change Rates

Location	Area Dimensions (m)			Minutes per Air Change	Volume (m^3)	Airflow (m^3/s)	Number of Areas	Total (m^3/s)
Office	5	5	60	5	1500	5.0	3	**15.0**
Training	5	5	60	6	1500	4.2	2	**8.4**
Warehouse	7	6	80	7	3360	8.0	2	**16.0**
Service Bay	7	6	40	3	1680	9.3	6	**18.6**
Total airflow								**58.0**

- Contaminants directed to exhaust at point of origin
- Fans can be used to provide localized flow direction
- Fuel Bays and lubricant storage areas should be directly exhausted (isolation or fire doors)

Airflow Calculation - Diesel



CAT R1700 LHD Loader

CAT AD30 Truck

CAT R1700 263 kW x 2 x 0.06 $m^3/s/kW$ = 31.6 m^3/s

CAT AD30 305 kW x 1 x 0.06 $m^3/s/kW$ = 18.3 m^3/s

Total Airflow for Level = 50 m^3/s

srk consulting 29

Airflow Calculation – NIOSH/MSHA

CAT R1700 LHD Loader

CAT AD30 Truck

MSHA Web Site Approved Equipment List

				Dilution	PI
7E-B018	CATERPILLAR	3406E ATAAC	400 @ 2100	18500	13000

Truck – Diesel Dilution = 18,500 cfm (8.73 m^3/s), DPM 5x13,000 = **65000 cfm (30.68 m^3/s)**

				Dilution	PI
7E-B018	CATERPILLAR	3406E ATAAC	360 @ 2100	17000	14000

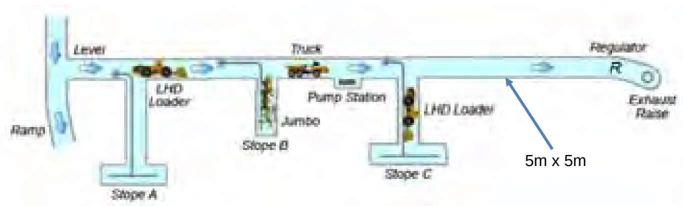
LHD – Diesel Dilution = 17,000 cfm (8.02 m^3/s), DPM 5x14,000 = **70000 cfm (33.04 m^3/s)**

Total Level Airflow (Diesel Dilution)– 8.73+8.02+8.02 = 24.77 m^3/s

Total Level Airflow (DPM Dilution to 160)– 30.68+33.04+33.04 = 96.76 m^3/s

srk consulting 30

Airflow Calculation – Minimum Velocity



High equipment usage area, Equipment loading, Dust Generation

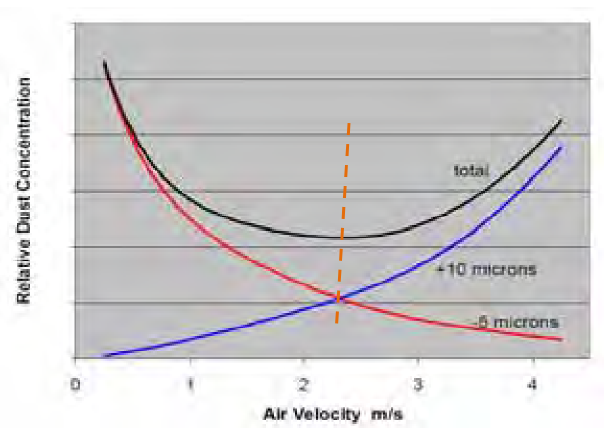
Cross Sectional Area with 95% Arch Factor

$2\text{m/s} \times (5\text{m} \times 5\text{m} \times 95\%) = 47.5\ \text{m}^3/\text{s}$

Minimum Air Velocity, See Dust Figure Above

srk consulting 31

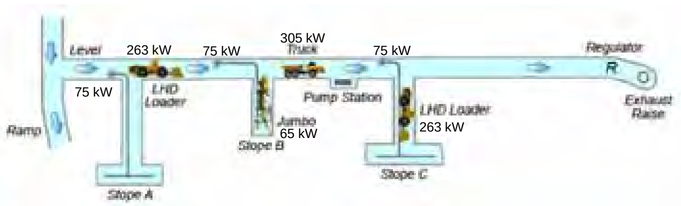
Airflow Calculation – Minimum Velocity



srk consulting 32

Airflow Calculation - Heat

Heat loads are equipment, power stations, sumps, concrete/fill, and explosives



When considering heat loads, all heat loads (electric and diesel are considered)

Equipment Load For This Example

- 1 305 kW truck
- 2 263 kW LHD
- 1 65 kW Jumbo
- 3 75 kW Auxiliary Fans

Airflow Calculation - Heat

Equipment need to have a basic motor utilization added (average % of full load)

Equipment Heat Loads

- 1 305 kW truck, Utilization 50%, Diesel
- 1 263 kW LHD, Utilization 75%, Diesel
- 1 263 kW LHD, Utilization 50%, Diesel
- 1 65 kW Jumbo, Utilization 100% Electric
- 3 75 kW Auxiliary Fans, Utilization 75% Electric

Diesel equipment need to have a value of water per liter of fuel added (3.2 liters/liter for this example) (values between 1.1 and 1.5 have been determined in laboratory analysis but can reach as high as 9 in field studies)

Simulation or Calculation Programs are used for this; CLIMSIM, VentSIM, VUMA, and Others.

Rock Mass Heat Loads

Airflow Calculation - Heat

Level Inlet Conditions 27°C Dry Bulb/23°C Wet Bulb, Barometric Pressure 101.325 kPa

Depth – 1310 meters below collar elevation

Friction Factor – 0.012 kg/m^3

Drift Wetness Factor – 0.15

Virgin Rock Temperature – 27.2°C

Geothermal Step – 30 meters per °C

Conductivity 4.2 W/m°C

Diffusivity 1.5 m^2/sx10^{-6}

Fine Tuning Heat Related Items Not Used In This Example (Omitted for Simplicity)

Airflow Calculation - Heat

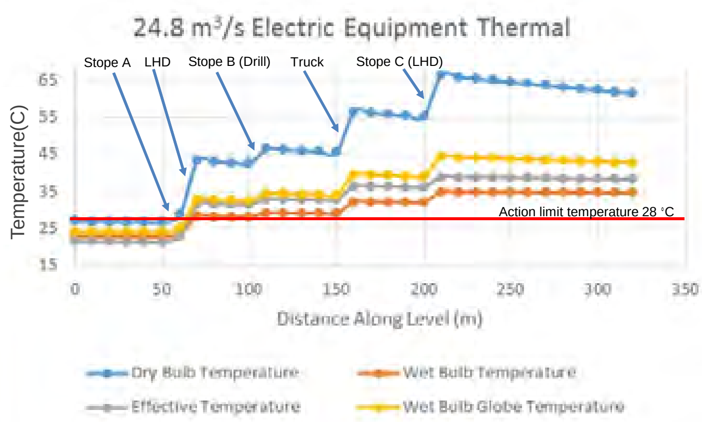
Additional parameters not included in this example;

- Sumps
- Broken Ore/Muck
- Transformer Stations
- Compressed Air (provides slight cooling)
- Use of Explosives

Airflow Calculation – Heat, Diesel Equipment (Airflow from NIOSH/MSHA)

In general, diesel equipment produces 2.3 to 2.6 kW heat per kW work

Assume 1300m Level inlet conditions are 27C dry bulb temperature and 23C wet bulb temperature

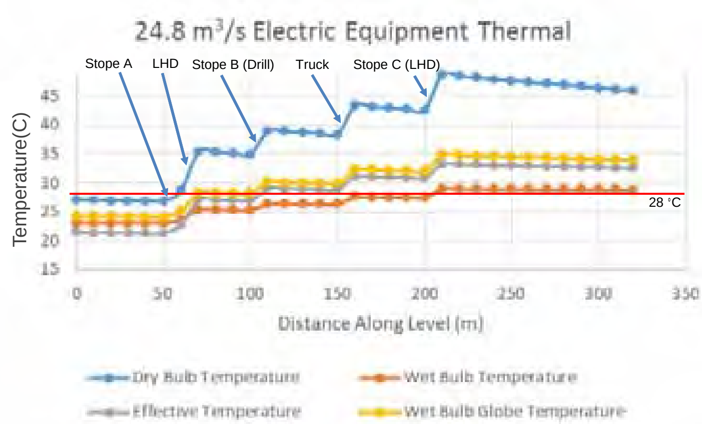


srk consulting 57

Airflow Calculation – What if All Electrical Equipment is Used? (Airflow from NIOSH/MSHA)

Dry bulb temperature is still very high, wet bulb temperature is just above 28°C

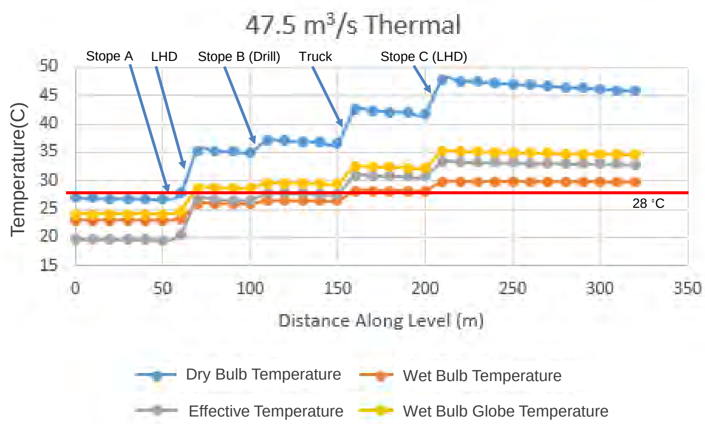
If all of the diesel equipment is replaced with electric equipment then the wet bulb temperature will be depressed by approximately 2 ½ °C



srk consulting 58

Airflow Calculation –
Heat Diesel Equipment
(Airflow from General Dilution/Velocity)

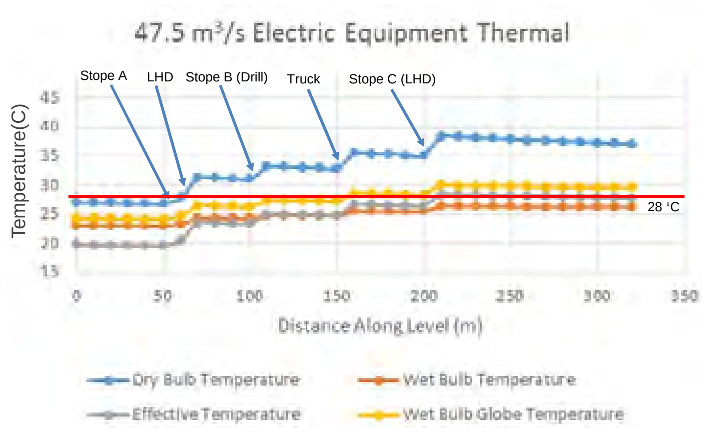
Assume 1300m Level inlet conditions are 27°C dry bulb temperature and 23°C wet bulb temperature



srk consulting 59

Airflow Calculation –
What if All Electrical Equipment is Used?
(Airflow from General Dilution/Velocity)

If all of the diesel equipment is replaced with electric equipment then the wet bulb temperature will be slightly below 26.5°C

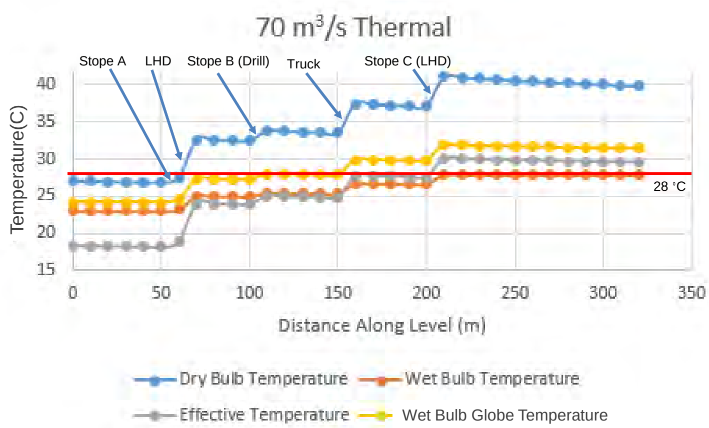


srk consulting 60

Airflow Calculation – Heat Diesel Equipment

Assume 1300m Level inlet conditions are 27C dry bulb temperature and 23°C wet bulb temperature

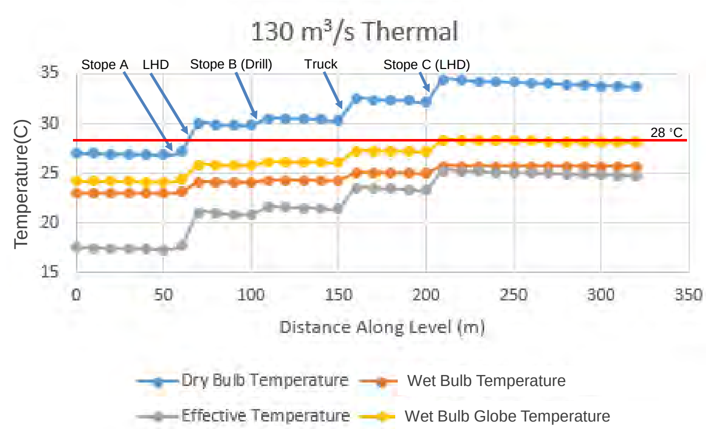
70 m³/s would be required to maintain the wet bulb temperature below 28°C



srk consulting 31

Airflow Calculation – Heat Diesel Equipment

130 m³/s would be required to maintain the wet bulb, wet bulb globe and effective temperature below 28°C



srk consulting 32

Airflow Calculation – Heat
What if LHDs are Electric?

Equipment Heat Loads

Equipment need to have a basic motor utilization added (average % of full load)

- 1 305 kW truck, Utilization 50%, Diesel
- 1 263 kW LHD, Utilization 75%, Electric
- 1 263 kW LHD, Utilization 50%, Electric
- 1 65 kW Jumbo, Utilization 100% Electric
- 3 75 kW Auxiliary Fans, Utilization 75% Electric

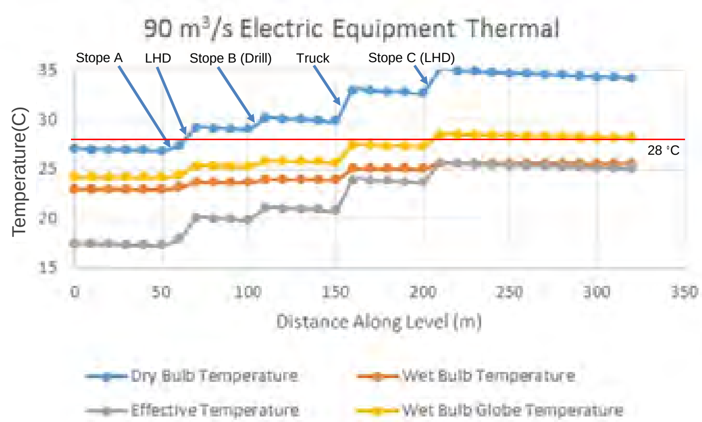
Diesel equipment need to have a value of water per liter of fuel added (3.2 liters/liter for this example) (values between 1.1 and 1.5 have been determined in laboratory analysis but can reach as high as 9 in field studies)

srk consulting 63

Airflow Calculation – Heat
Electric LHDs

In general electric equipment produces 2.3 to 2.6 times less heat than diesel equipment

90 m³/s with electric LHDs provides an equivalent thermal condition to 130 m³/s with diesel equipment



srk consulting 64

Airflow Calculation – Heat
What if all Equipment is Electric?

Equipment Heat Loads

Equipment need to have a basic motor utilization added (average % of full load)

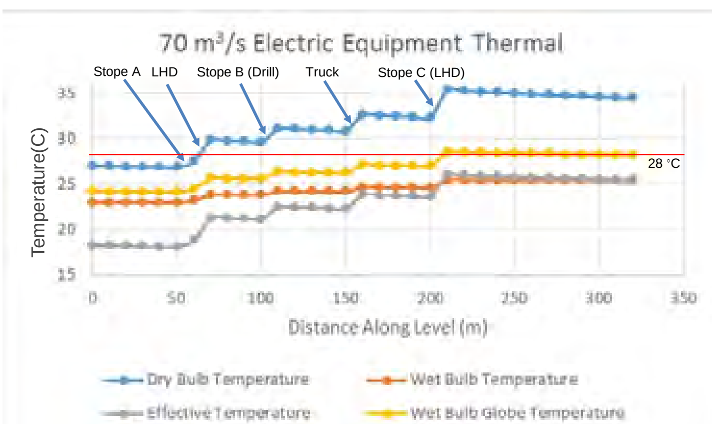
- 1 305 kW truck, Utilization 50%, Electric
- 1 263 kW LHD, Utilization 75%, Electric
- 1 263 kW LHD, Utilization 50%, Electric
- 1 65 kW Jumbo, Utilization 100% Electric
- 3 75 kW Auxiliary Fans, Utilization 75% Electric

srk consulting 35

Airflow Calculation – Heat
Electric LHDs and Truck

In general electric equipment produces 2.3 to 2.6 times less heat than diesel equipment

70 m³/s with electric LHDs and Truck provides an equivalent thermal condition to 130 m³/s with diesel equipment



srk consulting 36

Comparison of Values (Mining Area)

Each general mining area would require this type of airflow evaluation. This is not the overall airflow requirement for the mine, but the supplied airflow requirement

Method	Airflow (m^3/s)
Generalized Dilution Factor (0.06 m^3/s per kW)	50
MSHA (NIOSH) Dilution (Diesel)	25
MSHA (NIOSH) Dilution (Particulate)	97
Minimum Velocity (for Dust Control)	48
Max Wet Bulb Temperature (28°C)	70
Wet Bulb Globe Temperature (28°C)	130
Wet Bulb Globe Temperature (Electric LHDs) (28°C)	90
Wet Bulb Globe Temperature (Electric LHDs and Truck) (28°C)	70

Relationship Between Mining Area Values and Total Mine Airflow

The mining area airflow requirement does not directly translate to the overall mine airflow requirement.

- Leakage rates must be accounted for.
- Leakage rates may vary from 25% to 90% depending upon many site specific factors:
    1. Number of Bulkheads
    2. Type of Construction for Bulkheads
    3. Age of Infrastructure
    4. Doors
    5. Intake/Exhaust Connections
    6. Fan Placement
    7. Ventilation of Dedicated Areas (Ramps, etc.)

Relationship Between Mining Area Values and Total Mine Airflow

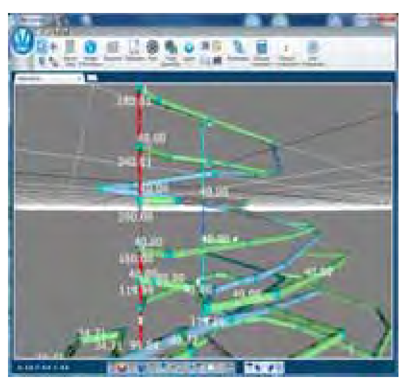
How is the total mine airflow determined?

- Applying generic system efficiency values – least accurate
- Developing a ventilation model based on empirically derived values (friction factors, resistance estimates) – moderately successful
- Developing a ventilation model based on site measured data and measured infrastructure values – greatest success
- More information on this will be discussed this afternoon

srk consulting 69

Relationship Between Mining Area Values and Total Mine Airflow

- Ventilation Modeling Software is Used to Establish These Models:
  - VnetPC,
  - VentSIM,
  - VUMA, etc.



srk consulting 70

Ventilation Design Process

Thank you for your attention

Feel free to ask questions here or contact me later at:

Brian Prosser, PE
MVS/SRK
1625 Shaft Ave., Suite 103
Clovis, CA 93611
bprosser@srk.com
(559) 452 0182

srk consulting 1

srk consulting 2