Ventilation system elements:

The eight basic elements of a ventilation system -

Primary Fans - These are required to provide the “work” necessary to induce flow through a ventilation system.

These are typically located on surface and either push air into (a forcing system) or pull air out of (an exhausting system) a mine. Or it could do both a “push-pull” system.

In certain mines these fan could be underground, along with other “booster” fans to provide extra work.

In shaft based delivery systems multiple fans may be required on each level if insufficient air power can be installed at surface due to head-frame leakage.

Ventilation system elements:

Primary Fans (2) - It is easier to install large fan systems on dedicated raises, rather than use shafts.

The number of fans and their size is very much dependant on the type of mine, its pollutants, and the airway infrastructure.

For example uranium mines can require more air than the typical mechanized metal mines due to the need to remove radon, metal mechanized mines can require more air than non-mechanized to remove diesel fumes. Coal mines can require higher air velocities to dispell methane layers.

Ventilation system elements:

Primary Fans (3) - The only way to determine the number of fans and delivery pressure required is to define the pollutant criteria and then the associated volume.

Once the volume is defined ventilation simulators can be used to establish the surface/booster fan pressures and optimum airway sizes.

It should be remembered that simulators only give the required static pressure.

Secondary Fans - These are similar to boosters but much smaller and are used in preference to airflow regulation to divert air in a specific direction.

Ventilation system elements:

Secondary Fans - These are similar to boosters but much smaller and are used in preference to airflow regulation to divert air in a specific direction.

These fans are typically installed in doors, bulkheads or seals on the top of raises or stopes. They provide the extra power required to compensate for the increased resistance of the route over which the airflow is to be induced.

Care should be taken in the application of such fans not to induce uncontrolled recirculation. This can be easily checked through the use of a ventilation model.

Ventilation system elements:

Main Openings - These are the surface connections that allow the air to delivered underground - they comprise dedicated ventilation raises, shafts used for transporting material, and surface declines which are again used for transportation.

Where these airways also serve a transportation function, the size of the airway is often dictated by non-ventilation criteria.

Where the airways are purely for ventilation, ventilation simulators are invaluable in determining the optimum size and even possibly their construction method.

Ventilation system elements:

Secondary Openings - these are the network of roadways, raises, stopes etc, by which the air is delivered to, and returned from the working place.

Similar to the primary openings, the size of these airways is often dictated by the mining equipment used or mining method.

For the most part, ventilation considerations only come into play in airways that are not part of the “production” circuit or where there may be another problem such as excessive air velocities.

Despite this ventilation models are still important in making sure these “other” airways are appropriately sized.

Ventilation system elements:

Bulkheads - these are one of three types of the passive control put in place to control airflow distribution. Bulkheads or other seals are used to stop the flow of air into areas of the mine that do not require ventilation. Maintenance of these is essential to control leakage.

The performance of these is dependant on the pressure differential and construction - they range from very good down to the ineffective.

Doors - these are similar to bulkheads, but allow the movement of men and materials. Generally they provide a lower quality seal that can deteriorate with time if not maintained. Where a better seal is required they can be combined in two's or three's to create an air-lock.

Ventilation system elements:

Regulators - these act as valves to limit/balance the flow of air in specific regions by artificially increasing the resistance of one route to compensate for the natural resistance of another route.

When using regulators the mine should be careful not to over regulate, there should always be one “free -path” with minimum to zero regulation to prevent over working the fans.

For minimum regulation, the resistance of this regulator should be greater than that offered by a piece of equipment in that area.

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Ventilation system elements:

Auxiliary Fans - these are the final fans that induce airflow to individual working locations. This class of fan is not in a “wall” and only serves to induce flow around a small circuit.

As such they do not form part of the primary ventilation system and are not generally considered in mine ventilation models.

General design:

Main Openings -

The location of the main openings that supply air to and remove air from the mine is important.

At least 2 openings are required - one to supply fresh air and one to exhaust contaminated air.

The location of the principal airways is typically governed by safety and economy.

Safety - all main access/escape routes should be through a fresh air stream.

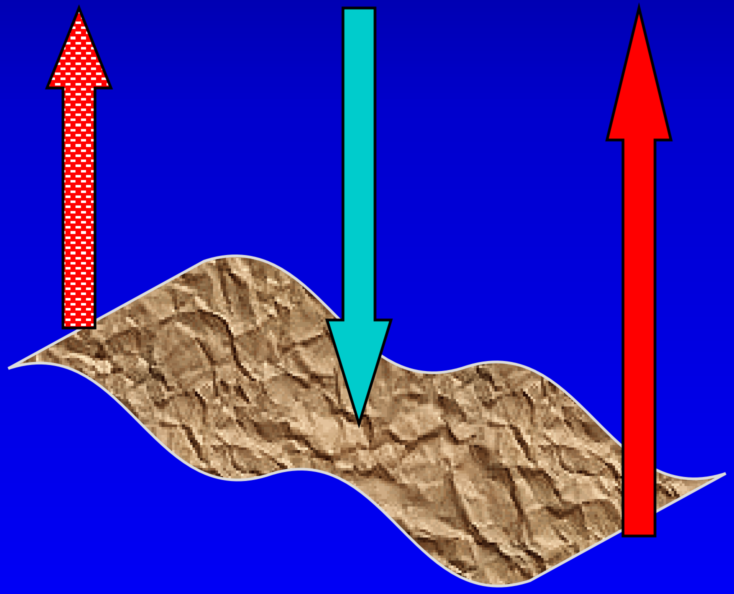
Economics - size, construction and function should always be considered.

General design:

Airway Location -

The three most common arrangements of ventilation connections in relation to an orebody are as follows:

1) **Intake** - Centre **Exhaust** - Perimeter



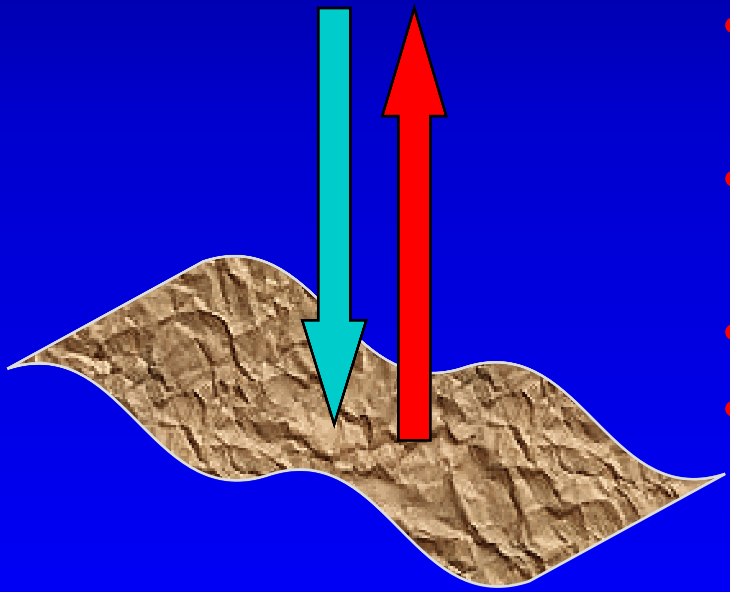
- Orebody should be well delineated.
- Needs lateral development before production can start.
- Can be expanded as required.

General design:

Airway Location -

To gain immediate access to the orebody

2) **Intake** - Centre **Exhaust** - Centre

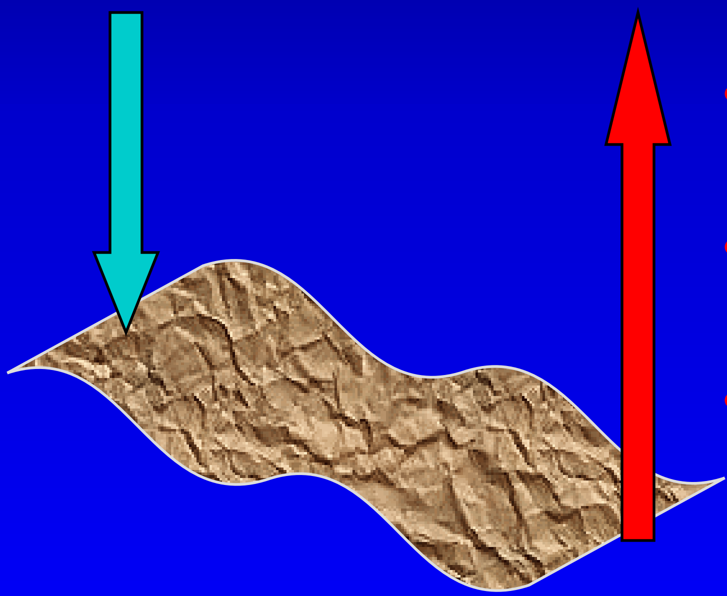


- Allows development in any direction.
- Minimal lateral development for production to start.
- Has higher leakage potential.
- Air has to travel out and back.

General design:

Airway Location -
"Through ventilation"

3) **Intake** - Perimeter **Exhaust** - Perimeter



- Needs significant lateral development.
- Provides good control of direction and leakage.
- Possible consideration as mine develops.

General design:

Airway Function -

Independent airways (raises) for ventilation are always preferable but mine development costs often dictate that the primary airways are also shafts for handling ore, men and materials.

- When a shaft (or shafts) is used, the one transporting men in usually kept as an intake unless alternative escape measures exist.
- In timbered intake shafts, drying out is always a concern.
- In exhaust shafts, fogging within the shaft or in the headframe could occur.
- The stability of the conveyance also warrants consideration.

General design:

Primary Vertical Airways -

The shape, size, and construction of a ventilation raise should offer the least resistance as possible.

Circular airways are the most efficient with respect to shape as they offer the lowest perimeter (friction surface) to area ratio.

However construction speed and logistics, waste handling, plus capital and operating costs all play a function.

- When a shaft is used, the size of the conveyance and services often dictates the dimensions, but the lining and infrastructure are important friction sources.
- In a divided shaft, a rectangular shape may be preferred.

Airway resistance:

Airway attributes

Length (L),Roughness (k factor)

Airflow details

Quantity (Q)

Velocity (v)

Shape factors

Perimeter (O)

Area (A)

Frictional Pressure Loss (P)

Ventilation Square Law

Pressure Loss(Pa) = Resistance(Ns^2/m^8) x Air Quantity^2(m^3/s)

$$P = R \times Q^2$$

Resistance (From Atkinson)

Resistance(Ns^2/m^8) = $\dfrac{\text{Friction (k) x Length (m) x Perimeter (m)}}{\text{Area}^3\ (m^6)}$

$$R = (k \times C \times L) / A^3 = (k \times C \times L \times V^2) / A$$

$R = (k \times C \times L \times V^2) / A$

Airway Friction -

1) As the area decreases, the friction effect increases.
2) As the perimeter increases, the friction effect increases. Therefore circular ducts are more efficient than square ones.
3) As the length increase, the friction effect increases.
4) As roughness increases, the friction effect increases.
5) As velocity increases, the friction effect increases.

From this equation it can be shown that the airway size is the most **critical** parameter in determining the resistance as:

$$\text{Resistance} \ \alpha \ 1/\text{Diameter}^5$$

For example: undersizing an airway by even 13% will double the resistance ($1/0.87^5 = 2$).

Ventilation cost:

Air Power (work required)

Air Power (W) = Pressure Loss x Air Quantity

= Resistance x Air Quantity^3 = $R \times Q^3$

Fan Power

Fan Power (W) = Air Power x 100 / Fan/Motor Efficiency(η,%)

= $\eta \times R \times Q^3 \times 100$

Annual Fan Operating Cost

Fan Cost ($) = Fan Power (kW) x Electricity Cost (ϵ,$/kWh)

x 24 (hours) x 365 (days)

= $\epsilon \times \eta \times R \times Q^3 \times 876000$

Cost α Quantity^3

Ventilation cost:

Cost α Resistance α 1/Diameter ^{5}

Therefore the two of the most important factors we need to get right are the design volume and the size.

However within the resistance calculation we must also be concerned about the roughness of the airway and to a lesser degree the shape.

Airway roughness:

K Factors (Empirical values @ ρ =1.2 kg/m^3)

AIRWAY CLASS (Straight)	K, Ns^2/m^4
Raise bored hole	0.0029
Smooth concrete lined	0.0037
Rock concrete lined	0.0040
Shotcrete lined	0.0055
Unlined minor irregularities	0.0100-0.0121
Unlined rough/irregular	0.0140-0.0160
Unlined mesh bolted	0.0140
Sedimentary Rock	0.0056-0.0130
Igneous Rock	0.0167-0.0362

Note: 5.5:1 ratio within airway type,
and 6.5:1 ratio for rock type.

Airway roughness:

K Factors (Empirical values @ ρ =1.2 kg/m^3)

AIRWAY CLASS	K, Ns^2/m^4
Sedimentary rock (straight)	
- clean	0.0056-0.0130
- slightly obstructed	0.0065-0.0139
- moderately obstructed	0.0084-0.0158
Sedimentary rock (curved)	
- clean	0.0074-0.0176
- slightly obstructed	0.0084-0.0186
- moderately obstructed	0.0102-0.0204

Note: 3.6:1 ratio within a rock type depending on level of obstruction and degree of curvature.

Airway roughness:

K Factors (Empirical values @ ρ =1.2 kg/m^3)

Shafts	K, Ns^2/m^4
Smooth/concrete lined (clean)	0.0030-0.0040
Tubbing lined no fittings	0.0070-0.0140
Concrete, rope guides, pipes	0.0065
Concrete, streamlined beams	0.0045-0.0250
Concrete, I beams	0.0500
Timbered	0.0450-0.0800

Note: 4.7:1 ratio within clean shafts
and 17.8:1 ratio within equipped shafts.

Airway roughness:

Due to the wide range of empirical values that can be applied, they should be used with caution and only in the absence of locally determined friction factors.

This is especially true for the "critical branches" of a ventilation system. These are typically the shafts and primary raises that handle the majority of a mine's airflow.

It is for this reason that CANMET/MMSL is an advocate of tracer gas techniques to accurately determine *in situ* resistance values.

Airway shape:

An airway's shape controls the ratio of perimeter (or rubbing surface to cross-sectional area.

The optimum shape is circular as this has the best ratio, it has a shape factor of 3.5449 (perimeter/area$^{0.5}$), the relative shape factor to determine the resistance multiplier of other airways of the same area include:

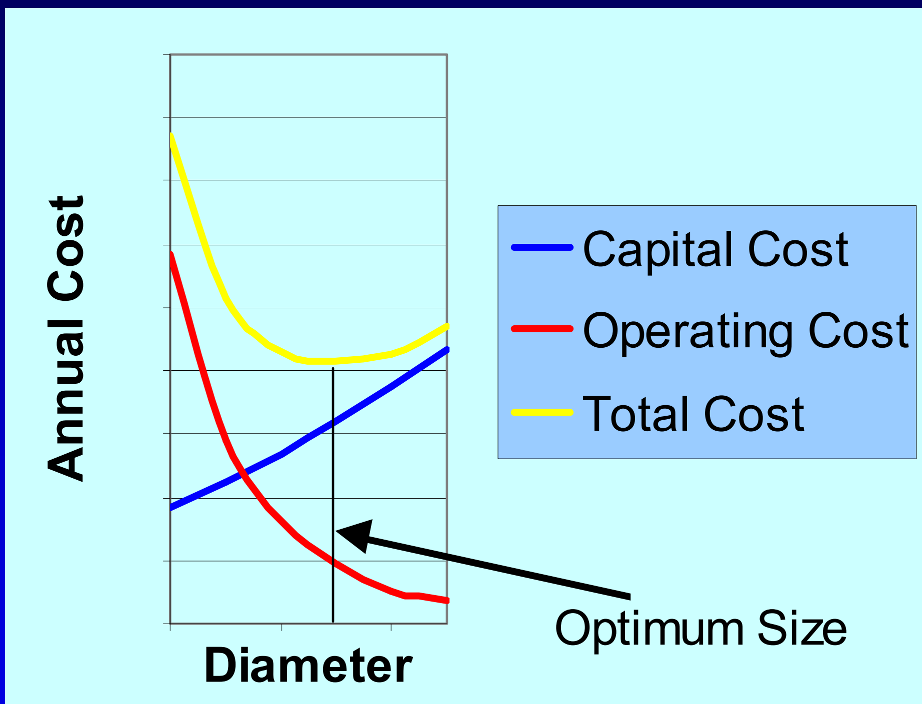
Shape	RSF	Shape	RSF
Arched	1.08-1.09	Square	1.13
Rectangular- width:height ratio			
1.5:1	1.15	2:1	1.20
3:1	1.3	4:1	1.41

Examples:

The examples have shown:

- that underestimating flow can be costly
- that underestimating size can be costly
- an alimak has to be significantly bigger than a raise bored hole
- shape has a minor influence
- opting for a shaft could incur higher operating costs.
- these calculations on a single airway can take time - they would be impossible for a network - that is why we use mine ventilation simulators

Bigger is better ?



From the ventilation standpoint “bigger” is better - however the optimum size can only be determined after considering the capital cost of the excavation.

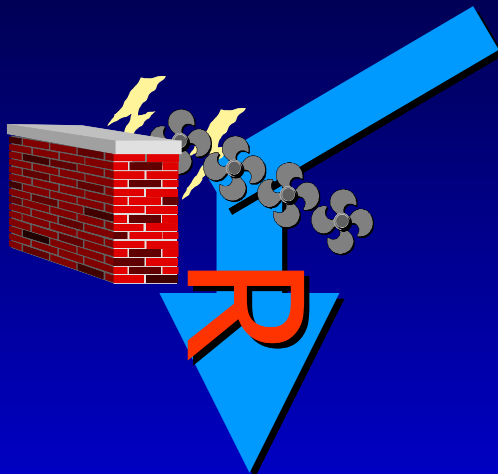
Shock losses

Shock losses are another important consideration especially in areas of high air velocity as the pressure loss is a function of the $(\text{velocity})^2$.

These types of losses occur where there is a change in airway size or airflow direction - and the magnitude of the loss is proportion to the severity of the transition.

In mines, the most common shock losses are: at the entry or exit to raises or shafts, transfers between raise sections,where an airway contains an obstruction, and at the discharge of fans. These areas often require special consideration and it is suggested that you refer to the basic ventilation texts.

Shock Losses

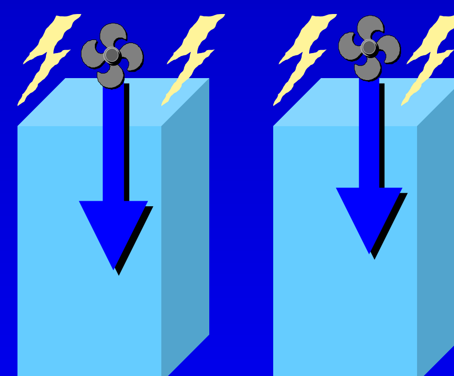


Primary Fans

Primary flow through small entry, round bend, 4th fan ineffective.

Secondary Raise Fans

Secondary flow through raises, fans discharge into large cross section only a small portion of their pressure induces flow.



Recommended air speeds:

So far we have only considered the need to dilute pollutants and some economic factors - the air velocity is mines is another important consideration for which guidelines have been developed over the years.

As a general rule airways where men are working have the lower velocites for comfort; non-travelled airways have the highest velocities limited by cost and physical controls.

Recommended air speeds:

Airway Type	Recommended Airspeed
Intake & Return : Metal Mines	6-8 m/s
Vertical Unequiped Shaft	18-22 m/s
Vertical Equiped Shaft [1]	10-12 m/s
Inclined Shafts	6-8 m/s
Conveyor Belt Excavations [2]	2-3 m/s
Face Airspeeds in Stopes [3]	1-2 m/s

[1] upcast critical velocities, avoid 7-12m/s due to suspended water droplets.

[2] combined velocity of the belt and air should not exceed 5 m/s due to dust.

[3] flows below 1m/s are not readily noticed by workers, above 3m/s air can be uncomfrotably fast.

Recommended air speeds:

Airway Type	Recommended Velocity Range
Production Shaft	7.6 - 10.2 m/s
Service Shaft	5.1 - 7.6 m/s
Main Entries	2.5 - 7.6 m/s
Conveyor Galleries, Declines	2.5 - 5.1 m/s
Ventilation Sills/Raises: No Production	10.2 + m/s
Ventilation Sills/Raises: Production	2.5 - 5.1 m/s
Exhaust Mains	10.2 - 15.2 m/s
Exhaust Shafts : Concrete	15.2 - 20.3 m/s
Exhaust Shafts: Rock [1]	10.2 - 15.2 m/s

[1] In upcast shafts and raises with saturated conditions, average air velocities between 7.5-12.5m/s are to be avoided due to the formation of water droplets which can contribute to fan stall

Recommended air speeds:

At the workplace:

Stope Air Temperature Condition	Recommended Velocity m/s
Comfortable	2.0
Excessive Cold	0.5
Excessive Heat	3.0

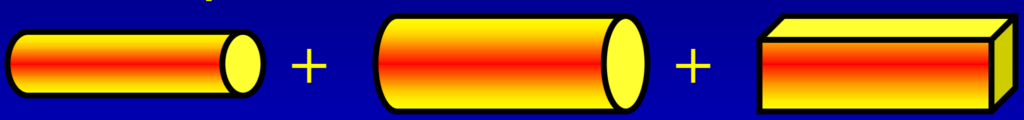
Also once drifts open up into repair galleries or other large openings 0.25m/s can be adequate.

Modelling basics:

Combining Airway Resistances

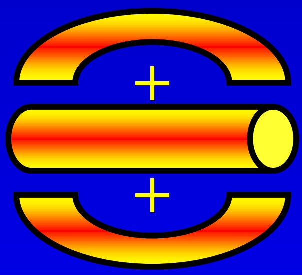
Mine Ventilation systems can be classified as a combination of airways either in series or parallel.

Airways in Series



$$R_E = R_1 + R_2 + R_3 + \ldots\ldots$$

Airways in Parallel



$$\sqrt{1/R_E} = \sqrt{1/R_1} + \sqrt{1/R_2} + \sqrt{1/R_3} + \ldots$$

Modelling basics:

Combining Airway Resistances

If you split the flow between 2 identical resistance airways the equivalent resistance drops to 1/4 i.e. 25% of an individual airway.

This is a valuable way to reduce pressure loss in a mine.

Because of this parallel reduction effect on airflow splitting, there are only a few critical airways in each mine that really control the overall volume/fan pressure of the mine.

Modelling basics:

Network theory

A mine is made up of numerous ventilation circuits or meshes. A mine ventilation simulator looks at all these circuits and comes up with a balanced solution based upon resitance of the airways and the air power supplied from fans.

The simulators use “Kirchoff’s Laws”

- the mass flows entering a junction = the mass flow leaving a junction.
- the sum of all the pressure drops around a closed path, or mesh, must be zero.

The End For Now .....