9

MINE VENTILATION SYSTEMS

Ventilation is the control of air movement, its amount, and direction. Although it contributes nothing directly to the production phase of an operation, the lack of proper ventilation often will cause lower worker efficiency and decreased productivity, increased accident rates, and absenteeism.

Air is necessary not only for breathing but also to disperse chemical and physical contaminants (gases, dusts, heat, and humidity). In the U.S., as well as in the rest of the world, mine ventilation practice is heavily regulated, especially in coal and gassy (noncoal) mines, and other statutes relate to air quantities required to dilute diesel emissions, blasting fumes, radiation, dusts, battery emissions, and many other contaminants.

To ensure adequate ventilation of a mine, provision is made for suitable paths (airways or aircourses) for the air to flow down the mine to the working places and suitable routes out of the mine when it has become unsuitable for further use. The primary ventilation system thus consists of an intake or intakes (or downcasts) through which the fresh air passes, the mine workings, and an exhaust or exhausts (or upcasts) where the air passes after having ventilated the working places of the mine. Mine fans can be installed on intake airshaft, return airshafts, or both, either on the surface or underground (Figure 9-1).
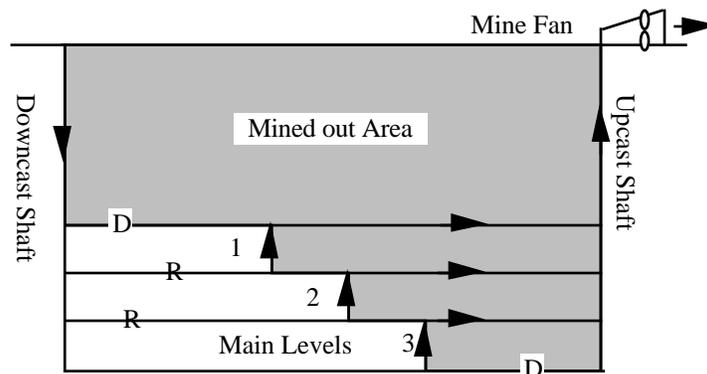

*Figure 9-1.   Basic ventilation system underground where D is a ventilation door or airlock,
R is a mine regulator and 1, 2, 3 are working places with a surface exhaust fan.*

To maintain adequate ventilation through the life of a mine, careful advance ventilation planning is essential. Advance ventilation involves the consideration of two principal factors: (1) the total volume flow rate of air required by the mine, and its satisfactory and economic distribution, and (2) the pressure required by the mine fan(s). A well designed ventilation system should be

effective, flexible, and economical.

1. Mine System and Control Devices

A well designed and properly implemented ventilation system will provide beneficial physiological and psychological side effects that enhance employee safety, comfort, health, and morale. In planning a ventilation system, the quantity of air it will be necessary to circulate to meet all health and safety standards must be decided at the outset. Once the quantity required has been fixed, the correct size of shafts, number of airways, and fans can be determined. As fresh air enters the system through the *intake* airshaft(s) or other connections to the surface, it flows along *intake airways* to the *working areas* where the majority of pollutants are added to the air. These include dust and a combination of many other potential hazards, such as toxic or flammable gases, heat, humidity, and radiation. The contaminated air passes back through the system along *return airways*. In most cases, the concentration of contaminants is not allowed to exceed mandatory threshold limits imposed by law. The return (or contaminated, exhausted) air eventually passes back to the surface via *return* airshaft(s), or through inclined or level drifts.

Air always flows along the path of least resistance, but this may not be where it is required for use. To direct the air where it is needed, ventilation devices are necessary; the primary means of producing and controlling the airflow for the entire system are mine fans (either in the form of single fan installation or multiple fans). In addition, many other control devices also are necessary for effective underground air distribution:

1. *Stoppings - Temporary or permanent*
    Stoppings are simply air walls made of masonry, concrete blocks, pre-fabricated steel, gob walls, fire-proofed timber blocks, or any other material used to channel airflow for effective air distribution. Depending on the size of mining entries, stopping sizes range from as small as 4-ft by 20-ft in low coal to as large as 30-ft by 40-ft in limestone mines.

2. *Overcast/undercast*
    Overcasts are air bridges where intake and return airways are required to cross each other. They could be constructed of masonry, concrete blocks, or pre-fabricated steel.

3. *Regulator*
    Regulators commonly are used to reduce the airflow to a desired value in a given airway or section of the mine. Depending on its permanency and the pressure differential to be experienced across the regulator, materials used in the construction of regulators range from a simple brattice sheet blocking the airway to a sliding shutter in a stopping.

4. *Man-doors*
    These generally are steel access doors mounted in stoppings between intake and return airways.

5. *Air locks*
    When access doors between intake and return airways are necessary and their pressure differential is high, man-doors generally are built as a set of two or more to form an air-lock. This prevents short-circuiting when one door is opened for passage of vehicles or personnel. The distance between doors should be capable of accommodating the longest train of vehicles required to pass through the air-lock.

6. *Line Brattice/Vent Tubing*

   As a short term measure, fire-resistant line brattices may be tacked to roof, sides, and floor in underground coal mines to provide temporary stoppings where pressure differentials are low in and around working areas. For metal and non-metal mines, vent tubing is generally used in and around working areas to channel fresh air to operating faces. Vent tubing also is commonly used in combination with auxiliary fans.

7. *Booster fans*

   When the airflow in a section of the mine must be adjusted to a magnitude beyond that obtainable from the open system, a booster fan may be used to enhance the airflow through a part of the mine. When they are used, they should be designed into the system in order to help control the leakage, without causing undesirable recirculation in either normal or emergency situations. In the U.S., booster fans are prohibited in underground coal mines.

8. *Machine-mounted watersprays and scrubbers*

   These are devices used to enhance the flow of fresh air in face areas. Scrubbers are "vacuum cleaners" used for dust suppression, while watersprays, when strategically located on machines, have been used successfully to act as a "booster fan" to re-direct airflow in certain directions in face areas.

2. Major Ventilation Systems

The objective of any ventilation system is twofold. First, the primary ventilation must course air through the main airways to the immediate working area outby the working faces, thus making fresh air available for face ventilation, and then return the contaminated air through return (exhaust) airways to the surface. Second, the face ventilation system must be designed to effectively utilize the available air in the immediate working area to sweep the working face, to capture and remove dust, and to dilute and carry away gas, if any, emitted during mining activities. Without a properly designed ventilation system, an efficient production cycle would not be possible. The system should provide the required air volumes and quality at reasonable pressure losses, perform with minimum interference and cost to production, and do so in the most cost-effective way possible. Furthermore, the primary ventilation system may be well designed, but if the available air brought to the working area is not properly utilized for ventilating the faces where most workers are located, the total system has failed (Bossard, et al., 1982).

Depending on the type of mine and disposition of local geology, ventilation layouts can be divided into two broad classifications; either a U-tube system or a through-flow arrangement (Figure 9-2, McPherson, 1993). Figure 9-2a shows a basic U-tube configuration where air flows towards and through the working area then returns along adjacent airways, often separated from intakes by long pillars and/or stoppings. Access doors in the stoppings facilitate traffic between intake and return airways. The variation of this arrangement would be room-and-pillar and longwall type mining methods. The other arrangement is shown in Figure 9-2b, where intakes and returns usually are separated geographically from adjacent airways, which are either all intakes or returns. Although less stoppings and airways are needed because of the geographical separation, which often results in less air leakage, air current regulations and boosters may be required for airflow control in work areas (McPherson, 1993). Parallel flows between intake and return airshafts across the multilevel metal mines and the bleeder system in a longwall panel would be typical examples of this type layout.
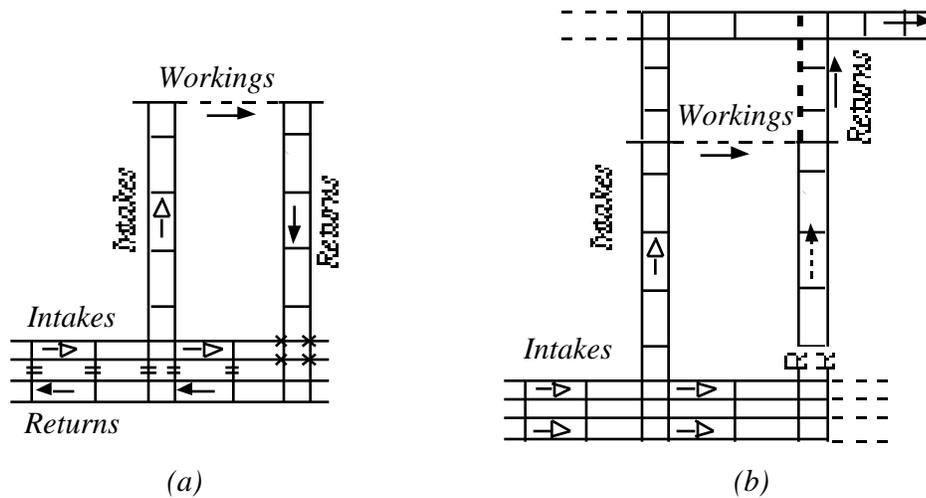
Figure 9-2.   Basic ventilation systems (a) U-tube and (b) through-flow (McPherson, 1993).

Actual layouts underground could be variations of any one system or a combination of the two arrangements.

For Stratified Deposits

The vast majority of underground mines extracting tabular forms of orebodies (coal, potash, salt, limestone, etc.) normally use one of two methods, longwall or room-and-pillar mining. While actual layouts can vary significantly from mine to mine and region to region according to local geological conditions, the basic design for these two methods remains the same. The following sections describe the airflow distribution system usually employed.

a)   Longwall systems

Two factors that have significantly influenced the design of the longwall ventilation systems are the control of methane or other gases that accumulate in the gob area (den Drijver, et al., 1997; Diamond, 1997; Dziurzynski and Nawrat, 1997; Haake, et al., 1985; Highton, 1980; McPherson, 1993) and the increasing high rate of rock breakage on heavily mechanized longwalls that has exacerbated the production of dust, gas, heat, and humidity (Uchino and Hirago, 1984; Battino and Mitchell, 1985; Organiscak and Jankowski, 1996; Colinet, et al., 1997; Stokes and Tuck, 1997).

Figure 9-3 depicts some of the commonly used ventilation layouts used on longwall sections. In the U.S., a minimum of two entries is used, while single entry longwalls primarily are employed in European coal mines (Fuller, 1989; McPherson, 1993). Refer to Chapter 17 for details.

System layouts become more complex when mining under inclined, thick, and gassy coal seams with frequent faults. Narrower and shorter panels are necessary to cope with these difficult conditions. There also have been other type of layouts to accommodate specific geological conditions (Fuller, 1989 and Tien, 1995).
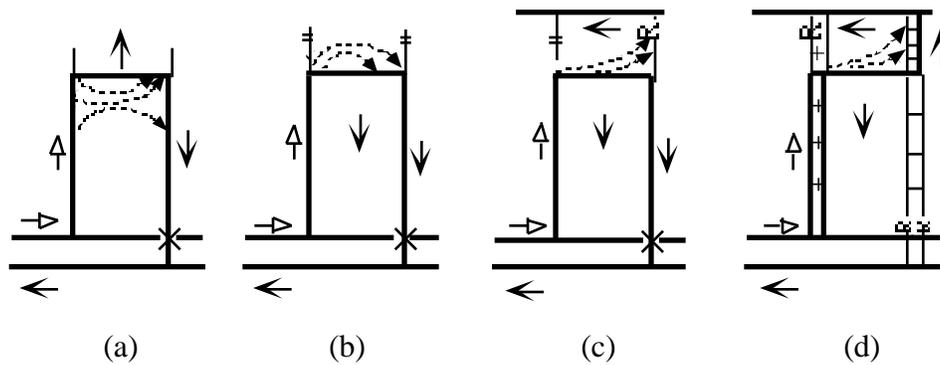
Figure 9-3.   Classifications of longwall ventilation systems (a) single-entry advancing; (b) single-entry retreating; (c) single-entry retreating with back bleeder; (d) double-entry retreating with back bleeder (after McPherson, 1993).
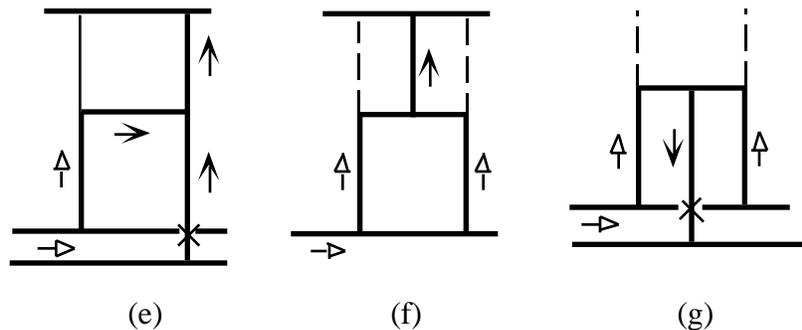

Figure 9-3a.   Classifications of longwall ventilation systems (e) Y-system; (f) double-Z system; (g) W-system. (after McPherson, 1993).

b)   Room and pillar systems

Figure 9-4 shows the two methods of ventilating a room and pillar development panel in a coal mine where multiple entries are driven. Figure 9-4a is the directional, or W-system, in which intake air courses are airways in the central portion of the panel, with return airways on both sides, often referred to as the fish-tail method. The method in Figure 9-4b is the unidirectional system in which intake and return are located on both sides of neutral airway (belt and track).

In both cases, the conveyor belt and/or track are located in the middle, with a brattice curtain at the end to regulate the airflow. In U.S. coal mines, air in these entries is not supposed to be used to ventilate working areas, so they are directed directly to the return airway through a regulator. Advantages of this system include: the airflow splits at the end of the panel, with each airstream ventilating the operational rooms sequentially over one half the panel only, resulting in less leakage due to less pressure differential across the stopping; and any gas emission will be flowing automatically to return airways. An obvious disadvantage is that the number of stoppings required is double that of the uni-directional system. The air leakage also is twice as much due to the extra stoppings (McPherson, 1993).

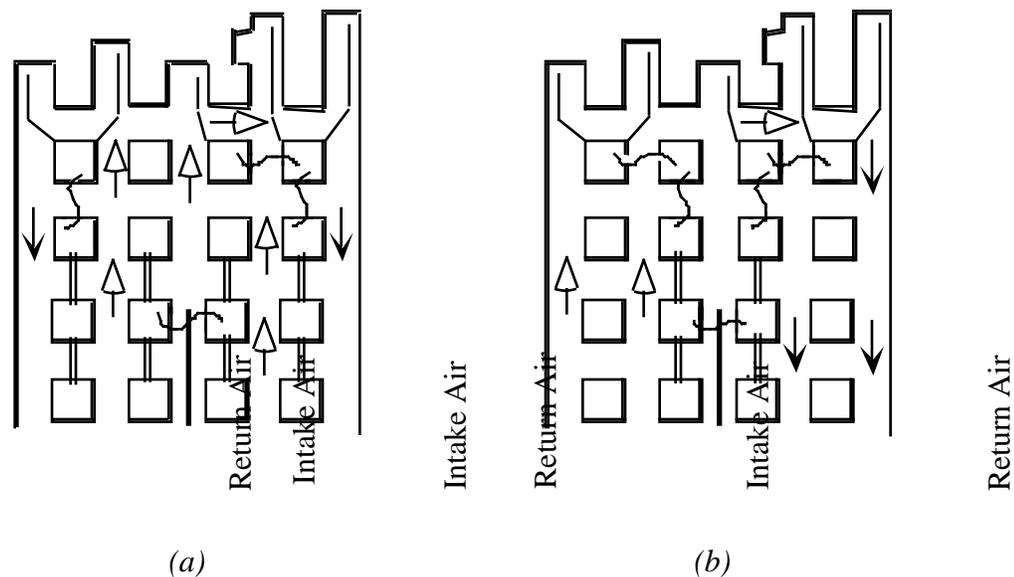*(a)*   *(b)*

Figure 9-4.   Room and pillar development with line brattices to regulate airflow in conveyor belt entry: (a) bi-directional system; (b) uni-directional system.

For a uni-directional system, it should offer a higher volumetric efficiency at the face because of the reduced number of stoppings. A disadvantage is that the higher volume also has a higher ventilation pressure, which in turn offers higher leakage.

c)   Mine with Large-size Entries

Typically, mines with large-size entries (e.g., limestone, salt, and oil shale) require large volumes of ventilating air (between 350,000 to 500,000 cfm, depending on specific conditions) to adequately ventilate underground workings. In trying to meet this requirement, two major problems usually are encountered: (1) air leakage through stoppings and (2) local air recirculation, both of which are caused by improperly constructed (and maintained) stoppings, or the lack of stoppings in many cases, and both can adversely affect the underground working environment. Oftentimes, mine management are reluctant to construct an adequate number of stoppings, either because of technical problems or the associated expenses.

Air is used to dilute diesel exhaust and to maintain a minimum air velocity in large-dimension airways in order to avoid air stratification, and every reasonable measure has to be taken to ensure that fresh air is effectively delivered to working places where air is needed. The cost of not maintaining adequate ventilation results in a poor working environment that not only is in violation of federal and state regulations, but can adversely affect worker performance and morale. To deliver fresh air to working places over large distances, control devices are required. They can either be: (1) conventional large-scale stoppings using pipes with metal sheeting, brattice and wire, a muckpile, etc. or (2) adopting a modular type pillar layout.

Constructing air-tight stoppings in large openings is not only time-consuming and expensive, it often is difficult, if not impossible, to be 100% effective (Adam, et al., 1987; Thimons, et al., 1987). The precise cost of constructing conventional metal-frame stoppings in a 35-ft wide by 20-

ft high entry is difficult to obtain because of the many variables involved, e.g., ranging from $20,000 to $24,000 per stopping in a limestone operation in Iowa (in 1996 dollars).

Oftentimes, brattice curtains are the only practical materials for use underground; the cost of which ranges from $1,500 to $3,000 per stopping (1997 dollars). This includes the cost of labor and materials. However, stoppings such as these are subjected to much higher leakage between the strips of brattice and around the peripherals. Leakage varies depending on many factors, such as workmanship, maintenance, mining practices (stoppings too close to working areas will suffer frequent blasting damage), and, to a lesser extent, geological conditions (roof sagging and bottom heaving can damage stoppings). A salt mine in Ohio with 20-ft x 40-ft entry sizes showed a leakage rate of 5,100 to 5,500 cfm per stopping.

Some mines have hung a continuous brattice line along the pillars, which stops most the leakage around the peripherals (Figure 9-5).
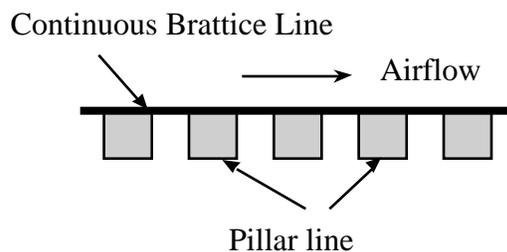

Figure 9-5.   A continuous brattice line will reduce leakage around peripherals.

Although the exact impact on power cost due to leakage is difficult to quantify, it is known to be significant. Since any leakage through a stopping has to be compensated for by "pumping" more air underground to meet safety requirements, it will dramatically increase energy requirements at the fan because fan power and air quantity have a cubic relationship. For example, a 26% increase in air flow would double the air power cost. Costs of other types of stoppings also can be estimated roughly in today's dollars using published information (Adam, et al., 1987; Thimons, et al., 1988).

A modular configuration provides an alternative. In this layout, it intentionally leaves long barrier pillars at four sides of a pre-planned mining block so air can be effectively coursed over longer distances. The following diagram (Figure 9-6) shows a hypothetical mine working with a modular configuration.

There will be small losses in percentage extraction. However, this loss can be reduced to a minimum by leaving only the last round of mining in a cross-cut (Figure 9-6). The reduction in air leakage, plus the savings created by replacing brattice and providing effective ventilation, will offset the cost associated with a lower extraction ratio. The following diagrams show the extraction ratio calculations. Figure 9-7a and 9-7b show 40-ft by 40-ft pillars mined on 70-ft centers. Calculations show that the difference in production is approximately 6%. But a more realistic figure would be around half that, or 3%, because only a fraction of the partial pillars are left on four sides within this block. Figure 9-7c and 9-7d show a similar 70-ft center pillar pattern,

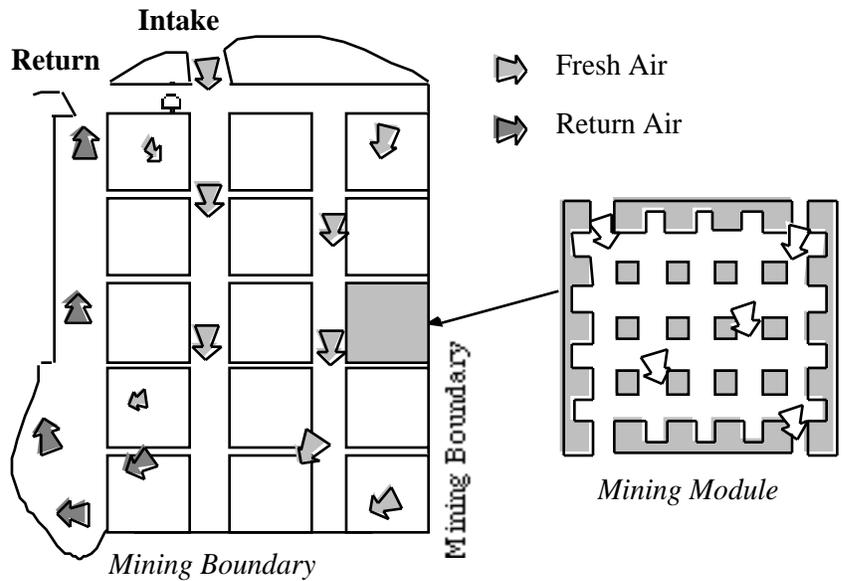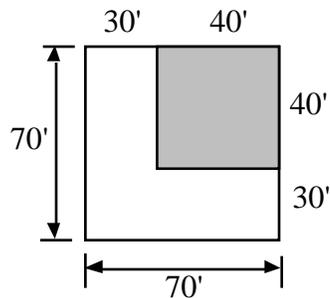however, 35-ft by 35-ft pillars are left. The difference caused by leaving a partial pillar is around 3.5%.
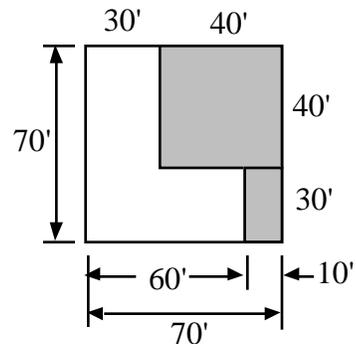

Figure 9-6.   A hypothetical underground limestone mine where a module system is used in lieu of stoppings to channel air to working areas.

Full extraction: $1 - \dfrac{40 \times 40}{70 \times 70} = 67.3\%$

(a)

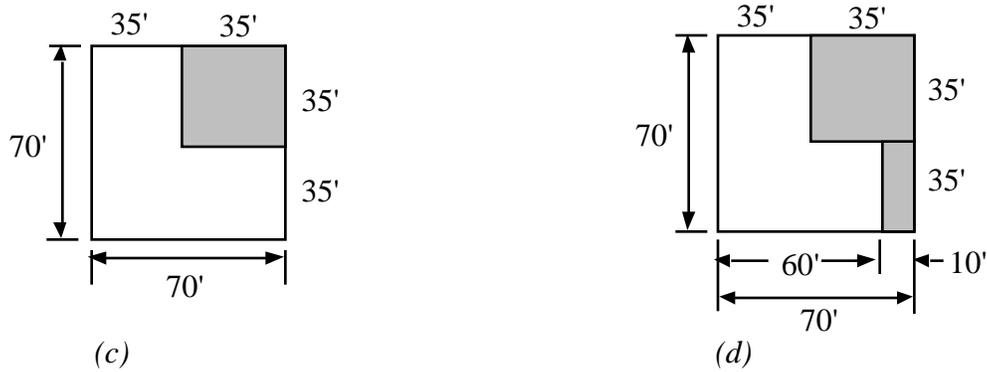Leaving partial pillar: $1 - \dfrac{35 \times 35 + 35 \times 10}{70 \times 70} = 67.9\%$

(b)

Figure 9-7. Extraction ratio calculations.

Full extraction: $1 - \dfrac{35 \text{ x } 35}{70 \text{ x } 70} = 75.0\%$

Leaving partial pillar: $1 - \dfrac{35 \text{ x } 35 + 35 \text{ x } 10}{70 \text{ x } 70} = 67.9\%$

For demonstration purposes, in a 6-pillar by 6-pillar block with 20-ft high by 35-ft entry widths, partial pillars will be left in 16 places (Figure 9-8). Assume the stones has a density of 165 lb/ft^3, total unmined rock in this system amounts to:

35' x 20' x 10' (height) = 7,000 ft^3 per working place

Total tons lost per working place = (7,000 ft^3 x 165 lb/ft^3) ÷ 2,000 lb/ton = 578 tons/place

Total tons lost due to partial pillars = 578 tons/place x 16 places = 9,248 tons
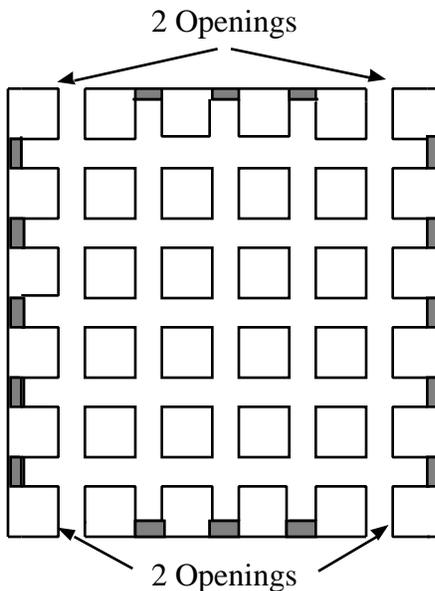
Figure 9-8. Partial pillars will be left in 16 places in a 6 x 6 block.

d) Recirculation of Air Underground

In addition to improperly constructed and poorly maintained stoppings, the other major cause of air recirculation underground is improper mine layout. One of the commonly encountered planning errors in underground limestone operations is that main intake and return airways are located adjacent to each other, causing the exhaust air to be recirculated back into intake airway(s). This situation is exacerbated when a box cut, often used in limestone and coal mines where ore crops out, is used to enter the mine. The air can not be discharged away from the intake area.

At the early stage of the mine development, main intake and return airways must be located near each other, and it will be at least several years before an airshaft can be drilled some distance from the portal and an entire ventilation circuit can be completed. It is recommended that intake and return in the portal areas be physically separated in the start up of the mine to avoid air recirculation (Figure 9-9).
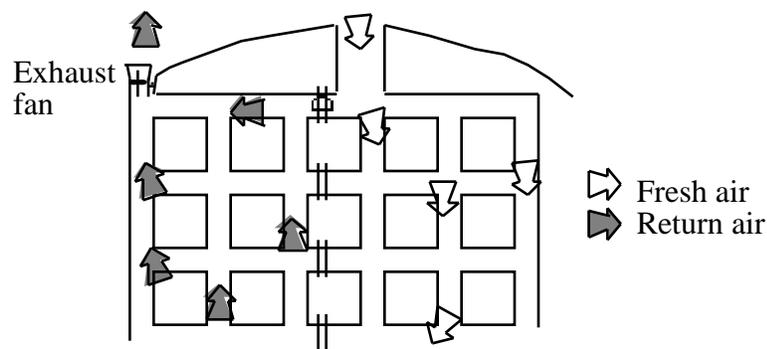

Figure 9-9.   Fan duct is used to deflect exhaust air and to recover lost velocity pressure.

If this is not possible, and both intake and return have to be located next to each other at the bottom of the boxcut, Figure 9-10 shows an alternative method of separating intake air and return air by the use of a vertical fan duct at the discharge end of the exhaust fan.
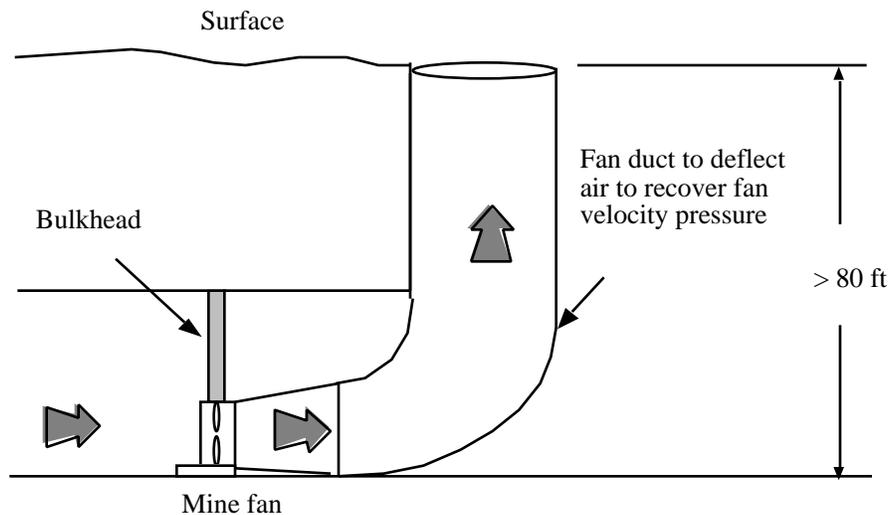
Figure 9-10.   Fan duct is used to deflect exhaust air and to recover lost velocity pressure.

Figure 9-10 shows a suggested layout where exhaust air is deflected upward using a vertical duct (evase`) at least 80 feet in length. The evase` also serves another useful purpose: it can recover fan velocity pressure (ranging from 0.2 in. to 1 in. W.G. depending on fan discharge velocity) which otherwise would be lost. To avoid additional shock losses, the connecting bend should be round and smooth.

Some of the other characteristics for mines with large openings are their low air velocity in airways which can result in air stratification, or fogging, in airways caused by influx of ground water and seasonal moisture content fluctuation. Excessive and fluctuating moisture content in air also can contribute to the deterioration of roof layers, causing safety problems. Also, for limestone operation, the combination of grade variation and fluctuating market demand requires certain flexibility in mine development, which also will impact ventilation planning.

Air Tempering for Roof Stability

In a mine with large openings, in the summer and sometimes in late spring and early fall, as warm, humid air enters the mine entries, air velocity is greatly reduced due to these large openings. The air starts to interact with the surrounding rock and quickly reaches mine temperature. As air temperature is reduced, its relative humidity will rise until the air is unable to carry the high moisture levels. Moisture at that point begins to condense on, or be absorbed by surrounding rocks. The intake air continues to cool and dry along the length of the entries until an equilibrium is reached between mine temperature and specific humidity levels.

Laboratory studies have shown that very short term (daily) fluctuations in specific humidity have little or no effect on shale moisture gains or losses. Shales require a 7- to 10-day exposure to changes in specific humidity, whether higher or lower, before equilibrium between moisture con-tent in the rocks and atmospheric conditions is reached (Haynes, 1975; Anon., 1976; Stateham and Redcliffe, 1978; Cummings, et al., 1983;). As the intake air travels along the entries, contact is made with rock and other materials in disequilibrium. Gradual moisture exchange takes place from that point at increasing residence time until equilibrium again is achieved. Figures 9-11 and 9-

12 show the seasonal effects (humidity and temperature) for an earlier study in a coal mine where the roof is predominately shale.
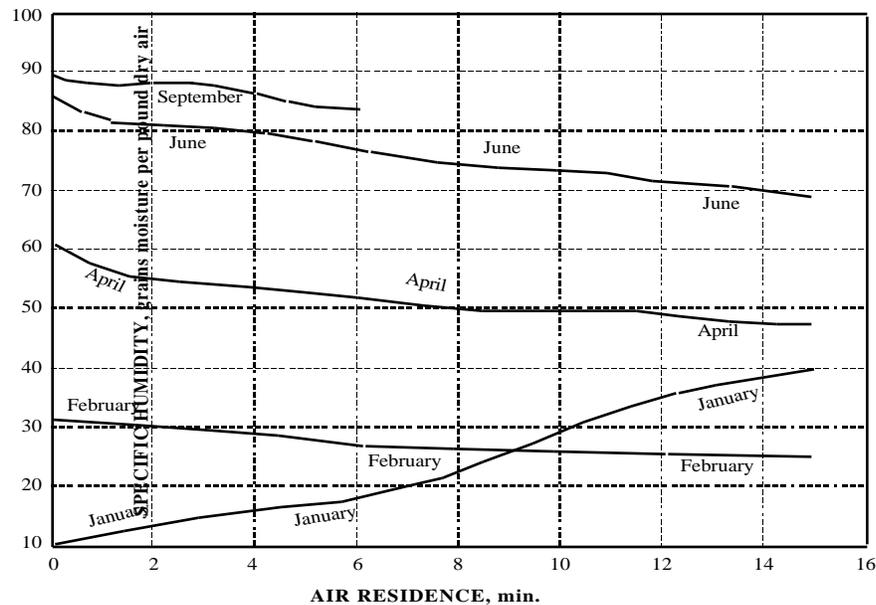

Figure 9-11.   Changes in mine air specific humidity as a function of air residence time.

Moisture exchanges between incoming air and surrounding rocks are site specific. Although the exact moisture absorbing characteristics of the rock are not known, studies on shale in other mines can be used as a guideline to reasonably estimate their interactions (Cummings, et al., 1983). Previous USBM research indicates that the maximum efficient air residence time for tempering summer air is 30 minutes; additional residence time will provide total tempering. In the above mentioned study, it assumed 60 grains per pound of dry air as a good approximate summer moisture equilibrium value and its results showed a 70% reduction in excess moisture in 15 minutes residence time. It was estimated that, if the residence reached 30 minutes, moisture reduction could be expected to reach 90 to 95% tempering. Based on this, a minimum of 15 minutes residence time can be used as a good design parameter that will provide sufficient tempering effect (Lucas, 1975; Haynes, 1975; Anon., 1976; Stateham and Radcliffe, 1978). Having adequate air velocity is the most effective means for reducing moisture condensation.
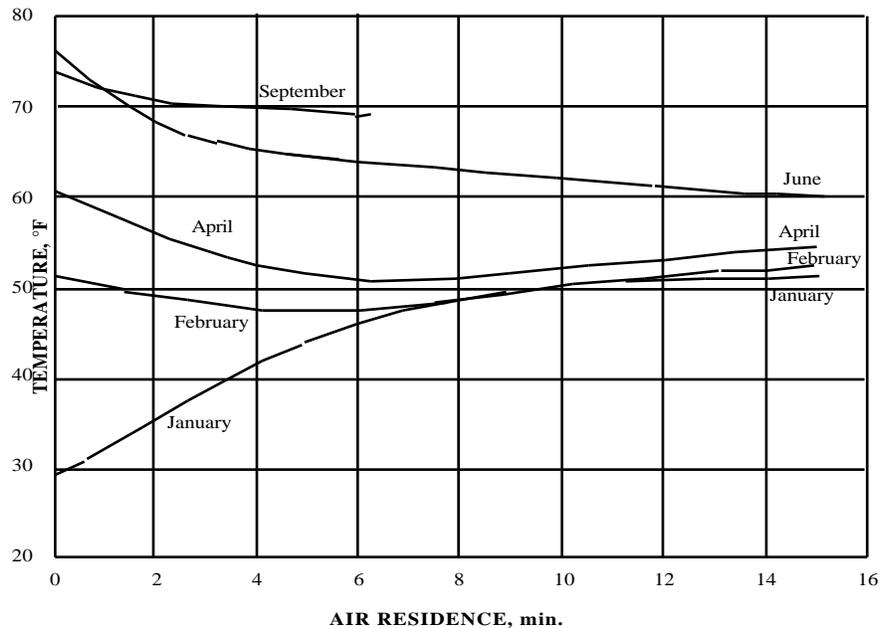
Figure 9-12. Changes in mine air temperature as a function of air residence time.

Orebody Deposits

Metalliferous orebodies often occur in deposits of irregular geometry, varying from tortuous veins to massive irregularly shaped deposits of finely disseminate metal and highly variable concentrations. This causes mining layout necessarily less ordered than those for stratified deposits. In addition, the grade variation in metal mines and the ever-changing metal prices necessitate that more stopes or working places be developed than would appear to be necessary, while with perhaps only a fraction of them operating on any one shift. Thus, the ventilation shift must be sufficiently flexible to allow airflow to be directed wherever it is needed on a almost day-by-day basis (McPherson, 1993).

Ventilation networks for metal mines tend to be more complex than for stratified deposits and usually are also three dimensional. Figure 9-13 illustrates the ventilation plan of many metal mines, although the actual geometry will vary widely.
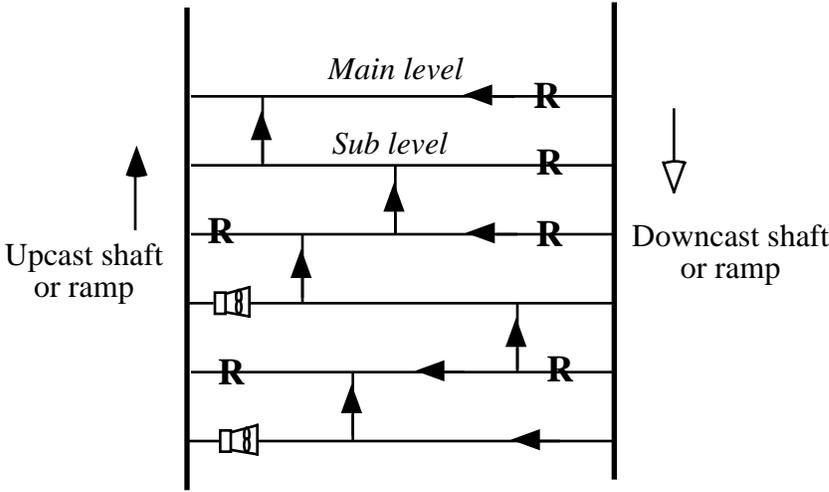
Figure 9-13. Section showing the ventilation system for a metal mine.

Airflow distribution systems for individual stopes also are subject to great variability, depending on the geometry and grade variations of the orebody. In most of the cases, where controlled vertical movement of the air is required, stope airflow systems employ ascensional ventilation. Although auxiliary fans and ducts may be necessary at individual drawpoints, every effort should be made to utilize the mine ventilation system to maintain continuous airflow through the main infrastructure of the stope. Series ventilation between stopes should be maintained so that blasting fumes can be cleared quickly and efficiently (Figure 9-14).
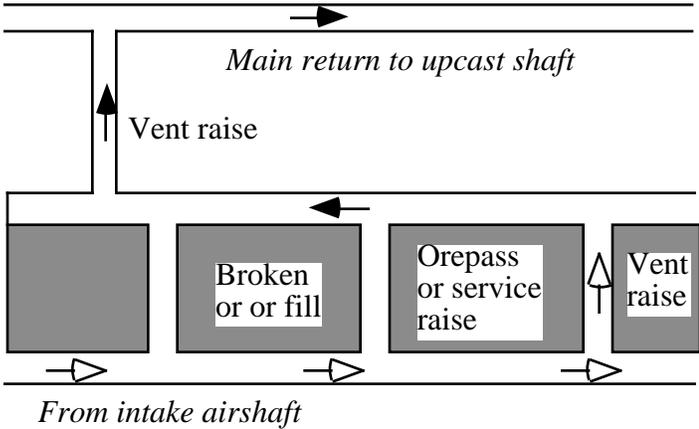
Figure 9-14. An example of a simple ventilation system for shrinkage or cut-and-fill stopes.

With respect to fan locations and airflow direction, there primarily are three ventilation systems: *exhaust* (pull) system, where the mine fan is located on top of the return airshaft; *blowing* (push) system, with the mine fan installed at the intake airshaft; and *combined* system (push-pull), with fans on both the intake and return airshafts. This refers to main ventilation systems only; local

arrangements, for example a face ventilation system for a working area, can be different from the main system.

Depending on the particular system, the mine pressure could be either negative (exhausting system, since the fan creates a suction in the system, putting mine pressure below the atmospheric datum) or positive (blowing system). This is because the mine pressure is measured against atmospheric pressure, as shown in Figure 9-15:
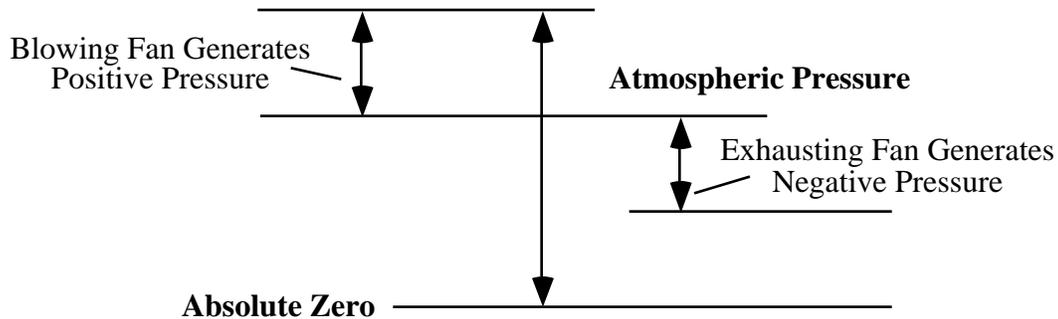
Figure 9-15. Schematic showing a positive mine pressure for blowing system and a negative mine pressure for exhausting system.

The best way to describe the relation between pressure loss and air traveling distance is to use a *pressuregradient*, as shown in Figures 4-14 and 4-15. The coal mine in Figure 4-14 shows that pressure loss is zero at surface, slowly building up to approximately 0.2 in. W.G. as it proceeds 2,000-ft underground. Pressure drop accumulates to 0.7 in. W.G. after 9,000-ft just before the longwall section. Total mine pressure is – 6 in. W.G. at the end of the circuit. The negative sign simply means it is an exhaust ventilation in which pressure is lower than the atmospheric pressure. Similar gradient is also demonstrated in Figure 4-15.

Airflow Direction

Airflow direction is affected by the location of the main fan which, in turn, will significantly impact the other aspects of operation or transportation. An *antitropal* system is one in which the airflow and transported rock move in opposite directions, implying that the mineral transportation is carried out in intake airways. This tends to put restrictions on the air velocities in intake airways so that dust and other gases will not be too excessive. Conversely, a *homotropal* system is one where the airflow and the mined rock move in the same direction, or the haulage is carried out in return airways. This system will ensure that dust, heat, and other pollutants from broken rock will be vented directly to the outside. In addition, this system also has the advantage in case of fire occurring in the haulageway.

Another factor in airflow direction is the inclination of the airway. An *ascensional* ventilation is when the airflow moves upwards through inclined workings. This takes advantage of the natural ventilation effects caused by the added heat to the air. *Descentional* ventilation may be employed on a more compact system, with both air and conveyed materials moving downhill.

It is the pressure difference that causes air to flow underground, regardless of how this

pressure difference is generated. There are different merits and drawbacks in each system. A particular system must be selected to accommodate the specific mining situation, and not the ventilation designer's pet theories. The following is a list of pros and cons for both arrangements (Tien, 1978):

1)   Exhausting System

Advantages:
  a) When main fan stops, underground pressure builds up to atmospheric. The increase in pressure slows gas emissions from the gob and prolongs the time required for the gas to reach active workings.
  b) The haulage roads, where most travel is done, are kept free from dust, gas, and smoke. This permits the men to perform their work in fresh air.
  c) In the event of a fire or explosion, exhausting ventilation enables the rescue work to proceed more rapidly, because the fresh air is on the haulage road, which provides an easy route for carrying material and equipment to make mine repairs.
  d) Both intake airways and track entries serve as escapeways, if stopping lines are well maintained.
  e) Greater power savings are possible if mine openings are small. This is due to the potentially greater recovery of velocity pressure through the use of discharge evasè (gradual expansion ducts) on exhaust fans.

Disadvantages
  a) It reduces temperatures in the belt slope, slope bottom, and main haulage line. During winter, the belt sprinkler system, damp coal on the belt rollers, and water lines along the haulageway can freeze. The temperature also is uncomfortable for the people working in these areas.
  b) It is more difficult to detect a fire in belt and track entries since the air is carried directly to the return airways.
  c) Dust produced at the portals and along the haulage road contaminates the intake air stream. Similarly, fire in the belt and track entries can be carried to the working areas.
  d) Contaminated air goes through the fan, corrosive particles settle on the fan blades and corrode them, reduces effective air passage area, and can throw the fan out of balance.

2)   Blowing System

Advantages
  a) It applies a continuously decreasing overpressure from the air intake portal to the discharge opening. This characteristic produces airflow from intake airways to the return and prevents contaminated flow into working areas from idle areas and return airways. In fact, the blowing system may be the only practical method of ventilation in shallow mines having fractured ground, as well as areas of contiguous mining where there may be ground cracks into abandoned mines.
  b) The haulage roads and hoisting shaft stay free from ice, making it more comfortable for the men in winter.
  c) A fire in any part of the mine is soon evident, due to leakage, to anybody working in the air current coming away from the face area.
  d) Only outside air, non-corrosive and with normal moisture content, goes through the fan.
  e) Fan unit is cheaper because of a shorter fan duct (diffuser).

Disadvantages
   a) Products of combustion from a mine fire or explosion are carried into the neutral escapeway. Thus, fire-fighting and rescue work are more difficult because access often is blocked by smoke. Ventilation reversal, in these cases, may endanger the men.
   b) Dust, smoke, and other impurities are carried away from the face area and along the haulage road. Methane tends to accumulate in pockets in the roof, sometimes causing slight explosions.
   c) Since neutral air flows away from working sections to the slope bottom, any accumulated air contaminants converge on workmen in the slope bottom area.
   d) Shock losses are greater. It requires a distance of 30 times the duct diameter away from the pressure jet for the air velocity to lose 90% of its original velocity. For an exhausting system, only one duct diameter distance is required to lose 90% of its velocity. As result, pressure loss caused by shock, which is in addition to frictional loss, is considerably more in a blowing system.
   e) Dirt and dust from outside will settle on the fan blades.

3) Push-pull (combination) System

In the push-pull system, it is easier to get air to difficult places. The disadvantage of this system is that it is harder to balance the ventilation system, resulting in neutral spots in the mine. According to recent survey, the majority of the underground coal mines in the U.S. use exhausting ventilation as their main ventilation system.

4 . Ventilation Planning/Designing

The ultimate goal for ventilation planning is to design a system that will be capable of adequately ventilating all working faces, airways, and areas underground at minimum costs. A good mine ventilation system always begins with the initial development of the mining plan, which always should have alternatives. A well-thought out ventilation system can minimize long-term problems, builds in flexibility for expansion without exorbitant cost, reduces up-front capital expenditures, and phases in capital outlay over the life of the project (Bossard, et al., 1982).

Air volume requirements can be substantial in some operations. The presence of diesel, gaseous products, strata gases, heat and humidity, and large openings all require a significant increase in the minimum air velocity required, and hence a higher air volume requirement. Since energy requirement is proportional to the cube of air volume circulated, optimization between air volume and resistance must be considered. Other factors also must be factored in, such as environmental requirements and available resources. Figure 9-16 shows a basic model for planning a new underground mine (Viljoen, 1990).

Although many factors enter into an ultimate ventilation planning scheme, minimizing friction and shock losses are the two most important among all the items considered.

1. To minimize friction losses

From the equation,

$$R = \frac{KPL}{5.2A^3N^2}$$

anything that can lower K, P, and L and increase A and N will reduce R, and ultimately lower costs in terms of having lower overall ventilation pressure, realizing that there will be practical limitations.
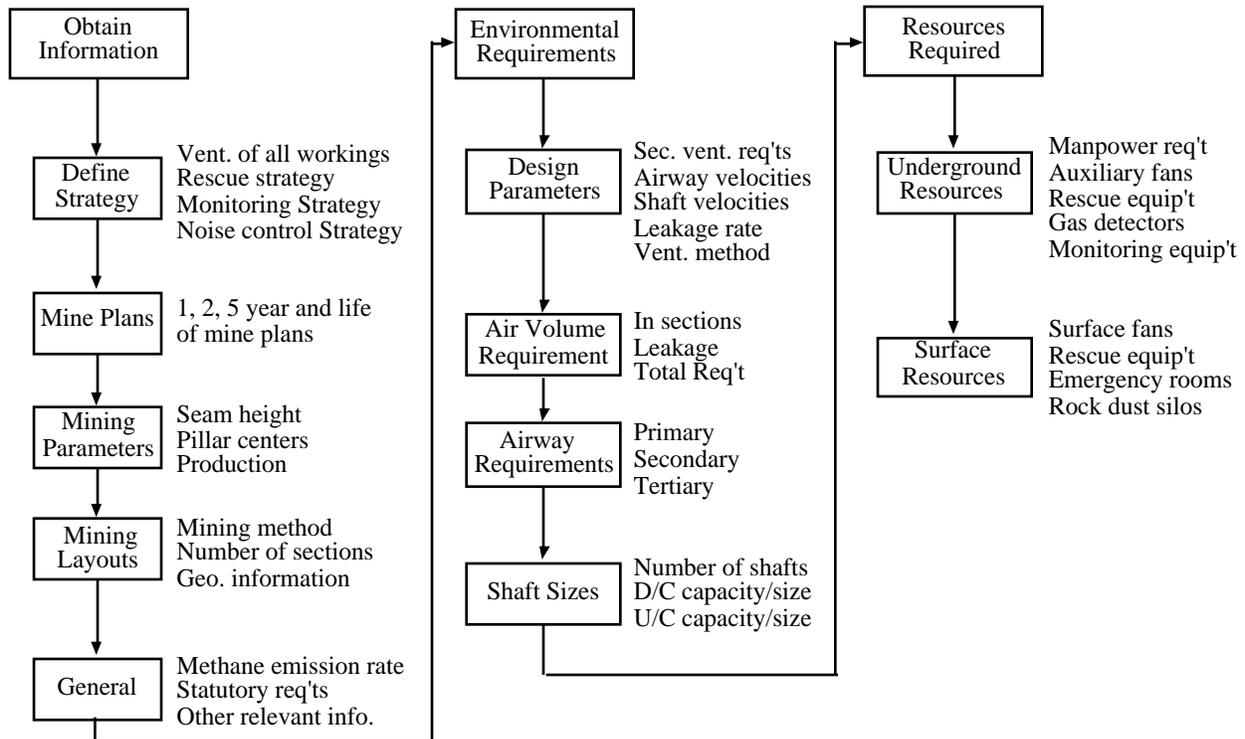
Obtain Information		Environmental Requirements		Resources Required	
Define Strategy	Vent. of all workings Rescue strategy Monitoring Strategy Noise control Strategy	Design Parameters	Sec. vent. req'ts Airway velocities Shaft velocities Leakage rate Vent. method	Underground Resources	Manpower req't Auxiliary fans Rescue equip't Gas detectors Monitoring equip't
Mine Plans	1, 2, 5 year and life of mine plans	Air Volume Requirement	In sections Leakage Total Req't	Surface Resources	Surface fans Rescue equip't Emergency rooms Rock dust silos
Mining Parameters	Seam height Pillar centers Production	Airway Requirements	Primary Secondary Tertiary		
Mining Layouts	Mining method Number of sections Geo. information	Shaft Sizes	Number of shafts D/C capacity/size U/C capacity/size		
General	Methane emission rate Statutory req'ts Other relevant info.				

Figure 9-16.   Factors considered in planning a new mine (Viljoen, 1990).

2.   To minimize shock losses

Since up to 30% of total losses underground comes from shock losses, it is essential that shock losses be minimized to lower costs. From the equation,

$$H_x = XH_v$$

The obvious thing to do is to lower shock loss factor, X, for given air velocity. This can be achieved by rounding off corners, avoiding sudden air velocity and airflow direction changes, etc.

5. Ventilation Planning and Design Parameters at Homestake – A Case Study

The goal of a ventilation system is to provide a work environment that contains minimal safety and health risks and is conducive to hard work. Since ventilation is a cost function, this goal should be met as inexpensively as possible.

Homestake is the largest underground gold mine in the U.S., currently operating at the 8,000-foot level. The mine is ventilated by 1,069,000 cfm (504 m^3/sec) of air measured at mid-exhaust-circuit density. Its air conditioning system includes a 2,300 ton (8.1 MWR) controlledrecirculation plant, a 580 ton (2.0 MWR) chilled water plant, a 290 ton (1.0 MWR) drite exploration plant, 28 spot-coolers totaling 960 tons (3.4 MWR), and 35 spray coolers totaling 420 tons (1.5 MWR). The mine employs 117 diesel units with a total nameplate rating of 10,672 hp (7,961 kW), plus other mining equipment (Marks and Shaffner, 1993).

Faced with these challenges, the mine management formulated a ventilation planning method called Requirements and Resources Analysis (Marks and Justus, 1993). A requirement is defined as the air quantity or the amount of refrigeration necessary to meet the goal stated above. A resource is a tangible thing: a fan, cooler, or an airway. A properly designed system has the resources to meet the requirements. If not, work areas will be excessively warm or cold, or will suffer from high contaminant concentrations. Requirements and Resources Analysis has four basic components: 1) Establishing and justifying design parameters, 2) ascertaining present ventilation system status, 3) projecting ventilation requirements, and 4) analyzing ventilation resources alternatives.

Design parameters specify what is too hot or too cold, what concentrations of contaminants are too high, and what specific air quantities and velocities are used for specific operations. For heat, the economic temperature range for work is 80° to 85°F wet-bulb, designated as the design reject temperature. The 85° to 91°F wet-bulb increment is considered the safety-factor range where only temporary work is permitted. Above 91°F wet-bulb, ingress is for short duration only.

For dust, toxic and dangerous gases, the guidelines set forth by Mine Safety and Health Administration (MSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) are followed. For diesel equipment, a minimum 110 cfm per rated horsepower (0.07 m^3/sec per kW) is specified for ramp systems and general work areas. Dead and auxiliary fans can get by with less air if diesel vehicles are only in the heading part-time. Scrams under 100 ft in length usually are well enough ventilated by convection currents and the reciprocating action of the loader.

References

Adam, et al. (1987) "Leakage Testing of Large Ventilation Control Structures for Room and Pillar Oil Shale Mining," *Proc. 3rd U.S. Mine Ventilation Symposium,* Mutmansky, J.M., ed., SME, Littleton, CO, pp. 365-370.

Anon. (1976) "Humidity Effects on Coal Mine Roof Stability," USBM Contract #H0232057, OFR 5-78, 164 pp.

Bossard, F.C., et al. (1982) "Chap. 22: Primary Mine Ventilation Systems," *A Manual of Mine Ventilation Design Practices,* First Ed., Floyd C. Bossard & Asso., Inc., Butte, MT, 2 pp.

Cummings, R.A., Singh, M.M., and Moebs, N.N. (1983) "Effect of Atmospheric Moisture on the Deterioration of Coal Roof Shales," *Min. Engg.,* Mar., pp. 243-245.

Haynes, C.D. (1975) "Effects of Temperature and Humidity Variations on the Stability of Coal Mine Roof Rocks – Final Report," USBM Contract # H0122111, OFR 8-77, 385 pp.

Highton. W. (1980) "The Case Against Bleeder Entries and the Reasons for a Safer and More Efficient Alternative," *Proc. 2nd Int'l Mine Ventilation Cong.,* P. Mousett-Jones, ed., SME-AIME, NY, pp. 437-447.

Lucas, W.S. (1975) "Tempering Mine Air to Prevent Roof Falls," *Proc. Illinois Min. Inst. Annual Meeting,* Oct., pp. 47-55.

McPherson, M.J. (1993) "Chap. 9: Ventilation Planning," Subsurface *Ventilation and Environmental Engineering,* Chapman & Hall, New York, pp. 282-321.

Sames, G.P. (1985) "Coal Mine Air Tempering: Effectiveness, Design, and Roof Support," USBM *Rpt Investigation No. 8955,* 20 pp.

Stateham, R.M. and Radcliffe, D.E. (1978) "Humidity: A Clyclic Effect in Coal Mine Roof Stability," USBM *Rpt Investigation No. 8291,* 19 pp.

Thimons, E.D., et al. (1988) "Leakage and Performance Characteristics of Large Stoppings for Room-and-Pillar Mining," USBM *Rpt Investigation No. 9148,* 17 pp.

Tien, J.C. (1978) "Pros & Cons of Underground Ventilation System," *Coal Min. & Proc.,* Jun., pp. 110-113.

Tien, J.C. (1997) "Chap. 17: Longwall Mining," *Short Course Text*, University of Missouri-Rolla Press, Rolla, Missouri, Apr., pp. 341-378.

Uchino. K. and Hiraga, T. (1984) "Control of Thermal Environmental Conditions in a Retreating Longwall Coal Face by E- and W Ventilation Systems," *Proc. 3rd Int'l Mine Ventilation Cong.,* Howes. M. J. and Jones. M. J., eds., Inst. Min. and Met.. London, pp. 339-342.

Viljoen, P.L.J. (1990) "Planning of a New Colliery (Flow Diagram)," *Journ. Mine Ventilation Soc. S.A.,* Apr., p. 80.

Longwall Ventilation

Banerjee, S.P. et al (1984) "Methane Emission and Control in Caved Longwall Faces in Moonidih Colliery, India," *Proc. 3rd Int'l Mine Vent Cong*, Howes, M.J. and Jones, M.M., ed., Inst. of Min. Engrs., London, England, Jun., pp. 171-176.

Battino. S. and Mitchell. P.B. (1985) "Ventilation Experiences with Longwall Mining at Macquarie Colliery," *Proc. of the 2nd U. S. Mine Ventilation Sympo.,* Mousset-Jones, P., ed., A.A. Balkema, Rotterdam, pp. 409-418.

Cecala, A, Konda, B.W. and Klinowski, G. W. (1989) "A Comparison of Methane Flow Patterns on Advancing and Retreating Longwalls," *Proc. 4th U.S. Mine Vent Sympo.*, McPherson, M.J., ed., SME, Littleton, CO, pp. 484–490.

Cecala, A. B. et al (1985) "Determining Face Methane Liberation Patterns During Longwall Mining," *Proc. 2nd U. S. Mine Vent Sympo.,* Mousset-Jones, P., ed., A.A. Balkema, Rotterdam, pp. 361-367.

Colinet, J.F., Spencer, E.R., and Jankowski, R.A. (1997) "Status of Dust Control Technology on U.S. Longwalls," *Proc. 6th Int'l Mine Ventilation Cong.,* Ramani, R.V., ed., SME, Littleton, CO, pp. 345-351.

Compoli, A.A., McCall, F.E., Finfinger, G.L., and Zuber, M.D. (1995) "Potential for Improved Longwall Dust Control by Surface Borehole Water Infusion," SME Annual Meeting, Denver, CO, March 4-9, *Preprint # 95-139,* 8 pp.

den Drijver, et al. (1997) "Calculation of the Amount of Methane Degassing from Longwall Based on a Mathematical-Physical Model," *Proc. 6th Int'l Mine Ventilation Cong.,* Ramani, R.V., ed., SME-AIME, NY, pp. 237-241.

Diamond, W.P., et al. (1997) "Analysis and Prediction of Longwall Methane Emissions: A Case Study in the Pocahontas No. 3 Coalbead, VA," *Proc. 6th Int'l Mine Ventilation Cong.,* Ramani, R.V., ed., SME, NY, pp. 223-229.

Divers, E. F. et al (1987) "Ventilation Drum Controls Longwall Dust and Methane," Proc. *3rd U.S. Mine Vent Sympo.,* Mutmansky, J.M., ed., SME, Littleton, CO, pp. 85-89.

Divers, E.F. (1991) "Coping with Longwall Dust," *Coal*, Jun., pp. 55-57.

Dziurzynski, W. and Nawrat, S. (1997) "Optimal Choice of the Parameters for Ventilation and

Methane Drainage in a Longwall Face with Caving," *Proc. 6th Int'l Mine Ventilation Cong.,* Ramani, R.V., ed., SME, NY, pp. 359-364.

Fuller, J.L. (1989) "An Overview of Longwall Ventilation System Design," SME Annual Meeting, Las Vegas, NV, *Preprint # 89-53*, 13 pp.

Garcia, F. and Cervik, J. (1985) "Methane Control on Longwalls With Cross-Measure Boreholes (Lower Kittanning Coalbed)," USBM *Rpt Investigation No. 8985,* 17 pp.

Goodman, T. W. and Cervik, J. (1986) "Comparisons Between Cross-Measure Boreholes and Surface Gob Holes," USBM Rpt *Investigation No. 9013*, 14 pp.

Haake. J., Koppe. U., and Phillip. W. (1985) "Gas Emission and Ventilation in a Working with Y-type Ventilation on the Return Side," (English translation). Gluckauf. v. 121, pp. 1144-1150.

Haneyn R.A., et al. (1993) "Influence of Airflow and Production on Longwall Dust Control," *Proc. 6th U.S. Mine Vent. Sympo.,* Bhaskar, R., ed., SME, Littleton, CO, pp. 43-49.

Hanson, B.B. and Poepke, W.W. (1988) "Computer Modeling of Dust and Forces for Longwall Mining Systems," USBM *Rpt Investigation No. 9203,* 24 pp.

Heising, C. and Becker, H. (1980) "Dust Control in Longwall Workings," *Proc. 2nd U.S. Mine Vent Cong.,* Mousset-Jones, P., ed., SME, NY, pp. 603-611.

Jankowski, R. a. and Babbit, C. A. (1986) "Using Barriers to Reduce Dust Exposure of Longwall Face Workers," USBM *Rpt Investigation No. 9037,* 10 pp.

Jankowski, R. A., Kissell, F. N. and Daniel, J. H. (1986) "Longwall Dust Control: An Overview of Progress in Recent Years," *Min Engg*, Oct., pp. 953-958.

Jankowski, R. A., Organiscak, J. A. and Jayaraman, N. I. (1990) "Dust Sources and Controls on High Tonnage Longwall Faces," SME Annual Meeting, *Preprint #90-73,* 9 pp.

Lama, R.D. and Liu, Y. (1993) "Use of Diamond Tipped Picks for Dust Control on Longwall Faces," *Proc. 6th U.S. Mine Vent. Sympo.,* Bhaskar, R., ed., SME, Littleton, CO, pp. 545-549.

Longson, I. and Tuck, M. A. (1985) "The Computer Simulation of Mine Climate on a Longwall Coal Face," *Proc. 2nd U. S. Mine Vent Sympo.,* Mousset-Jones, P., ed., A.A. Balkema, Rotterdam, pp. 439-448.

Longson, I., R.D. Lee, and I.S. Lowndes (1985) "The Feasibility of Controlled Air Recirculation around Operating Longwall Coal Faces," *Proc. 2nd U.S. Mine Vent Sympo.*, Mousset-Jones, P., ed., A.A. Balkema, Rotterdam, pp. 227-237.

Mukherjee, S. K. et al (1985) "Laboratory Investigation on the Effectiveness of an Air Spray System for Dust Control on Longwall Faces," *Proc. 2nd U. S. Mine Vent Sympo.,* Mousset-Jones, P., ed., A.A. Balkema, Rotterdam, pp. 727-732.

Mundell, R. L. et al (1979) "Respirable Dust Control on Longwall Mining Operations in the United States," *Proc. 2nd Int'l Mine Vent Cong.*, Mousset-Jones, P., ed., A.A. Balkema, Rotterdam, pp. 585-593.

Niewiadomski, G.E. and Jankowski, R.A. (1993) "Longwall Dust Trends and Development in Longwall Dust Controls," *Proc. 6th U.S. Mine Vent. Sympo.*, 'Bhaskar, R., ed., SME, Littleton, CO, pp. 551-556.

Ondrey, R.S., Haney, R.A., and Tomb, T.F. (1995) "Dust Control Parameters Necessary to Control Dust on Longwall and Continuous-Mining Operations," SME Annual Meeting, Denver, CO, March 4-9, *Preprint # 95-145,* 6 pp.

Organiscak, J.A. and Jankowski, R.A. (1996) "U.S. Longwall Practices for Controlling Respirable Dust Sources Outby the Shearing machine," *Proc. Respirable Dust Hazard Control in the Mining Industry,* Szczyrk, Poland, Sep. 17-19, pp. 19-25.

Organiscak, J.A. and Leon, M.H. (1993) "Translucent Face Partition for Longwall Dust Control," *Proc. 6th U.S. Mine Vent. Sympo.*, Bhaskar, R., ed., SME, Littleton, CO, pp. 557-562.

Organiscak, J.A., et al. (1985) "Factors Affecting Respirable Dust Generation from Longwall

Roof Supports," USBM *Information Circular No. IC-9019*, 19 pp.

Pickering, A. J. and Robinson, R. (1984) "Application of Controlled Air Recirculation to Auxiliary Ventilation Systems and Mine District Ventilation Circuits," *Proc. 3rd Int'l Mine Vent Cong*, Howes. M. J. and Jones. M. J., eds., Inst. Min. and Met.. London, pp. 315-322.

Srinivasa, R.B., et al. (1993) "Three Dimensional Numerical Modeling of Air Velocities and Dust Control Techniques in a Longwall Face," *Proc. 6th U.S. Mine Vent. Sympo.,* Bhaskar, R., ed., SME, Littleton, CO, pp. 287-292.

Stevenson, J. W. (1985) "An Operators Experience Using Antitropal and Homotropal Longwall Face Ventilation System," *Proc. 2nd U. S. Mine Vent Sympo,* Mousset-Jones, P., ed., A.A. Balkema, Rotterdam, pp. 551-557.

Stoke, A. W. (1985) "Air Leakage through Longwall Wastes in the Sydney Coalfield," *Proc. 2nd U. S. Mine Vent Sympo,* Mousset-Jones, P., ed., A.A. Balkema, Rotterdam, pp. 75-84.

Stokes, M.R. and Tuck, M.A. (1997) "Future Configurations of High Output Longwall Faces," *Proc. 6th Int'l Mine Ventilation Cong.,* Ramani, R.V., ed., SME, Littleton, CO, pp. 487-492.

Tien, J.C. (1995) "Chinese Mine Ventilation," *COAL*, June, pp. 51-53.

Tomb, T.F., et al (1990) "Evaluation of Respirable Dust Control on Longwall Mining Operations," SME Annual Meeting, Salt Lake City, Utah, Feb., *Preprint #90-41,* 10 pp.

Tuck, M.A. and Longson, I. (1989) "Heat and Moisture Transfer within Advancing Longwall Coalface Goafs and the Effect of Face Climatic Conditions," *Proc. 4th U.S. Mine Ventilation Sympo.*, McPherson, M.J., ed., SME, Littleton, CO, pp. 271–277.

Uchino, K. et al (1980) "Study of Ventilation of Longwall Coal Face by Model," *Proc. 2nd Int'l Mine Vent Cong.*, Mousset-Jones, P., ed., SME, NY, pp. 103-107.

Urosek, J.E., Zuchelli, D.R., and Beiter, D.A. (1995) "Gob Ventilation and Bleeder Systems in U.S. Coal Mines," SME Annual Meeting, Denver, CO, March 4-9, *Preprint No. 95-78,* 5 pp.

Watts, W.F. and Niewiadomski, G.E. (1991) "Respirable Dust Trends in Coal Mines with Longwall or Continuous Miner Sections," *Proc. 7th Int'l Pneumoconiosis*, Pittsburgh, 12 pp.

Webster, J.B., Chiaretta, C.W. and Behling, J. (1990) "Dust Control in High Productivity Mines," SME Annual Meeting, Salt Lake City, Utah, Feb., *Preprint #90-82,* 9 pp.

Note: References on longwall dust control and related subjects are abundant and can be found in many sources; refer to those sources for further details.

Other Related Information

Buchan, G. (1998) "Long Panels for Longwall Mining: A Case Study at Twentymile Coal," SME Annual Meeting, Orlando, FL, *Preprint #98-101,* 6 pp.

Carruthers, J, et al. (1993) "Chap. 28: Ventilation," *Australasian Coal Mining Practice,* Australasian Inst. Mining and Metallurgy, Victoria, Australia, pp. 461-503.

Dalzell, R. W. (1972) "Longwall Ventilation Systems," *Min. Cong. Journ.*, March, pp. 53-61.

Johnson, B. R. and Ramani, R.V. (1992) "Chap. 11.7: Mine Ventilation Design," *SME Mining Engineering Handbook,* 2nd Ed., Vol. 1, Hartman, H.L., ed., pp. 1093-1121.

Lowndes, I.S. and Tuck, M.A. (1995) "Review of Mine Ventilation System Optimization," *Trans. Instn. Min. and Metall.,* May-August, pp. A114-A126.

Marks, J.R. (1989) "Nuts-And-Bolts Ventilation Planning for Hardrock Mines," Pre-symposium Short-Course, *4th U.S. Mine Ventilation Sympo.*, Berkeley, CA, Jun., 61 pp.

Marks, J.R. and Justus, B.D. (1993) "Mine Ventilation Planning with Computer Exercises for Metal Mines," Pre-Symposium Short-Course, *6th U.S. Mine Ventilation Symposium,* Salt Lake City, Utah, June.

Marks, J.R. and Shaffner, L.M. (1993) "An Empirical Analysis of Ventilation Requirements for Deep Mechanized Stoping at the Homestake Gold Mine," *Proc. 6th U.S. Mine Ventilation Symposium,* Salt Lake City, Utah, June, pp. 381-385.

Montgomery, W.J. (1936) *Theory and Practice of Mine Ventilation,* Jeffrey Manufacturing Co., Columbus, Ohio.

Mutmansky, J.M. and Wang, W.H. (1997) "Results of Field Studies on Stratification of Diesel Particulate Matter in Mine Openings," *Proc. 6th Int'l Mine Ventilation Cong.,* Ramani, R.V., ed., SME, Littleton, CO, pp. 155-162.

O'Neil, T.J. and Johnson, B.R. (1991) "Chap. 14: Metal Mine Ventilation Systems," *Mine Ventilation and Air Conditioning*, Hartman, L.H. et al, ed., Kreiger Publ, Malabar, FL, pp. 379-420.

Ramani, R.V. (1992) "Chap. 11.6: Mine Ventilation," *SME Mining Engineering Handbook,* 2nd Ed., Vol. 1, Hartman, H.L., et al., ed., pp. 1052-1092.

Roberts, A. (1960) "Chap. 13: Ventilation Planning – Estimation of Air Quantity," *Mine Ventilation, Roberts,* A., ed., Cleaver-Hume Press, Ltd., London, pp. 244-261.

Suboleski, S.C. and Kalasky, J.D. (1991) "Chap. 15: Coal Mine Ventilation Systems," *Mine Ventilation and Air Conditioning*, Hartman, H.L. et al., ed., Kreiger Publ, Malabar, FL, pp. 421-452.

Tisdale, J.E. and Urosek, J.E. (1997) "Examination of Bleeder Systems," *Proc. 6th Int'l Mine Vent Cong,* Ramani, R.V., ed., SME, Littleton, CO, pp. 95-98.