SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

SIMRAC

Final Project Report

Title: IMPROVING UNDERGROUND VENTILATION CONDITIONS IN COAL MINES

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1) INTRODUCTION

The aim of this project was to establish the needs of the industry with regard to bord and pillar ventilation requirements. In addition, the aim was to establish whether sufficient research has already been done by the mining industry and if further projects could be initiated by Miningtek in co-operation with the different mines.

This report deals with the findings of this project and also deals with the future of research within Miningtek with regard to underground ventilation.

2) THE USE OF FREESTANDING FANS.

The trend throughout the industry is to change from using auxiliary fans with ducting, to using smaller fans that can be used without ducting. This has cost implications as well as practical implications and, under certain circumstances, better results are also achieved.

Tests were conducted at a few mines where the performance mainly of jet fans was determined; this was because vortex fans have been tested thoroughly in the past and jet fans appear to be an improvement on the vortex fans. The fans were placed in different positions with relation to the heading and the last through road, and different mining situations prevailed inside the headings during the tests. Normal production was carried out during most of the tests and, in some cases, the last through road air velocity was varied as well to establish whether there was any difference in the performance of the fans.

Detailed results of these and other tests have been compiled into a comprehensive reference report on research results [A]. Further investigations into the correct uses of freestanding fans are to be carried out during 1994 with the aid of computer simulations as well as underground tests.

3) UNDERGROUND FRICTION FACTORS.

In this particular area the Rand Mines group has done some work to find solutions for specific problem areas. For example, work performed determining flow resistances of airways and air crossings, as well as leakage characteristics of various ventilation structures [B]. The overall perception on the mines was that it would not be worthwile to initiate a full scale project in this area, as there are too many variables, and the underground situations differ significantly from mine to mine. Each mine tends to carry out it's own studies when needed to solve airflow problems in a certain area. At this stage, the Environmental Control personnel are not suppotive of possible guidelines dealing with underground resistance figures for different airways and airway obstructions.

Different computer programs exist that can assist in solving airflow problems in airways [B]. For example, a company, M-Tech at Potchefstroom University has a program, Flownet, that can be used to solve flow problems. Any mine can take isolated measurements to determine resistance figures for their specific problem areas which in turn can be fed into the computer program.

4) CONTROLLED RECIRCULATION OF AIR INSIDE A BORD AND PILLAR HEADING.

No research on the controlled recirculation of air inside a heading has been conducted in South African coal mines as yet. Overseas mines are using this method of ventilation with great success and efficiency [C]. Results show that this method of ventilation can be exercised without creating any danger to workers inside the heading with regard to dust and gas levels [D].

Legislation in South Africa prohibits the re-use of air inside a coal heading, although in some instances uncontrolled recirculation is taking place. With the number of gas and dust related incidents occurringinside headings recently, legislation should perhaps be revised to introduce more effective measures to prevent recirculation or to control it in a positive manner. Proof, however, that controlled recirculation is a viable and safe option for ventilating headings will require time and money as well as inconvenience to those mines willing to accomodate the tests. Overseas trips may also be required to gather facts and figures and firsthand knowledge from the mines already using this method of ventilation. At this stage a project of this nature is not a high priority of the different mining companies.

During the past year, a project was completed on the use of controlled recirculation to ventilate a ventilation district on one of the collieries [E]. The project involved the re-introduction of 65 m^3/s of return air into the main intake airstream supplying six sections of fresh air. This project proved to be very successful and showed that air could be re-used without creating any hazards to the underground workers.

During 1994 a series of computer simulations will be performed on the use of different ventilation systems under different mining situations. During these tests, the aspect of recirculating air inside a heading will be addressed and valuable information should become available during the project.

5) FUTURE OF RESEARCH IN UNDERGROUND VENTILATION.

The economic situation in the country has forced the coal mining industry to take a critical look at the value of research with regard to coal mine ventilation.

The overall perception is that the individual mines sufficient experience and expertise among their environmental control personnel to solve problems that are occurring and therefore no further research by outside institutions is supported.

Ventilation research in the future should be centred around solving dust and methane problems. Fundamental ventilation research work is no longer viable and the work done to date should be used as guidelines for future dust and methane research projects which incorporate ventilation flow as part of the solution.

The coal mining industry recognizes the fact that many dust and methane problems still exist in the headings and there is still much work to be done. The industry is therefore prepared to support specific projects that could produce practical, useful results with regard to methane and dust in the working face. These projects could not, however, be executed without using ventilation flow and airflow patterns as a basis and previous results as guidelines [A].

6) REFERENCES.

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[C] ROBINSON, R. Trials With A Controlled Recirculation System In An Advanced Heading, Paper Presented At The Symposium On Environmental Engineering In Coal Mining, Harrogate, October 1972.

[D] PICKERING, A, J. ALDRED, R. Controlled Recirculation Of Ventilation-a Means Of Dust Control In Face Advance Headings, Paper Presented At The General Meeting Of The IMinE Mines Rescue Station, Mansfield, April 1976.

[E] MEYER, C, F. DIEDERICKS, J, A. Controlled Recirculation Of Mine Air In An Underground Colliery, COMRO Reference Report No 17/92, September 1992.

CSIR

MININGTEK

PREVIEW OF RESEARCH DONE IN THE AREA OF COAL MINE VENTILATION FOR THE PERIOD 1989 TO 1992.

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MINING ENVIRONMENT

PROJECT NUMBER: COL029A/93
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SUMMARY

This report deals with the research carried out in the field of underground coal mine ventilation for the period 1989 to 1992, and covers the aspects of primary ventilation, section ventilation and headings ventilation.

Tests were carried out on the flow of air inside the last through road and the effect of different velocities on the airflow patterns inside the heading. The results indicated that air penetrates the headings to a maximum distance which is influenced by the air velocity in the last through road and the seam height. Tests were also carried out on the use of scoop brattices to ventilate headings.

Another investigation dealt with the use of freestanding fans to ventilate bord and pillar headings. Tests were carried out to determine the effect of different last through road air velocities on the performance and air penetration of the fans when used in different positions. It was found that air speed definitely does have an influence on the airflow patterns inside the heading.

An interesting aspect that was dealt with is the use of controlled recirculation of mine air to ventilate sections. This report deals with the recirculation of 65 m^3/s of return air inside a ventilation district in an attempt to increase the total available air volume flowing into the sections. The results showed that no dangerous or unhealthy situation was caused as a result of the recirculation.

This report also deals with all the different ventilation methods used by the industry to ventilate total extraction sections. Mining methods dealt with are rib-pillar extraction and pillar extraction. Ventilation methods are described for the development stages as well during the actual extraction of the pillars. This report also provides some history of the number of goaf-related incidents relative to the particular ventilation system used.

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1 INTRODUCTION

Throughout recent years, much research work has been carried out in the field of underground ventilation and especially on heading ventilation. Much has been learned from the results, but the point has been reached where past achievements need to be assessed, and future needs of the industry determined with regard to research for heading ventilation systems and primary ventilation flow.

At this point, it is necessary to evaluate results obtained over a period of time and combine these results into a single report that can be used for reference purposes. The aim of this report will therefore be to provide the coal mining industry with all relevant information obtained during research carried out at COMRO (now the division of Mining Technology of the CSIR) concerning ventilation practices and systems in underground coal mines.

The information in this report cover the period 1989 to 1992 and will include information on last through road air velocities, friction factors for underground ventilation ducting, ventilation methods for stooping sections, the use of ductless fans in bord and pillar headings and the use of controlled recirculation of air in underground coal mines.

2 HEADING VENTILATION

2.1 Last Through Road Air Velocities (Meyer 1991)(1)

2.1.1 **Field Trials.**

In order to ventilate an underground bord and pillar section effectively, sufficient volumes of air must reach the section and especially the last through road. It is important to know the behaviour of airflow once it reaches the point of last through ventilation and if it has an influence on the airflow patterns inside the headings.

A series of tests was conducted to determine the effect of different last through road air velocities on airflow patterns, and to what extent air penetration into an unventilated heading would occur.

Tests were carried out in bord and pillar sections with different seam heights and heading depths. The air velocities in the last through road were varied using a temporary regulator. The velocities used ranged between 0,2 m/s and 2,1 m/s and the influence on the airflow patterns inside the headings and the air penetration distances were determined.

Test Results.

The first fact learned from this, was the fact that the air flowing in the last through road definitely entered the headings. It always enters a heading on the opposite (downstream) side of the heading and flows to a maximum depth inside the heading before it joins up with the airflow in the last through road (Figure 1). This air penetration distance is affected by various factors such as air velocity and seam height.

The first series of tests were conducted in production sections and the second series in single headings that were prepared in back areas. In the production sections, normal production circumstances existed in the form of machinery, cables and piping which cause resistance to airflow. The only difference was that all forms of auxiliary ventilation were removed to prevent any influence on the normal airflow patterns (Figure 2 + 3).

The two seam heights used in the section trials were 1,5 m and 3,6 m. In both cases four velocity settings were used and the velocities ranged between 0,27 m/s and 2,1 m/s. The velocity settings in the two sections were set to be approximately the same but for comparison purposes average velocities will be used in results from the tests.

In Table 1 only the best air penetration distances achieved during the section trials are shown.

TABLE 1: Results from tests 1 and 2 - Section Trials.

Average LTR Air Velocity (m/s)	Air Penetration Distances (m)	
	Section 1 Seam Height=1,5 m	Section 2 Seam Height=3,6 m
1,99	10,5	8,0
1,38	11,5	8,8
0,93	10,1	8,0
0,29	4,0	4,7

LTR = Last Through Road

The second series of tests in the single headings were carried out at three different mines, representing three different seam heights. Initially, ventilation brattices were used to simulate different heading depths (Figure 4), but experience has shown that heading depths have no effect on penetration distances, and therefore these results will not be discussed. The air velocities will be averaged again for comparison purposes. The air penetration distances achieved in the three headings are given in Table 2.

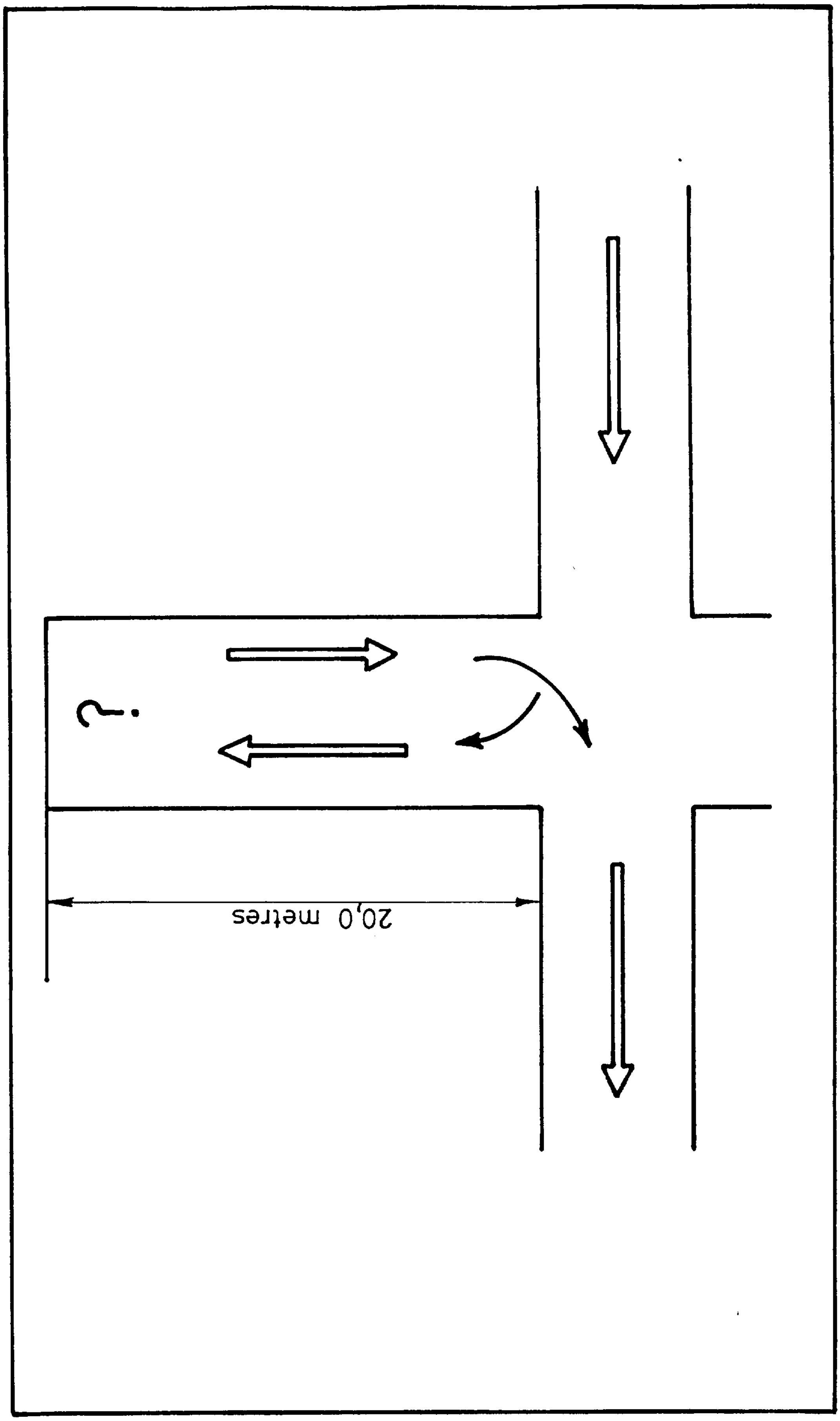

Figure 1: Behaviour of air flowing past empty heading.

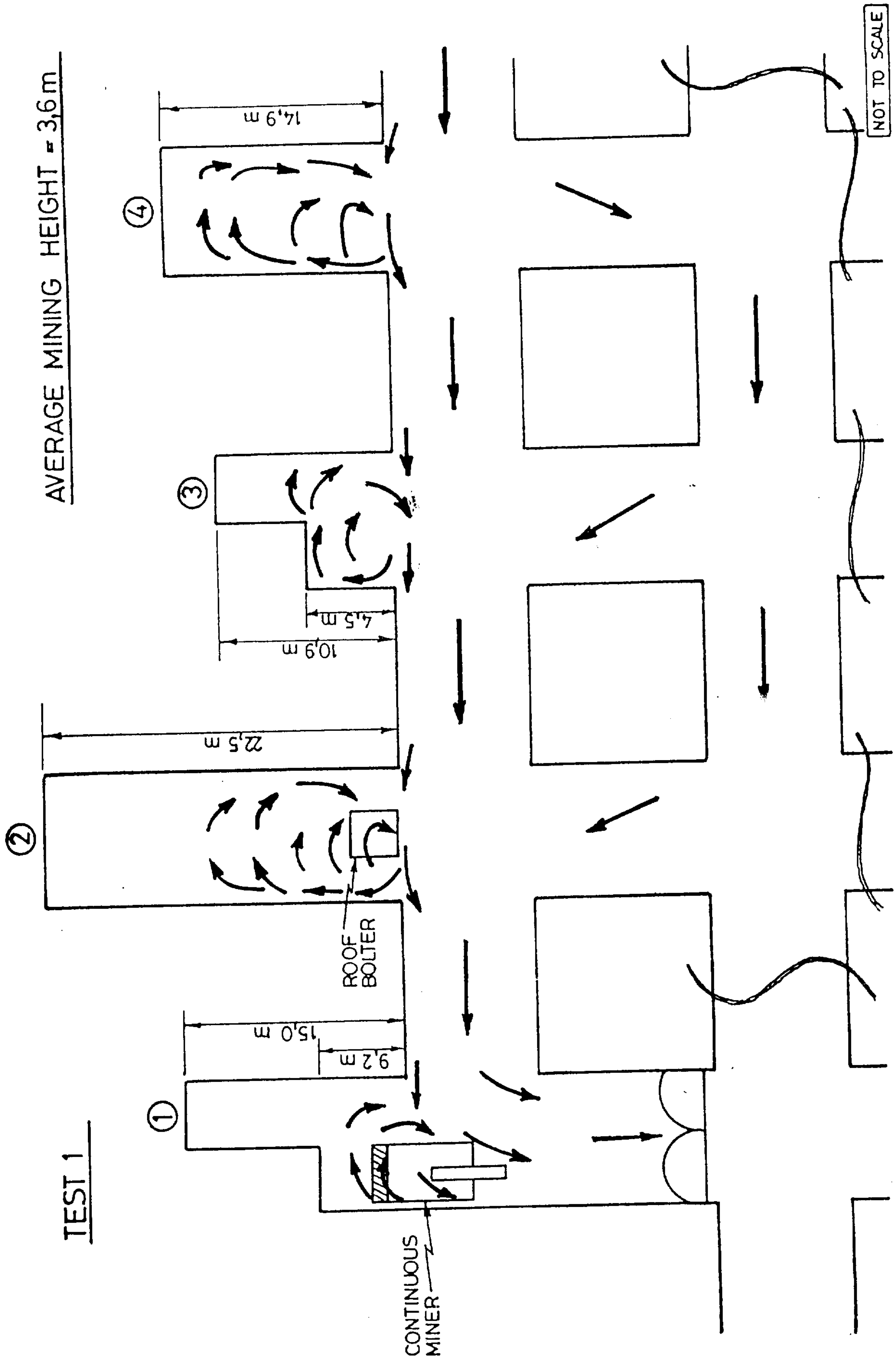

Figure 2: Layout of first section used for first series of tests.

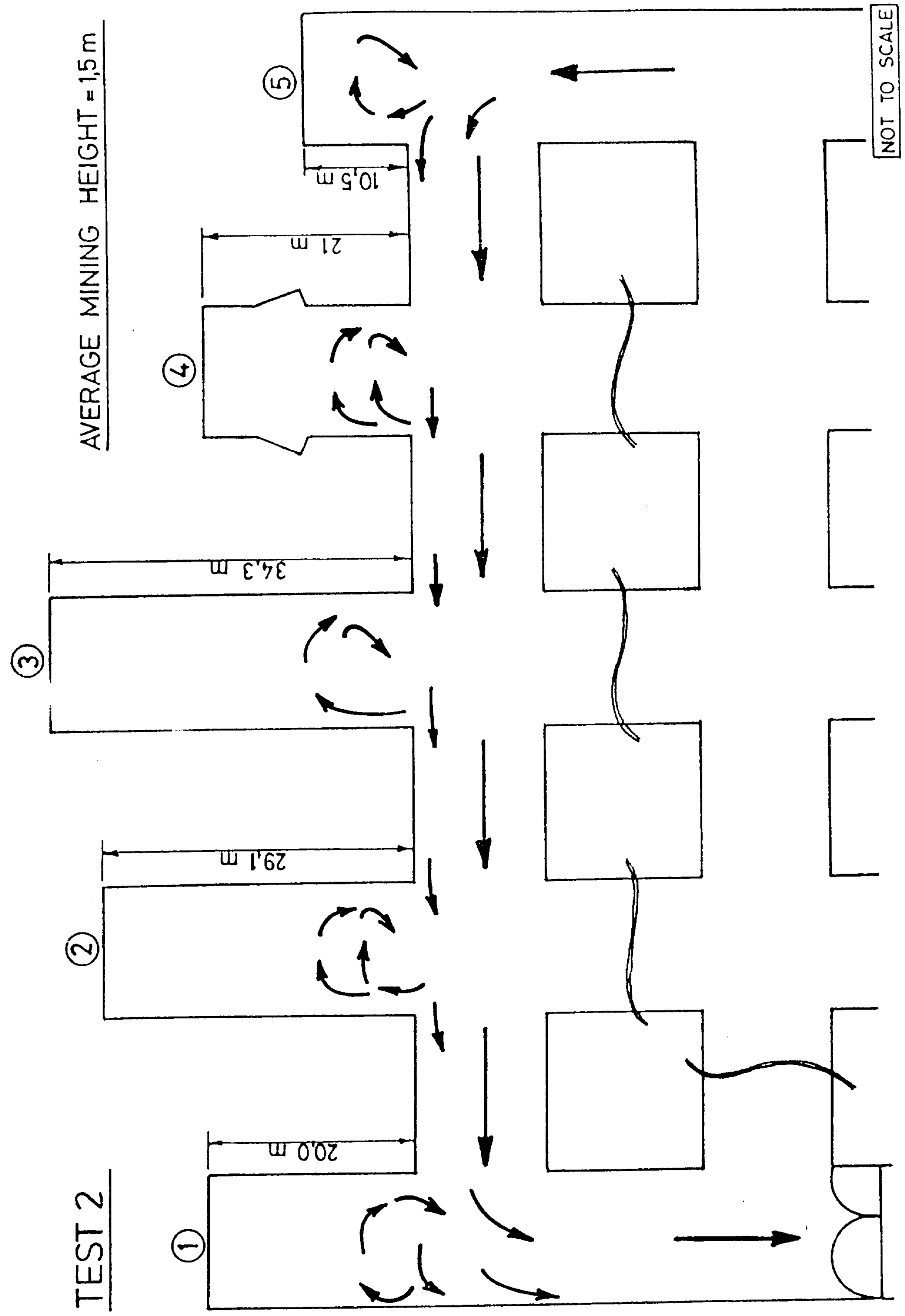

Figure 3: Layout of second section used for first series of tests.

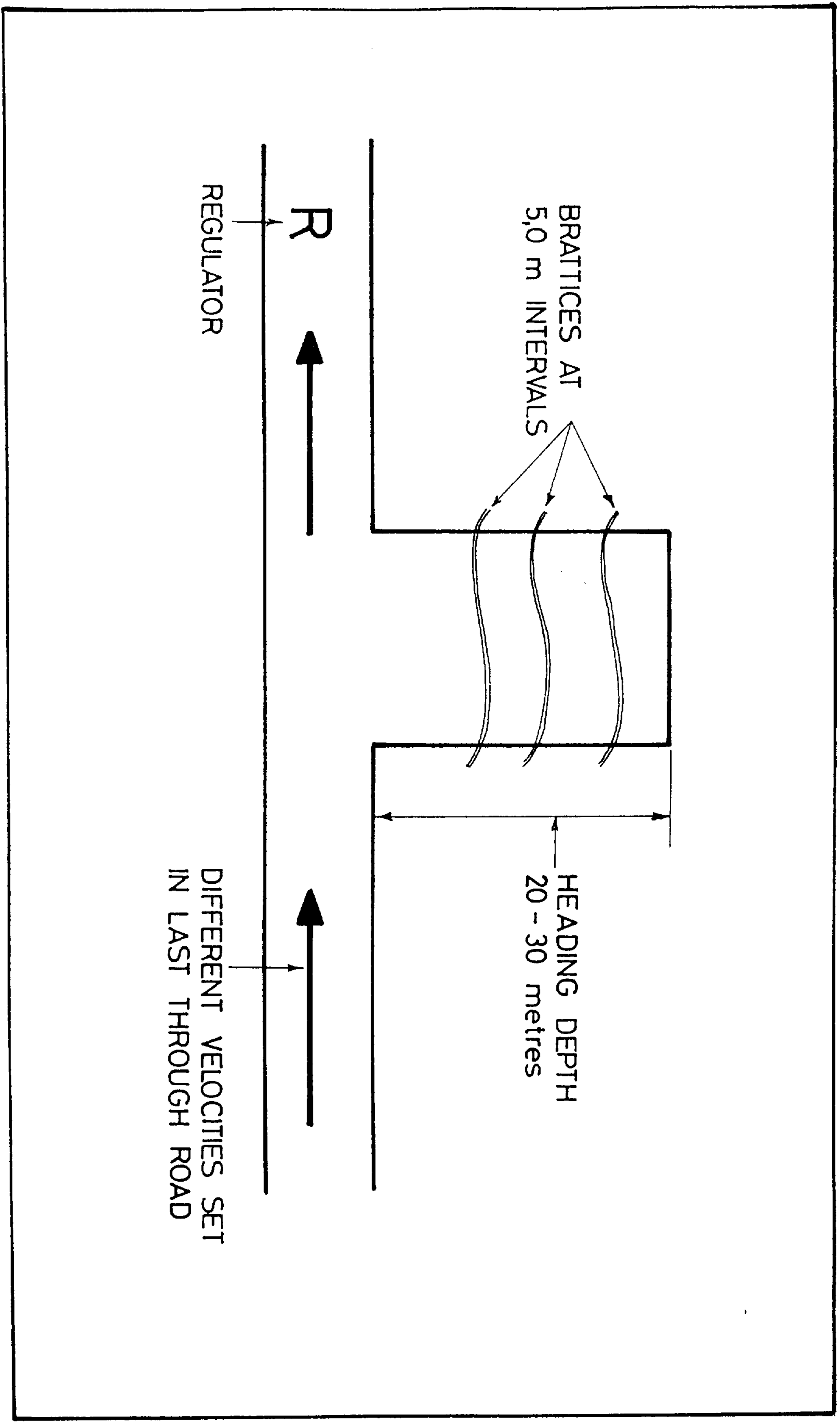

Figure 4: Layout of heading for single heading trials.

TABLE 2: Results from tests 3, 4 + 5 - Single Heading Trials.

Ave LTR Vel (m/s)	Air Penetration Distances (m)		
	Heading 1 Seam Height-4,0 m	Heading 2 Seam Height-2,1 m	Heading 3 Seam Height-3,0 m
2,1	9,0	12,0	12,4
1,35	11,3	16,0	16,8
1,0	10,2	15,8	15,8
0,65	8,0	12,2	12,2

LTR = Last Through Road

As can be seen from the results in Tables 1 and 2, there is a significant difference in the air penetration distances achieved in the two situations. The reason for this is the fact that, during the single heading trials, anything that could cause resistance to airflow, had been removed. The experiment proved that under normal production situations, normal airflow is not likely to ventilate a heading beyond a point of approximately 10,0 m. If, however smooth surroundings and no obstructions can be assured, air penetration of up to 16,0 m can occur.

All the results that were obtained during the section trials and the single heading trials (all results not mentioned in this report) were evaluated, and it was found that the best air penetration distances into the headings occurred when the air velocity in the last through road was in the region of 1,4 m/s. In future this velocity will be referred to as the **critical velocity**. Seam height also had an influence and the best results were apparently obtained when the seam height was in the region of 3,0 m.

2.1.2 Computer Simulations To Verify Underground Results.

As a continuation on the research into the behaviour of last through road airflow, it was decided to verify the results from the field trials by using a computer simulation program. The Engineering Faculty of the Potchefstroom University is in possession of a finite volume computer program which is capable of doing fluid dynamic simulations and this university was approached for assistance.

Like with any new simulation program, the reliability of the results had to be proven and this was done by simulating some of the field trials and by comparing the results.

Keeping costs in mind, it was decided to simulate a heading with a seam height of 3,0 m and a heading depth of 20,0 m (Figure 5). The air velocity flowing in the last through road was simulated at 1,4 m/s (critical velocity). A continuous miner was simulated inside the heading to provide a reasonable amount of airflow interference. The dimensions of the continuous miner were programmed to have a total length of 10,5 m, a height of 1,5 m and a width of 3,0 m.

Three configurations were simulated and the results compared with the actual field trials.

The three simulations were:

a) empty heading.
b) heading with a continuous miner in the left hand corner of the heading against the face.
c) heading with a continuous miner in the right hand corner of the heading against the face.

Simulation Results.

Since the program does three dimensional simulations, the results were obtained from slices through the heading at different heights. The results from the program show velocity contour lines inside the heading and, for clarity, a sketch is shown alongside the computer printout depicting the corresponding airflow patterns. Not all the results will be discussed in this report, only the more important ones that could demonstrate the effectiveness and thoroughness of the program.

a) Empty Heading

The slice in this simulation was made at a height of 1,5 m. This simulation was meant to verify the results from the single heading trials. Figure 6 shows the results from this simulation and it indicates the airflow patterns and velocity contour lines inside the heading.

The results from this simulation show an air penetration distance of approximately 16,0 m at a last through road air velocity of 1,4 m/s. This compares very well with the 16,8 m that was measured during the field trials.

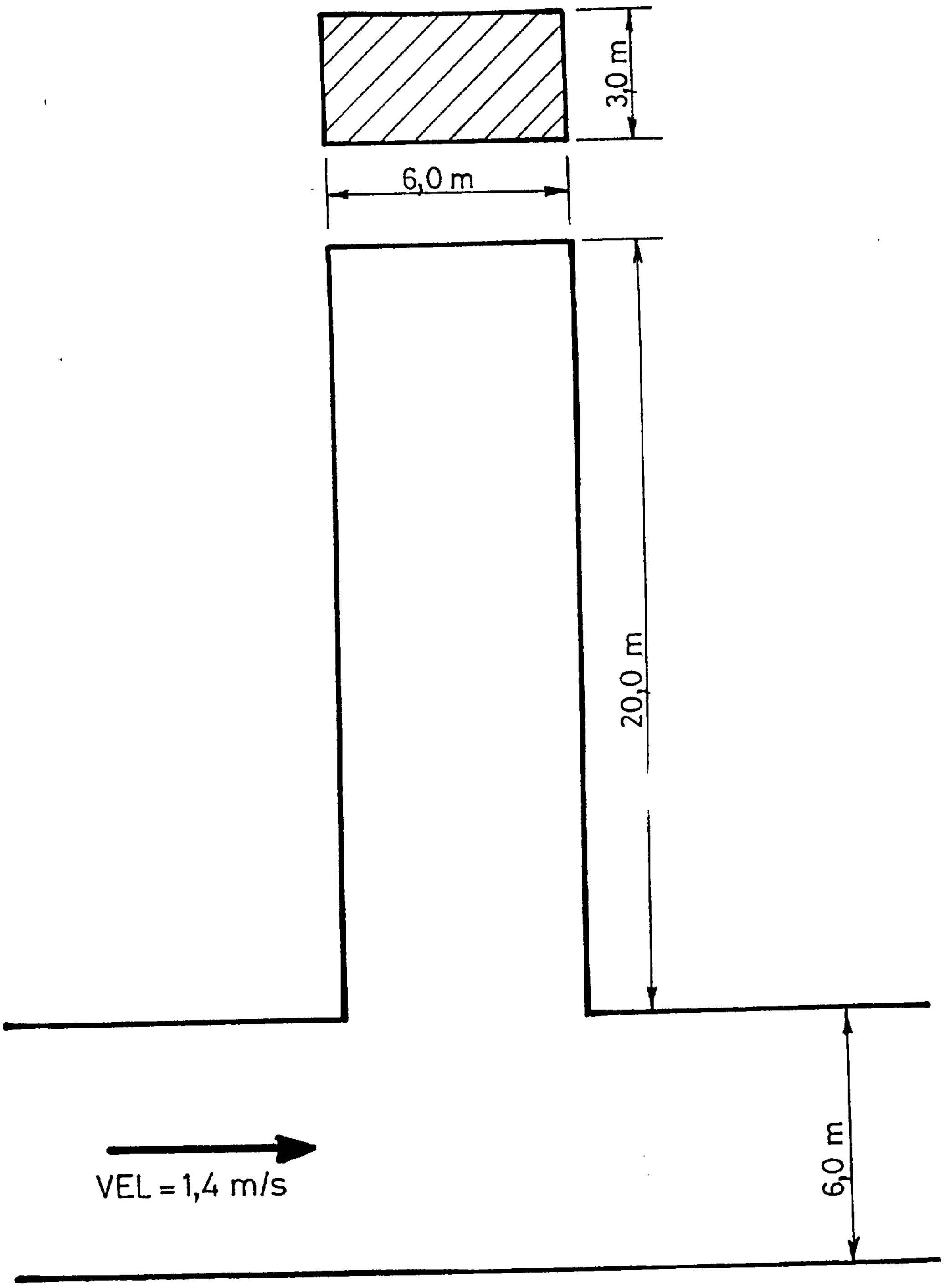

Figure 5: Configuration of simulated single heading.

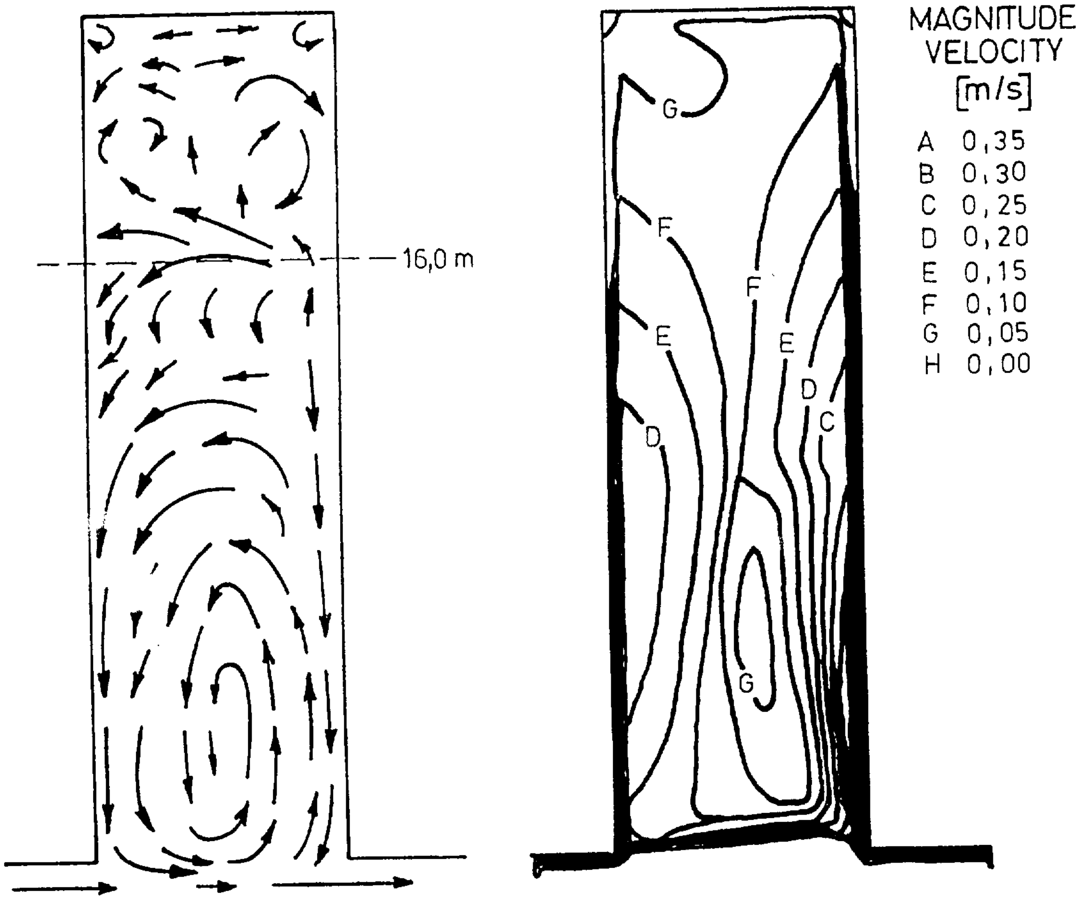

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Figure 6: Airflow patterns and velocity contour lines inside empty heading.

A major advantage of the computer simulation, is the additional detail that is made available regarding the slow air movement beyond the point of maximum intake air penetration. These areas are normally difficult and dangerous to examine when no auxiliary ventilation is present. From the simulation it can be seen that there is slow air movement in this extremity of the heading, but it is obviously insignificant. It is only slow, convective recirculation of air, rather than positive air movement.

b) Continuous Miner In The Left Hand Corner Of The Heading.

Using the results from the empty heading as a basis, the difference between the airflow patterns and the air penetration distances with a continuous miner in the heading was analyzed. Although no continuous miner was present during the section trials, the results should compare favourably. Slices were again made at different heights, but only the results from the slice made at 2,0 m will be discussed.

Figure 7 shows the airflow patterns and velocity contour lines above and around the machine. The simulation shows the air penetration distance to be around 9,0 m, with the air velocity at this point being 0,2 m/s. Above the continuous miner and close to the face, areas of air recirculation are evident with average velocities of 0,05 m/s and 0,15 m/s according to the velocity contour lines.

c) Continuous Miner In The Right Hand Corner Of The Heading.

In this case, the simulation shows the air penetration to be in the region of 10,0 m at velocities of between 0,15 m/s and 0,25 m/s (Figure 8). As was the case with the previous simulation results, the air enters on the right hand side of the heading, which is the opposite (downstream) side of the heading with the air flowing from left to right past the heading.

This then proves the observation made during the field trials that the air will always enter the heading on the downstream side of the heading. This point is very important in the investigations to follow, where air scoops and ductless fans are concerned.

The simulation shows that some form of air movement exists beyond the point of maximum penetration above the continuous miner and close to the face area. The air velocities are shown to be between 0,05 m/s and 0,15 m/s in this region according to the velocity contours.

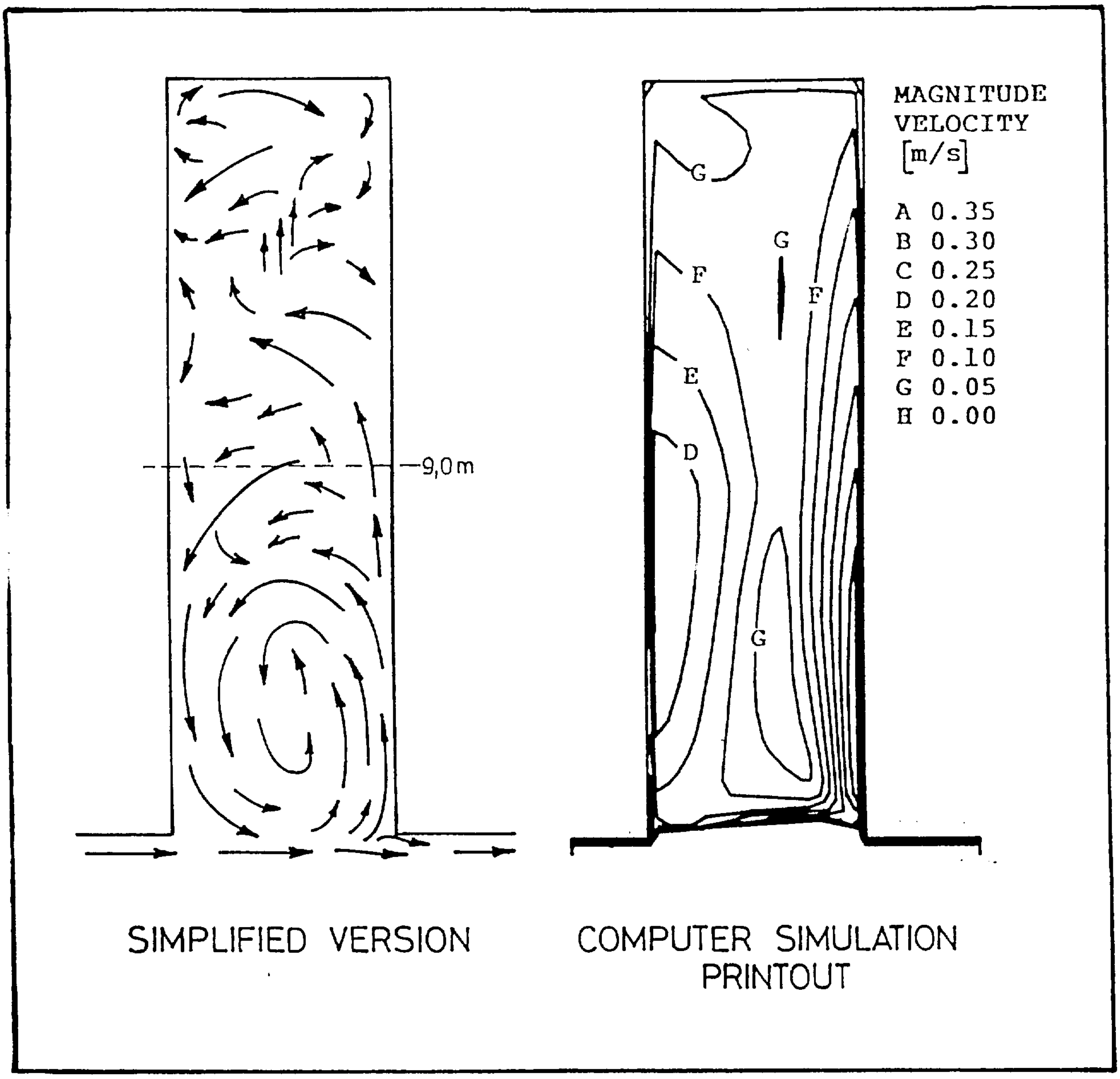

Figure 7: Airflow patterns and velocity contour lines with continuous miner in left hand corner of heading.

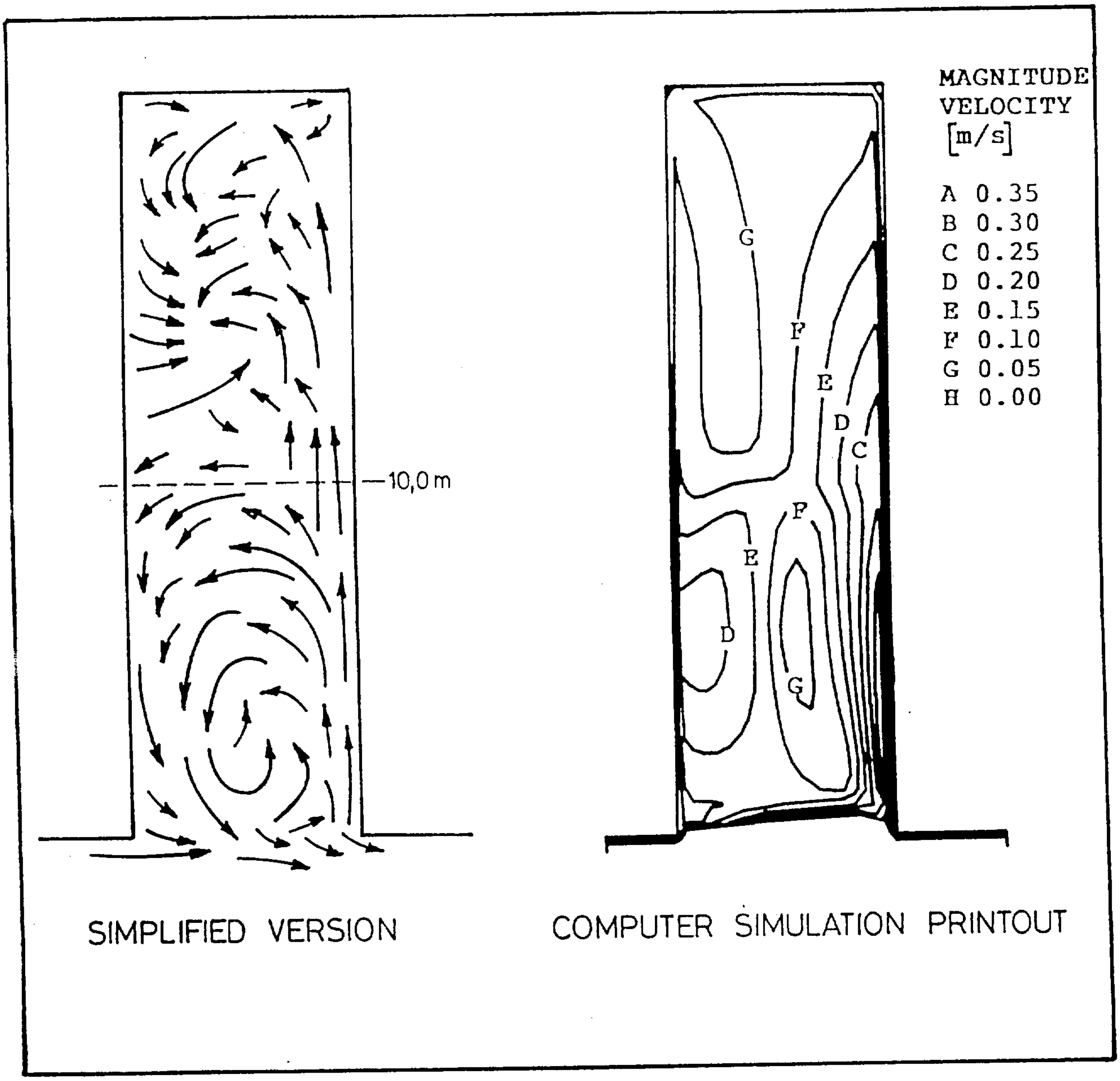

Figure 8: Airflow patterns and velocity contour lines with continuous miner in right hand corner of heading.

Analysing these and all other results not shown in this report, proved them to be reliable and close approximations of the results from the field trials. It was therefore decided to use this program as an additional research tool in solving underground ventilation flow problems.

2.1.3 Simulation Of Ventilation Scoops In Headings.

In an attempt to improve air flow into unventilated headings without the use of auxiliary fans, it was decided to use the computer program to simulate the use of ventilation scoops inside headings. The effectiveness of these scoops, and their influence on air penetration distances and airflow patterns inside a heading, could be determined before any field trials were carried out.

The scoops were simulated in two positions relative to the direction of airflow in the last through road, and the continuous miner was placed in the right hand corner of the heading (Figure 9). This position proved to be the worst scenario during the previous simulations with the air flowing from left to right past the heading.

Using the results from these simulations, the most effective position to place the scoop can be determined with regard to air penetration distances and airflow patterns. In both cases the heading depth was simulated to be 20,0 m from the last through road. The seam height was kept at 3,0 m with an average roadway width of 6,0 m. The last through road air velocity was set at 1,4 m/s.

In the simulations the scoops extended 1,0 m into the last through road and were installed 5,0 m into the heading and 1,0 metre from the side. They were simulated to be 3,0 m high, assuming no leakages for the purpose of the simulation. Again a few slices were made through the heading, but only the results from the slices made at a 2,0 m height will be discussed in this report.

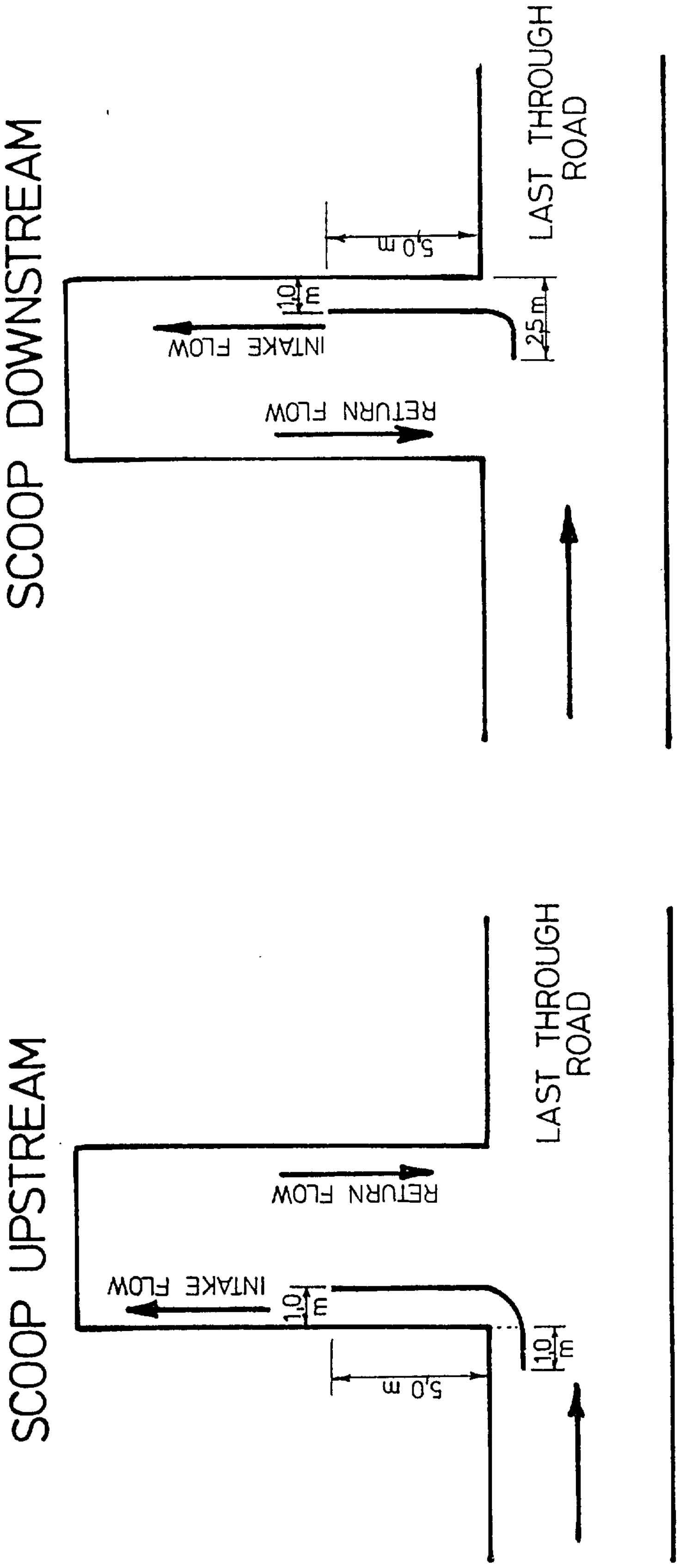

Figure 9: Configuration showing position of scoops simulated.

a) Ventilation Scoop Installed On The Upstream Side Of The Heading.

The positive air movement in the vicinity of the continuous miner is evident (Figure 10). The velocity contours show the air velocities in the heading ranging between 0,05 m/s and 0,10 m/s and a maximum air penetration distance of 17,0 m. This proves that use of an air scoop definitely improves airflow into a heading. It should be remembered at this stage that the normal flow of air has been reversed with the scoop in the upstream position. Although a large amount of air is exiting the heading fairly quickly, an acceptable flow of air still exists in the top section of the heading as a result of the scoop. The amount of air recirculation inside the heading is minimal.

b) Ventilation Scoop Installed On The Downstream Side Of The Heading.

With the scoop in this position, the normal airflow pattern is maintained with the air flowing into the heading on the downstream side (Figure 11). Most of the air is lost at the back of the scoop due to a difference in pressure being created. The remainder of the air is being projected towards the face of the heading at velocities ranging between 0,05 m/s and 0,35 m/s up to a maximum distance of 17,0 m. There is, however, a fair amount of air recirculation in the entrance of the heading.

DISCUSSION OF RESULTS.

The scoops definitely improved the flow of air into a heading, but, even with the improved air penetration distances, both situations have advantages and disadvantages.

Upstream Scoop

Advantages

1) Air penetration distances into heading increased to 17,0 m.
2) Most of the air drawn into the heading utilized to ventilate face area.
3) Not more than 10 per cent air recirculation inside the heading.

Disadvantages

1) Low air velocities at the point of maximum penetration.
2) Normal airflow tendency forced to change, which could mean a great amount of air leakage in the underground situation.

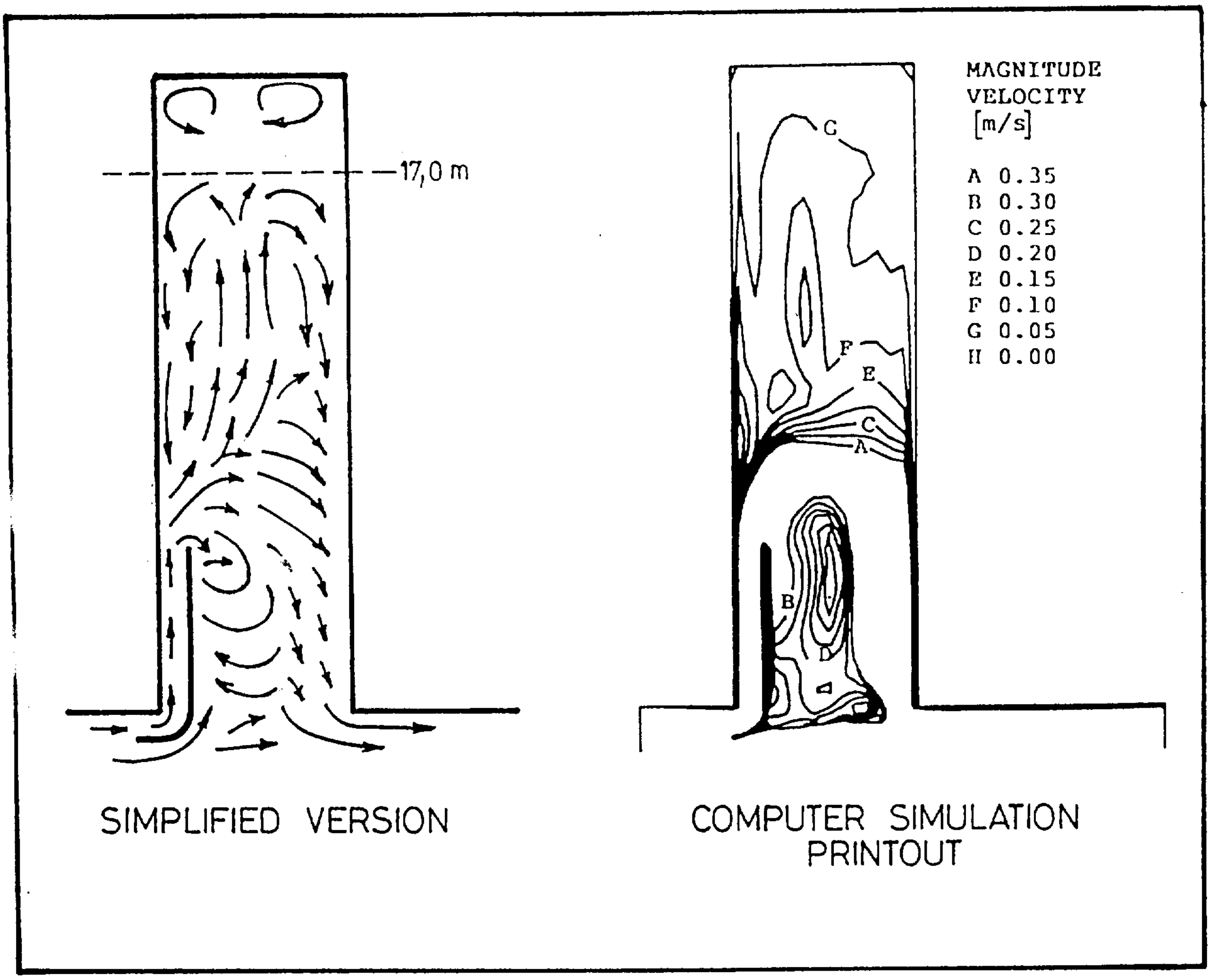

Figure 10: Airflow patterns and velocity contour lines with ventilation scoop installed upstream.

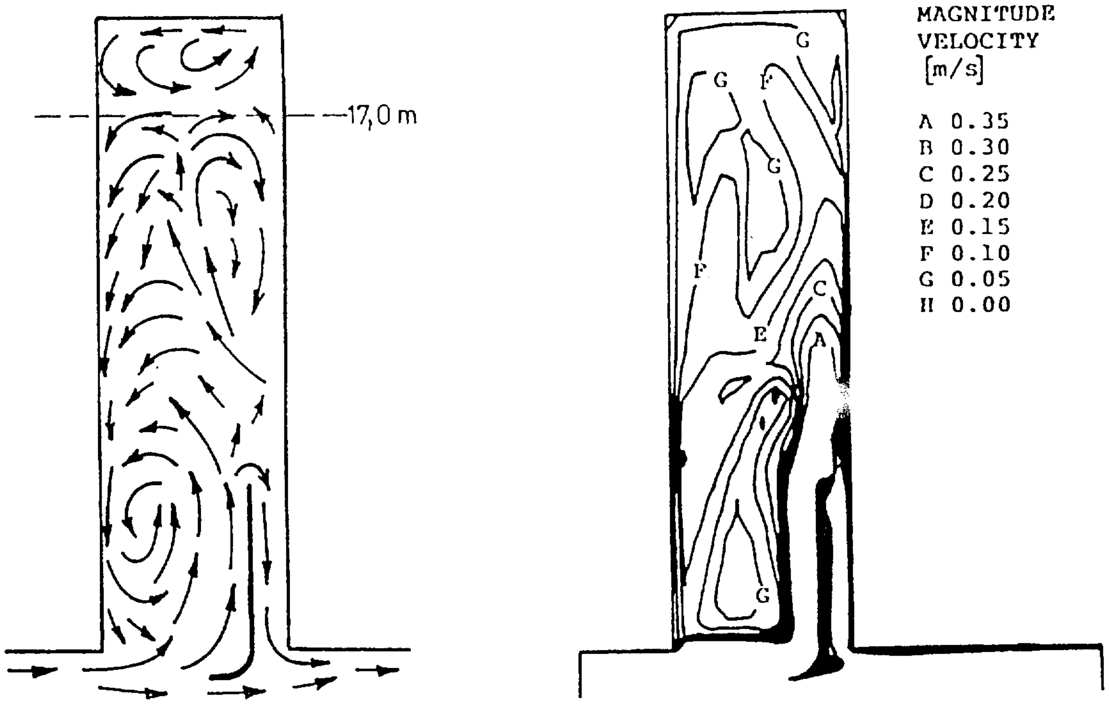

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Figure 11: Airflow patterns and velocity contour lines with ventilation scoop installed downstream.

Downstream Scoop

Advantages.

1) Normal airflow tendency is maintained and a smoother flow of air into the heading is occurring.
2) Air projected towards the face area at fairly high velocities.
3) Air penetration distances into the heading increased to 17,0 m.

Disadvantages.

1) Major loss of airflow at the back of the scoop.
2) Air recirculation of more than 50 per cent inside the heading. This results in only a small amount of fresh air being drawn into the heading.

After analysing the simulation results, it was decided to verify the results in an underground heading. A heading was prepared and, instead of the conventional brattice scoops, polycarbonate sheets were used as the scoops.

Figure 12 shows the two test positions of the scoops as well as the distances from the side and into the last through road. Figure 12 also shows the dimensions of the heading used for the tests. A temporary regulator was again installed to vary the air velocities in the last through road. By doing this it could be established whether the critical velocity also had an influence on the performance of the scoops.

The scoops were installed at different distances into the heading and extended until positive air movement was achieved on the face.

2.1.4 Results From The Heading Trials.

Tables 3 and 4 gives the results from the underground trials using the polycarbonate sheet as air scoops. Air leakage around the scoops proved to be a problem and hence influenced the results obtained, compared to the results from the simulations.

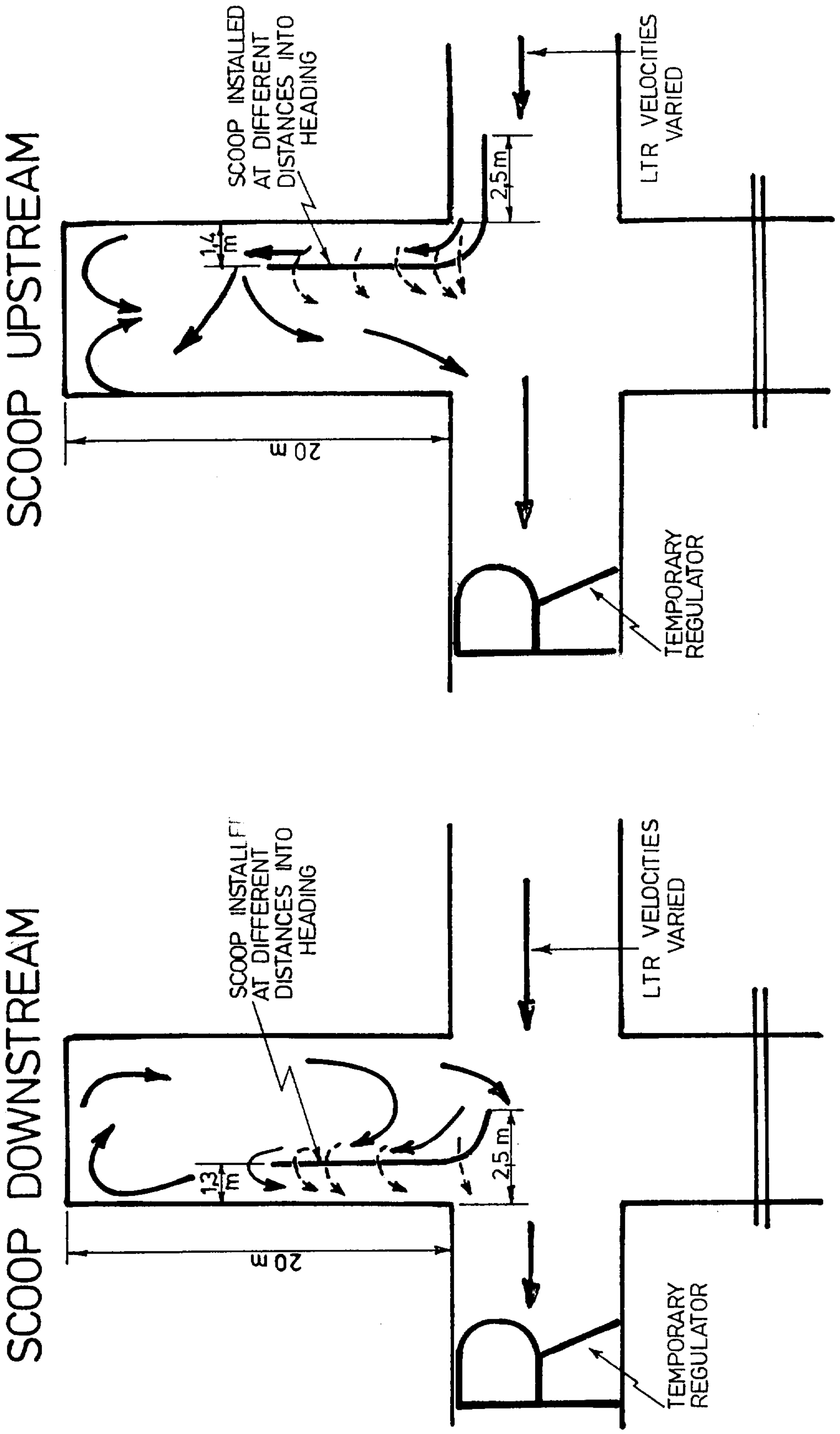

Figure 12: Test positions of scoops in underground heading.

TABLE 3: Results from scoop installed downstream.

Ave LTR Vel (m/s)	Air Penetration Distances (m)		
	Scoop At 7,2 m	Scoop At 10,2 m	Scoop At 13,2 m
3,2	10,0	12,2	13,3
2,7	11,1	13,0	14,5
2,0	13,2	13,7	16,0
1,4	15,4	18,0	20,0
1,0	13,2	14,0	18,3

LTR = Last Through Road

As with the simulations, a large quantity of air tends to be lost at the back of the scoop, resulting in less air being delivered to the face area. Because of this and the amount of air leakage that occurred, the scoop had to be extended 3 times to 13,2 m, before any air movement was noticed on the face. Unlike the simulations, no distinct air velocities were measured at the point of maximum penetration, but positive air movement at different positions was rather identified. It was also found that, with the scoop in this position and with the normal airflow pattern maintained, a significant amount of air recirculation was taking place inside heading. This results in only a small amount of air replacement taking place in the heading.

TABLE 4: Results from scoop installed upstream.

Average LTR Air Velocity (m/s)	Air Penetration Distances (m)	
	Scoop At 5,5 m	Scoop At 8,5 m
3,2	10,0	15,0
2,7	12,0	17,2
2,0	12,2	17,5
1,4	14,2	20,0
1,0	12,5	18,4

LTR = Last Through Road

During these tests, the scoop had to be extended only once to 8,5 m to enable positive air movement on the face, being 20,0 m from the last through road. Air leakage around the scoop still occurred and most of the air still flowed out of the heading without reaching the face. With the scoop in this position, very little air recirculation occurred inside the heading, which resulted in more fresh air being introduced into the heading and improved conditions on the face. From these test results as well as from the computer simulations, it is evident that the best position for a ventilation scoop will be on the upstream side of the heading.

Interim Conclusions.

From the information obtained during these underground trials and computer simulations, the following important facts surfaced:

1) Air flowing in the last through road does have a distinct airflow pattern.
2) Factors such as last through road air velocity and seam height do influence the penetration of air into an unventilated heading.
3) Headings developed for more than 10,0 m from the point of last through ventilation should be ventilated by means of auxiliary ventilation.
4) The use of computational fluid dynamic packages can successfully be used as a research tool.

These aspects are very important when planning heading ventilation systems and they proved to be very relevant to further investigations that were conducted. These will be dealt with later in this report.

2.2 Friction Factors For Underground Ventilation Ducting (Meyer 1990)(2)

Another important aspect of heading ventilation is the use of ventilation ducting connected to auxiliary fans to ventilate bord and pillar headings. Although most of the mines have done away with ventilation ducting, it is still of importance to know the friction factors for the different types of ventilation ducting that is available and in use throughout the industry.

These figures are important to the environmental control officer for his long-, medium- and short term planning, as they are used to determine pressure losses in the design of ventilation systems and air requirements. The friction factors that are listed in this report are not the actual design figures for the ducts, but are practical figures that could be more useful to the environmental control officer. These tests also show the importance of the correct installation of ducts and specifically of flexible ducting.

2.2.1 **Test Results**

A total of eleven ducts were tested, including steel ducting, fibreglass ducting and flexible ducting. These ducts represent the majority of the types of ducting in use in the mining industry. No details will be discussed in this report regarding the test procedures and test facilities. Attention will only be given to the actual results and the importance of correct installations and applications.

The figures tabulated are at a standard density of 1,2 kg/m^3.

TABLE 5: Friction losses for steel ventilation ducting.

Description Of Ducting Tested	Friction Factors Ns^2/m^4
570 mm ϕ, 6 swage standard galvanised ventilation ducting	0,00294
570 mm ϕ, 8 swage standard galvanised ventilation ducting	0,00334
570 mm ϕ, mild steel "hot dip" smooth bore ventilation ducting	0,00222
570 mm ϕ, "corten" smooth bore ventilation ducting	0,00200

TABLE 6: Friction losses for fibreglass and flexible force ventilation ducting.

Description Of Ducting Tested	Friction Factors Ns^2/m^4
600 mm ϕ, fibreglass force/ exhaust ventilation ducting	0,00237
570 mm ϕ, flexible force ventilation ducting with longitudinal suspension	0,00976

The following results are tabulated separately, since three different tests were carried out on this particular type of duct - a flexible force ventilation duct with full circumference suspension at 1 m intervals. The purpose of these tests was to determine the effect of poor underground installations on the friction factors. These ducts are usually joined together by means of the toggle-rope system, where one end of the duct is reinforced with a steel wire. The other non-reinforced end is slipped over the reinforced end and tightened by means of a rope. The result is normally a severe restriction of the duct as the rope is fastened too tightly and the area is reduced.

TABLE 7: Friction losses for flexible force ventilation ducting with full circumference suspension at 1,0 m intervals.

Description Of Ducting Tested	Friction Factors Ns^2/m^4
570 mm ϕ, flexible force ventilation ducting with full circumference suspension at 1,0 m intervals	0,01166
Two lengths, correctly joined ether by means of the le-rope system	0,0120
Two lengths, incorrectly jo together by means of the toggle-rope system. Area of duct reduced to 400 mm ϕ	0,04234

In the next set of tests, friction losses were determined for 570 mm Ø reinforced exhaust ventilation ducting. These ducts consisted of four different types of reinforcing with the reinforcing being provided at different pitch lengths. Tests were carried out on all four pitch types and the different k-values determined. These tests were carried out while using a force ventilation system.

In the practical underground situation, it is sometimes found that these ducts are not stretched out to their maximum length as should be the case if they were to be installed correctly. When they are not fully stretched out, excessive resistance is caused because of the reduction in the area, and the friction factor is therefore affected.

This situation was simulated by reducing the lengths of the ducts by 10 %, 20 % and 30 % to determine the effect of the reduction in length on the friction factors. From the results it is clear that flexible ventilation ducts should be installed correctly at all times, in order to obtain the best possible results.

TABLE 8: Friction losses for reinforced flexible exhaust ventilation ducting.

Description Of Ducting Tested	Friction Factors Ns^2/m^4
Ducting with 50 mm pitch	
(full length)	0,01184
(90 % length)	0,02312
(80 % length)	0,03340
(70 % length)	0,04807
Ducting with 75 mm pitch	
(full length)	0,01208
(90 % length)	0,03185
(80 % length)	0,04395
(70 % length)	0,07317
Ducting with 100 mm pitch	
(full length)	0,01241
(90 % length)	0,03657
(8 length)	0,04562
(70 length)	0,07375
Ducting with 150 mm pitch	
(full length)	0,01321
(90 % length)	0,04775
(80 % length)	0,06617
(70 % length)	0,09809

The results show that there is indeed a big difference in the friction factors of the individual ventilation ducts available. It is also clear that it is of great importance that the ducts should be installed in the correct manner in order to minimize the restriction and hence the friction.

To demonstrate the increase in friction factors due to bad installation, the figures obtained from the tests on the flexible ducting with the different pitches are tabulated below in Tables 9 and 10 together with the % increase in friction losses.

TABLE 9: Percentage increase in friction losses for different duct lengths and pitches.

Pitch	Length Of Duct	% Increase In Friction Loss
50 mm	full length - 90 %	97,3
	90 % - 80 %	44,5
	80 % - 70 %	43,9
75 mm	full length - 90 %	165,6
	90 % - 80 %	38,0
	80 % - 70 %	66,5
100 mm	full length - 90 %	194,6
	90 % - 80 %	24,7
	80 % - 70 %	61,7
150 mm	full length - 90 %	236,9
	90 % - 80 %	38,6
	80 % - 70 %	48,2

TABLE 10: Difference in friction losses for various pitches.

Pithes	% Increase In Friction Losses
50 mm - 75 mm	2,5
50 mm - 100 mm	6,5
50 mm - 150 mm	12,5
75 mm - 100 mm	3,9
75 mm - 150 mm	9,7
100 mm - 150 mm	5,6

2.3 The Use Of Ductless Fans To Ventilate Bord and Pillar Headings.

This report has so far shown some of the more important factors influencing the ventilation of a bord and pillar heading. As mentioned earlier, the use of ventilation ducting is disappearing as a means of ventilating headings, as technology is advancing.

The current trend in the industry is to change to ductless fans, and more specifically to electric driven jet fans, although the use of hydraulic driven vortex fans still seems to be popular in some collieries.

The use of freestanding fans is becoming more popular because of their flexibility. These fans can be placed at any position in the last through road blowing air into the heading (Figure 13). The energy from the air leaving the fan, causes air entrainment which results in more air entering the heading, ventilating the heading more effectively. These fans can also be used with the aid of line brattices to direct the air to specific places where air might be required (Figure 14).

These fans proved to be more cost effective than the conventional fan-duct system and easier to handle due to their size (Figure 15a + 15b). As mentioned earlier, there are mainly two types of freestanding or ductless fans in use: jet fans and vortex fans. Over the past year, a series of tests were conducted on the effectiveness of these fans and some of the results will be discussed in this report.

2.3.1 **Vortex Fans.**

These fans are hydraulically driven and are powered by a powerpack from which the hydraulic oil is fed through high pressure hoses to the fans. As many as five to seven fans can be driven simultaneously from the powerpack. This means that, if necessary, five to seven headings can be ventilated simultaneously using one powerpack. Unfortunately, some problems have been experienced with the system and it has become more expensive to run and maintain than was initially expected.

Some of the tests carried out on the vortex fans involved placing of fans at different positions in the last through road to determine the airflow patterns inside an empty heading, as well as the air penetration distances of these fans. At the same time, the velocity in the last through road was varied to determine whether there would be any influence on the fan performance figures.

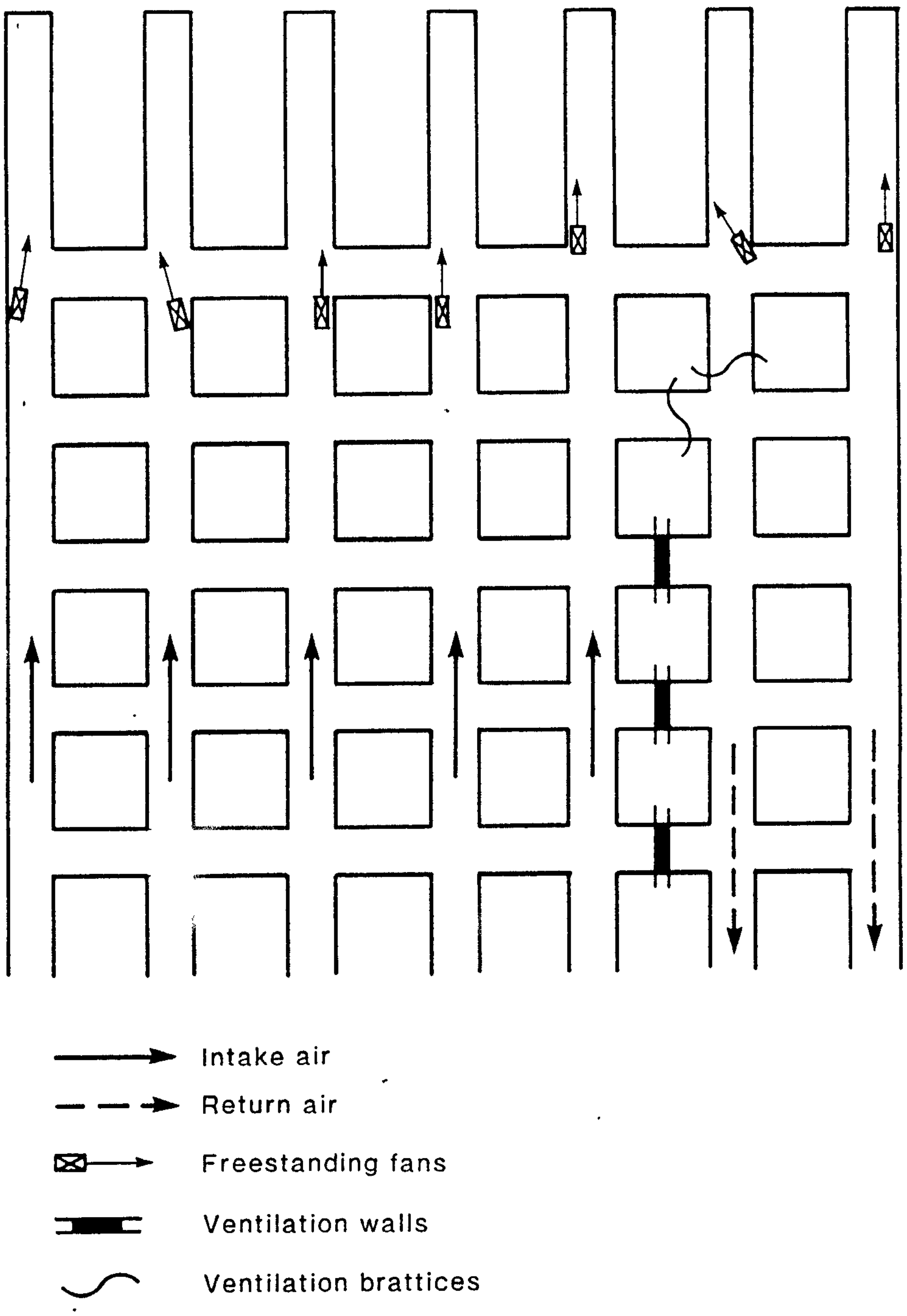

Figure 13 Different operating positions for freestanding fans.

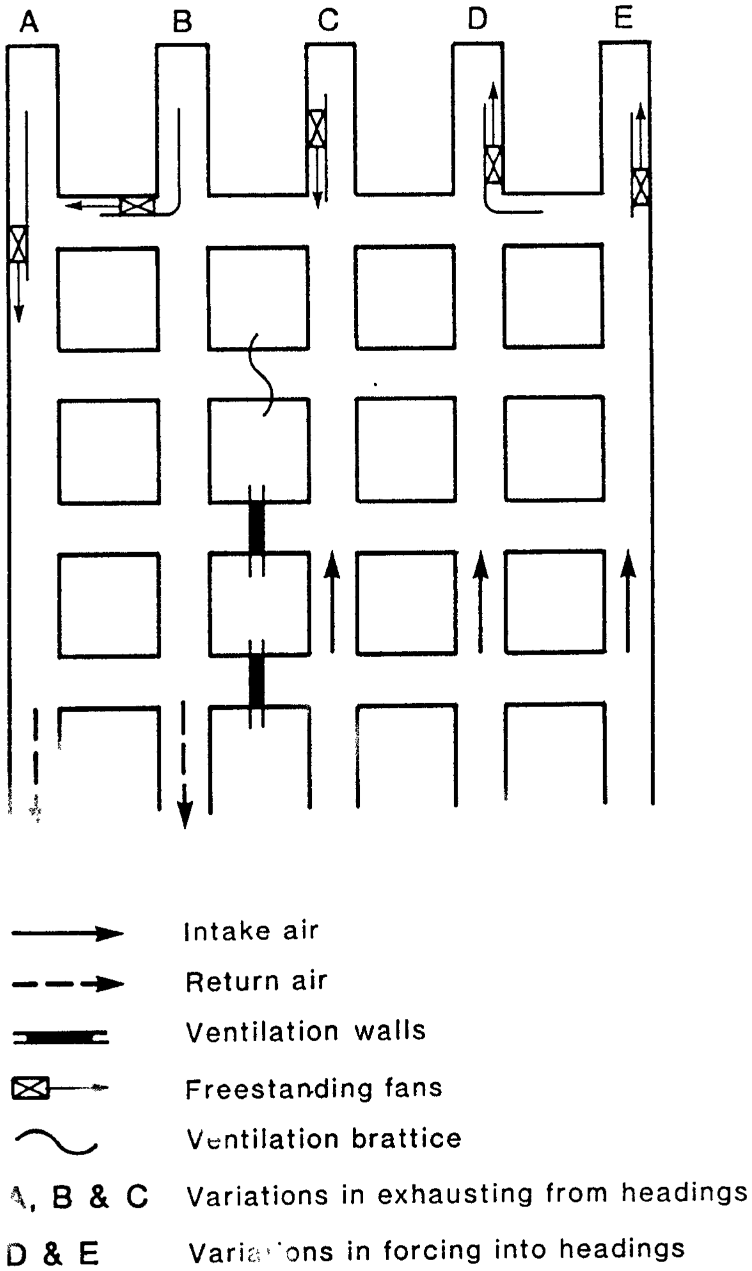

Figure 14 Use of freestanding fans with line brattices.

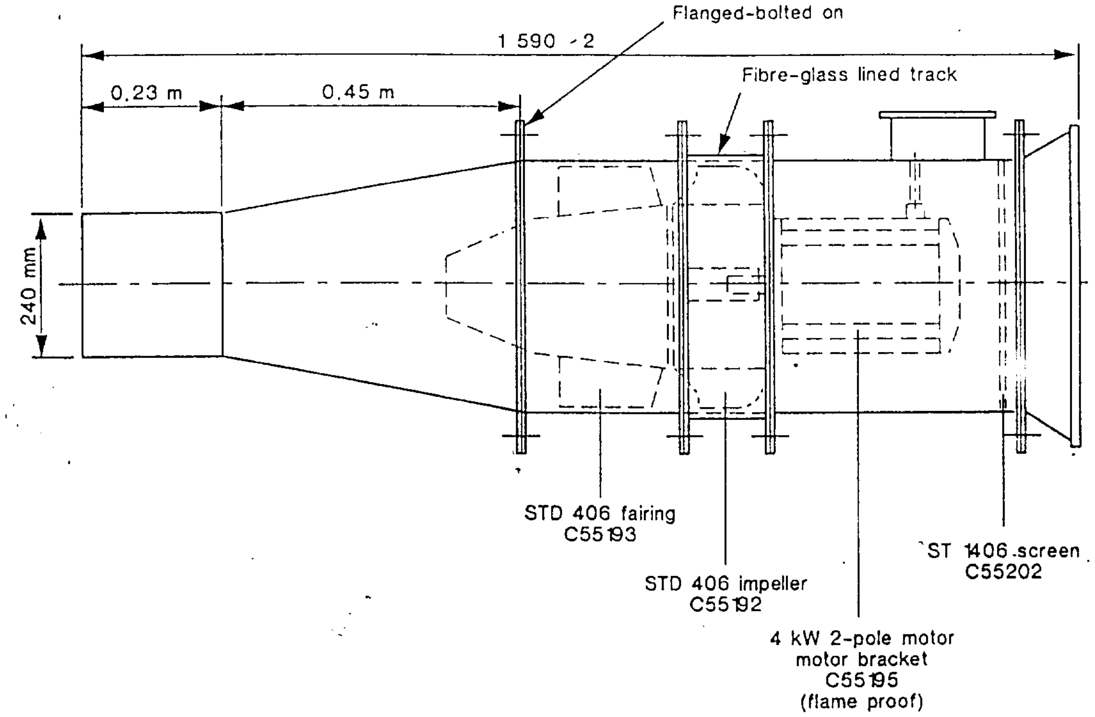

Figure 15a Detailed sketch of jet flow fan.

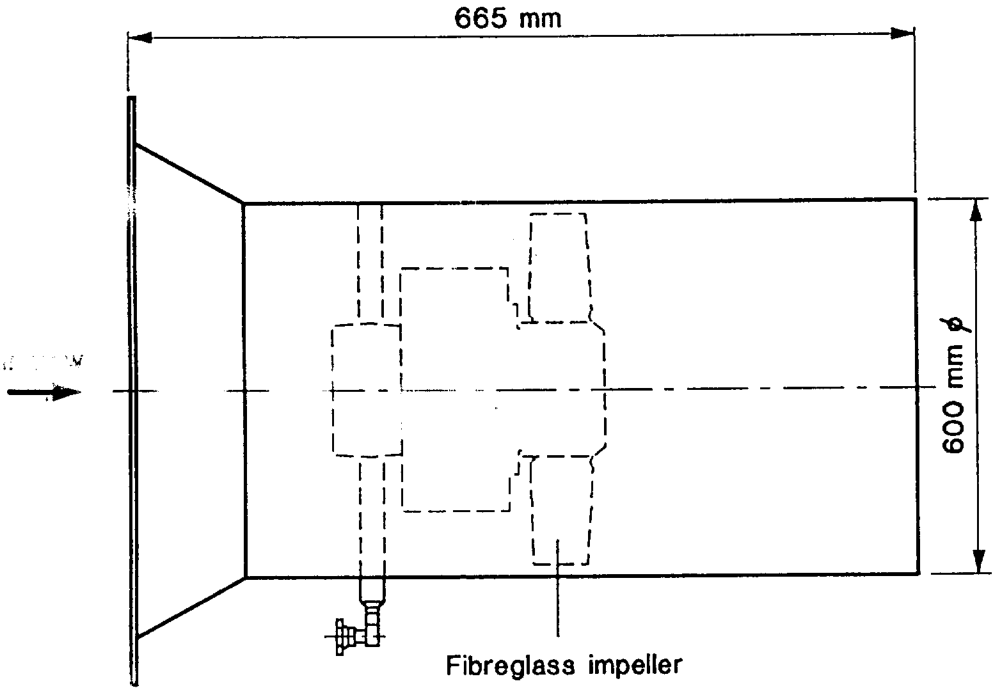

Figure 15b Detailed sketch of vortex fan.

Figure 16 shows the layout of the the area in which the heading, prepared for the tests, was situated. It also shows the position of the regulator that was used to alter the last through road air velocities and it shows the relevant airway dimensions. Together with this, the four positions in which the fan was tested are also shown, but not all the test results will be discussed in this report.

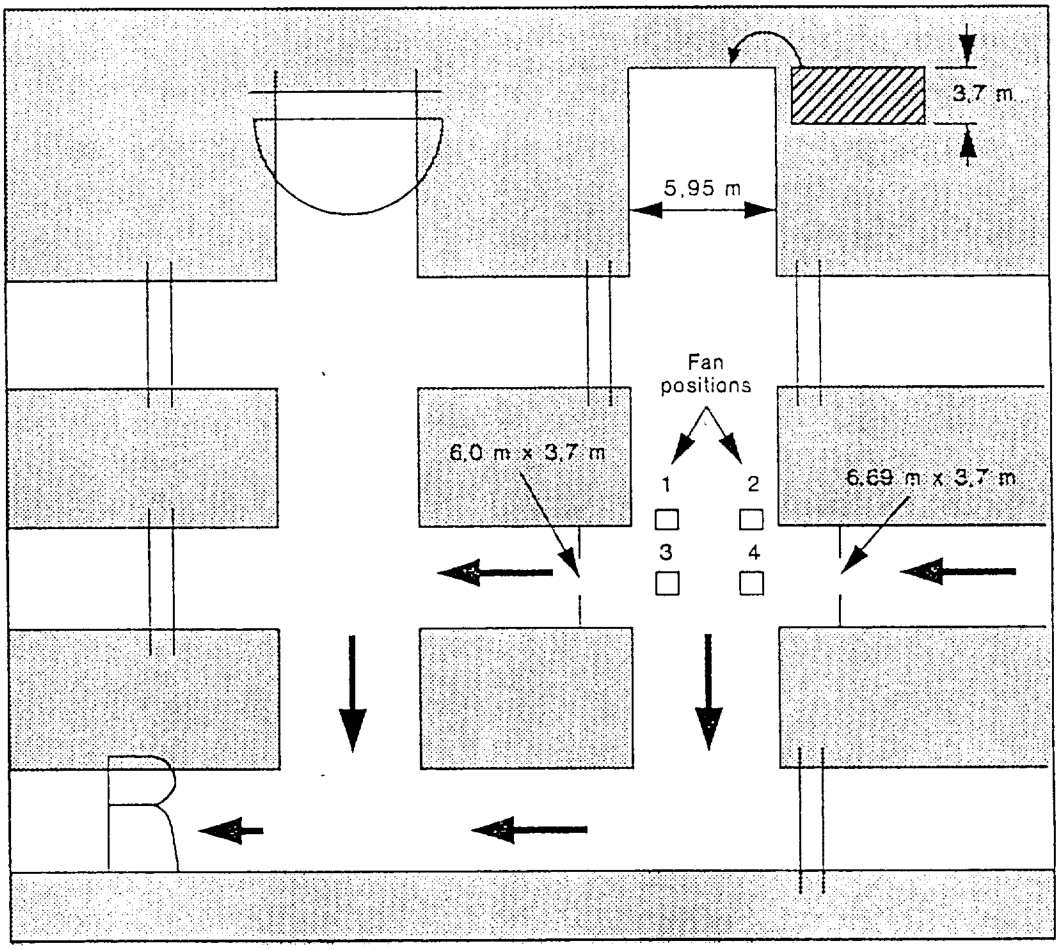

Figure 16: Detailed layout of area in which test heading was situated.

Test Results.

In the first case, the fan was placed on the downstream side of the heading with the tail end of the fan in the last through road. The last through road velocity was set at 2,0 m/s and the heading was developed to a maximum distance of 30 m (Figure 17a). This distance remained constant throughout the tests. The results show that maximum air penetration occurred up to 25 m into the heading with an estimated air velocity of 0,4 m/s at this point. The important aspect to note, is the amount of air recirculation that occurs inside the heading with the fan at this position, being approximately 40 %.

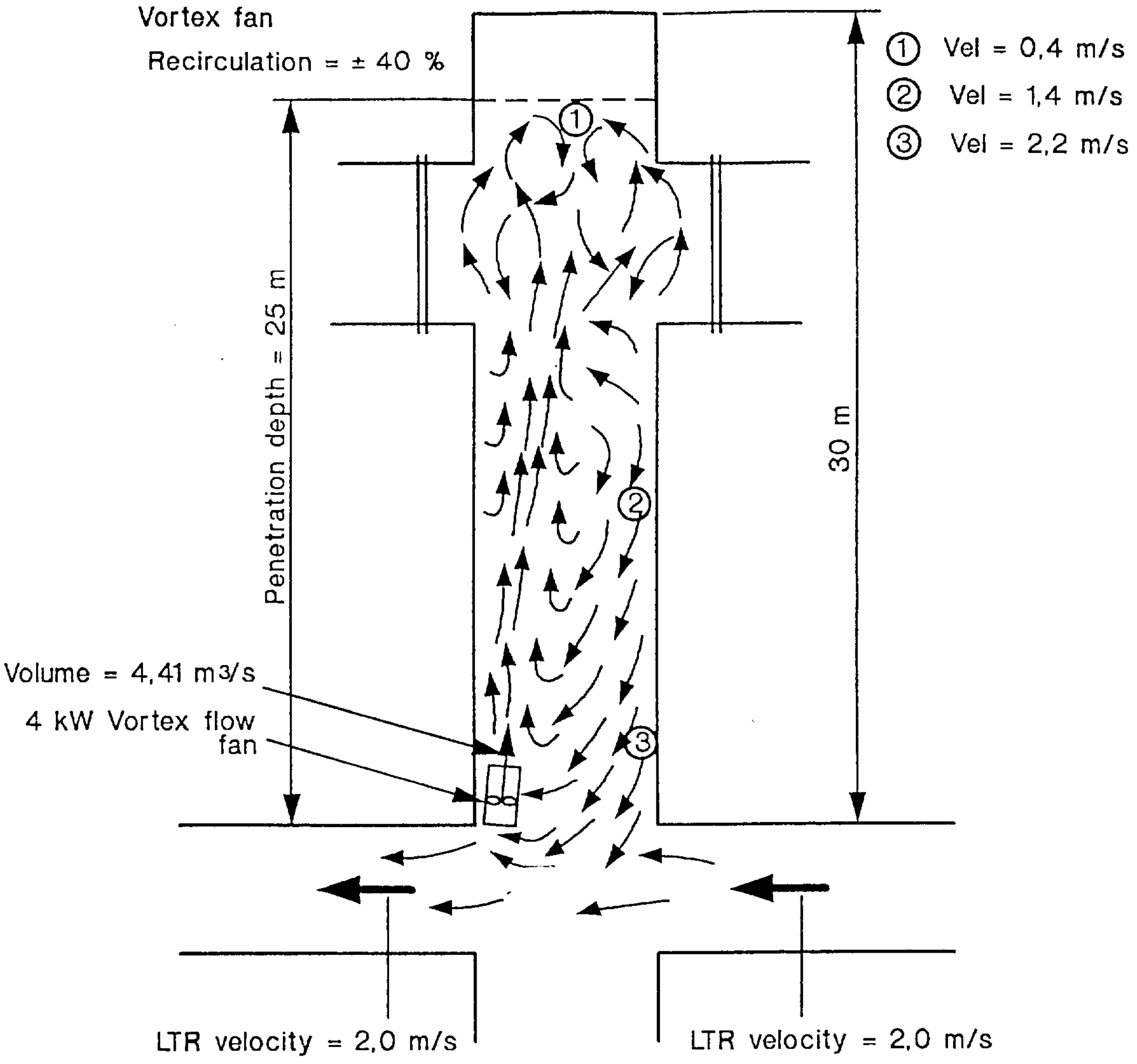

Figure 17(a): First test position of vortex fan with last through road air velocity at 2,0 m/s.

When the air velocity is reduced to 1,2 m/s (approximately critical velocity) in the last through road, air recirculation is reduced to 30 % (Figure 17b). The air penetration distance remained constant at 25 m and the air velocity at this point seemed to have decreased to 0,2 m/s. It must be remembered that airflow at this point is turbulent and not linear and the velocities measured at this point are only an indication of the airflow activity in this region. It definitely shows that air scrubbing across the face will be effective with this type of turbulent flow present.

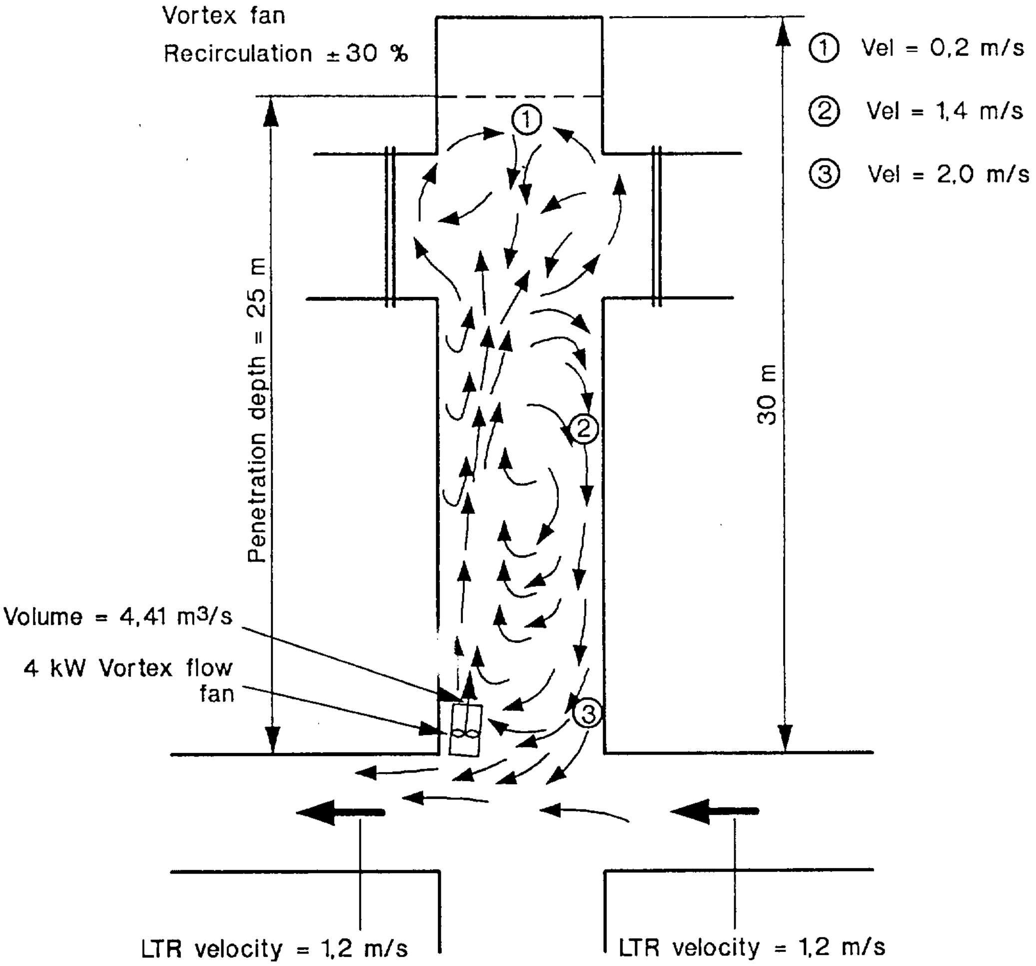

Figure 17(b): First test position of vortex fan with last through road air velocity at 1,2 m/s.

With the fan kept in the same position, the air velocity in the last through road was changed to 0,56 m/s and that resulted in the amount of air recirculation inside the heading increasing to 70 % (Figure 17c). The air penetration distance remained constant at 25 m and the estimated air velocity at this point was 0,3 m/s. The reason for the large amount of air recirculation could be that the amount of air flowing past the heading in the last through road was not sufficient to cause the air inside the heading to flow into the last through road. The effect of the air entrainment, caused by the fan, tends to keep the air inside the heading.

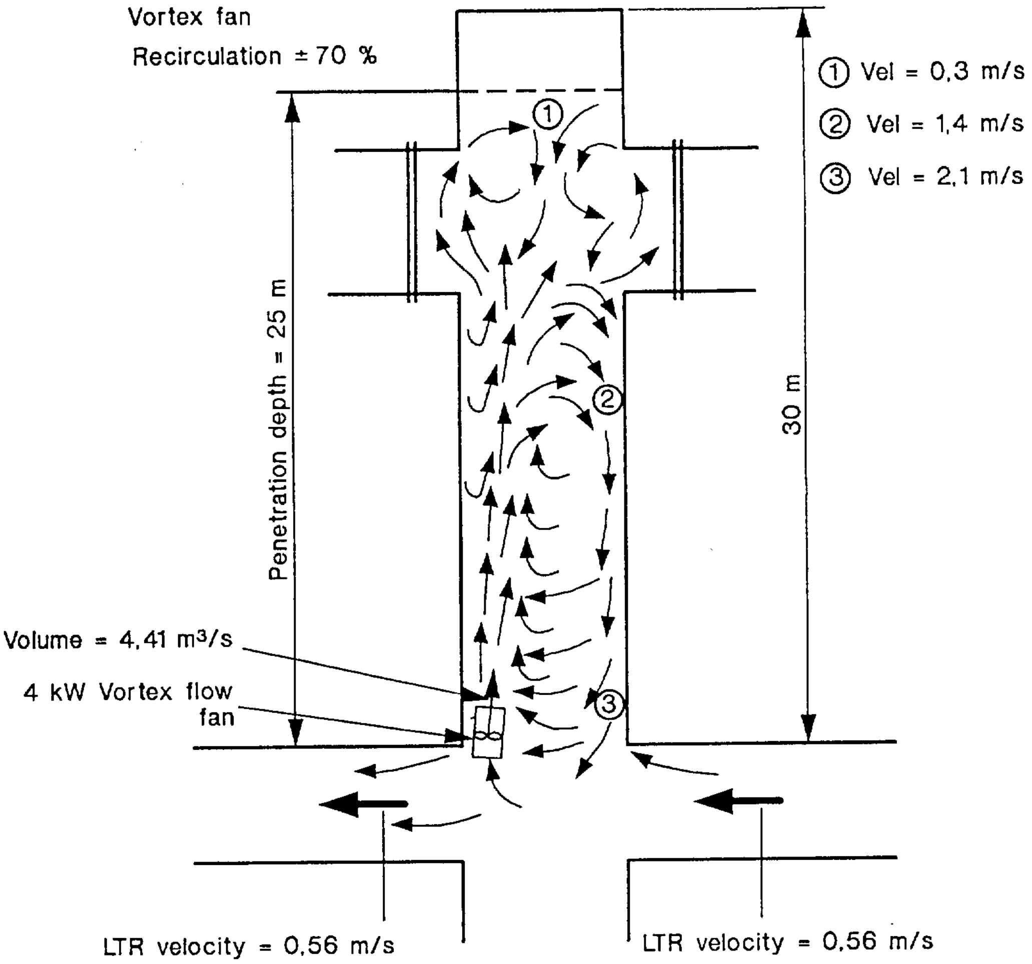

Figure 17(c): First test position of vortex fan with last through road air velocity at 0,56 m/s.

From the results, it is evident that, by using the fan in this downstream position, a large amount of air recirculation was caused inside the heading. This air recirculation is evidently influenced by the quantity of air flowing in the last through road, and, at this stage, it appears that the air velocity in the last through road should be kept above 1,0 m/s.

In the previous section, the best position to use an air scoop, was shown to be on the upstream side of the heading. In this postion the best results with the least amount of air recirculation were achieved. To assess whether the same principle would apply for ductless fans, a fan was placed on the upstream side of the heading, again with the tail end of the fan in the last through road. Again, the tests were conducted using three different last through road air velocities.

Figure 18a shows a very different and interesting airflow pattern inside the heading with the last through road air velocity being set at 2,0 m/s. Air recirculation inside the heading is down to approximately 5 %, but the air penetration distance has stayed at 25 m maximum. An estimate of the amount of turbulent flow, was 0,8 m/s compared to the 0,4 m/s with the fan in the previous position. An interesting factor to note is the velocity of the air flowing into the last through road (point number 3 on sketch) being 2,5 m/s. This adds up to a volume flow of approximately 55 m^3/s delivered by the fan, giving an indication of the effect of the air entrainment caused by the fan on the prevailing airflow.

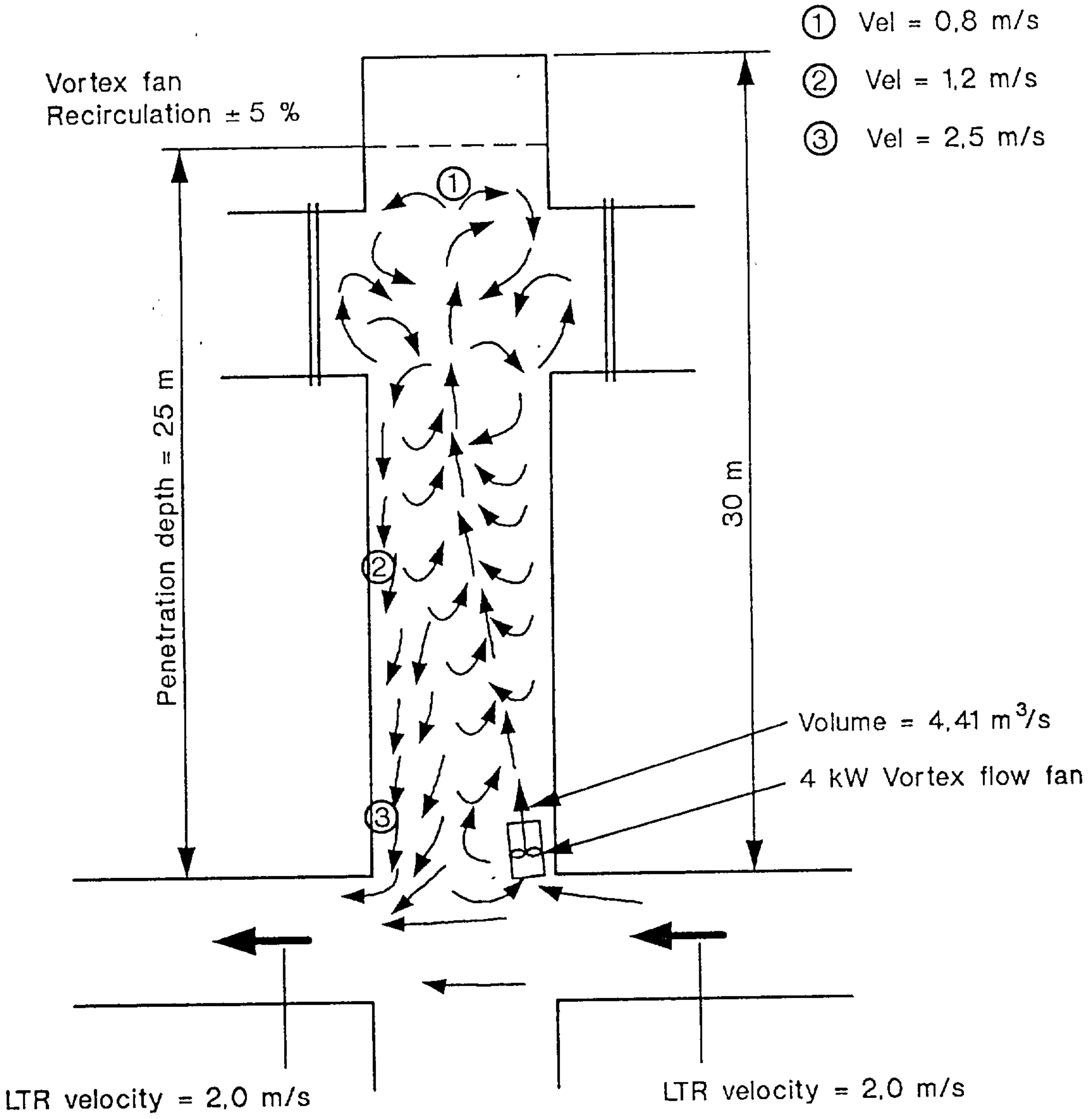

Figure 18(a): Second test position of vortex fan with last through road air velocity at 2,0 m/s.

With the last through road air velocity decreased to 1,2 m/s, there appeared to be a slight increase in the air recirculation to 10 %. Still, a very healthy airflow pattern existed inside the heading and, at 25 m air penetration distance, the air velocity was measured at approximately 0,6 m/s (Figure 18b).

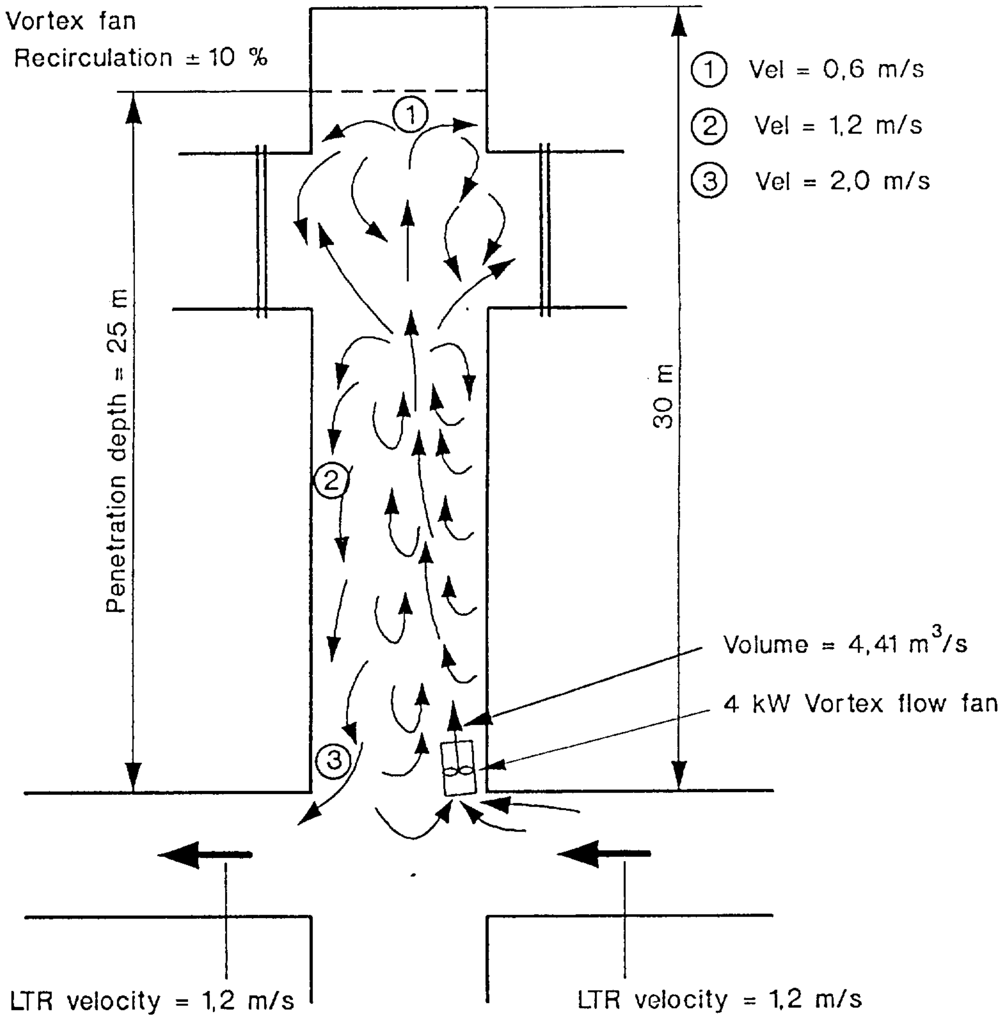

Figure 18(b): Second test position of vortex fan with last through road air velocity at 1,2 m/s.

When the air velocity in the last through road was lowered to 0,56 m/s, the influence on recirculation was drastic, increasing to 30 % (Figure 18c). Air velocities inside the heading remained fairly constant and the air penetration distance remained at 25 m. This confirmed that the velocity in the last through road could influence ventilation conditions inside a heading.

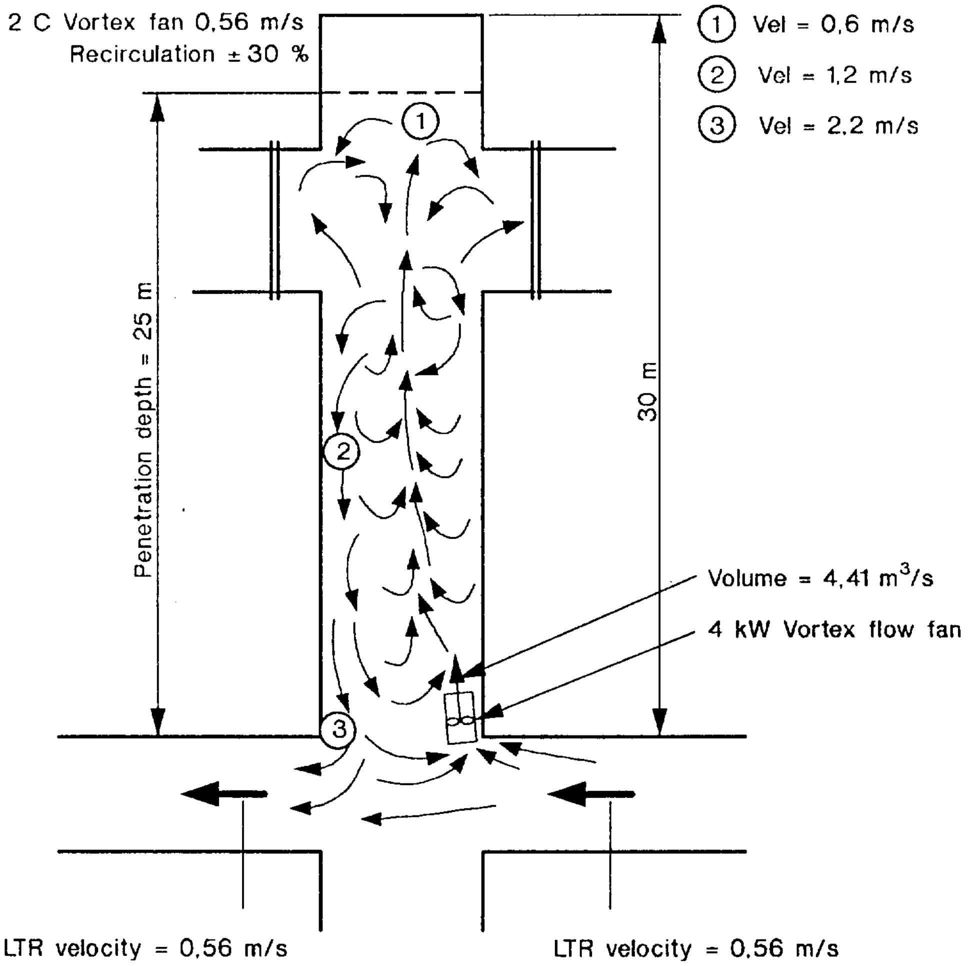

Figure 18(c): Second test position of vortex fan with last through road air velocity at 0,56 m/s.

Throughout the tests, the velocities inside the heading remained reasonably constant for the two positions, and the scrubbing effect of the turbulent airflow from the fan appeared to be quite sufficient in preventing accumulations of any gases that might be present. Maximum penetration distance for these fans is 25 m when placed inside the heading, but is likely to change should the fan be placed further back. When comparing the two positions tested, the best position for this fan proves to be on the upstream side of the heading. Airflow patterns seemed to be better from a recirculation point of view and, judging by the air velocities measured inside the heading, the rate of air replacement would be better, reducing the possibility of gas accumulation. It can also be said that velocities in the last through road, should be kept between 1,0 m/s and 2,0 m/s but preferably in the region of 1,4 m/s if possible.

Other fan positions were also tested with the different air velocities, but the results obtained were similar to those discussed above. More comprehensive tests were carried out in the past on the performance of these vortex fans in conjunction with continuous miners, but these results have been published in previous reports and will not be dealt with again in this report (Meets 1989,(3)).

2.3.2 Jet Fans.

As mentioned earlier, the hydraulic system of the vortex fans turned out to be very problematic and more expensive than initially anticipated. For this reason, research was aimed at identifying an alternative fan or system to use and the electric driven jet fan was born.

This fan is nothing more than a small axial flow fan, fitted with a cone on the outlet of the fan. This cone causes the "jet" effect of the air and performance figures up to this point have proved to be very convincing; the coal mining industry is therefore increasingly using these fans (Figure 15b).

Since the introduction of these fans, a few tests were conducted on the performance of these fans and the results will be dealt with in this report. Unfortunately, the tests that were carried out were not exactly the same as the trials on the vortex fans, which means that no linear comparisons can be made between them. There will be, however, some ground on which comparisons can be made to assess whether or not the performance of the jet fan exceeds that of the vortex fan.

Test Results.

The first series of tests that will be described in this report was conducted in a heading where a Voest Alpine continuous miner was in operation. The jet fan used in these tests had a 4 kW motor and delivered a volume of 2,2 m^3/s into the heading with a total entrainment volume of 4,5 m^3/s. The Voest Alpine was fitted with a wet scrubber dust suppression system, capable of handling a volume of 5,8 m^3/s. In addition to the scrubber system, a network of watersprays was fitted to the rotating cutting head. Normal ventilation and production conditions were maintained in the section while the fan performance was tested. At the time of the tests, the continuous miner was used to develop a heading to a depth of 30 m. The average seam height in this section was 3,0 m, with an average roadway width of 6,5 m. The air velocity in the last through road was set at 1,2 m/s and the air flowed from left to right past the heading.

The fan was placed at different positions in and around the heading, and the airflow patterns for each position were determined.

Figure 19 shows the first position in which the fan was tested. The fan was placed on the upstream side of the heading, facing the left hand corner of the face of the heading. The continuous miner was being used to develop the heading. During this first test, the machine was switched off, as well as the scrubber and the watersprays. Results show that air recirculation inside the heading was a mere 30 % because of the position of the machine and the air entrainment caused by the fan. Apart from the recirculation, good airflow patterns existed around and above the roadheader and across the face of the heading with air velocities of 0,1 m/s measured at the face.

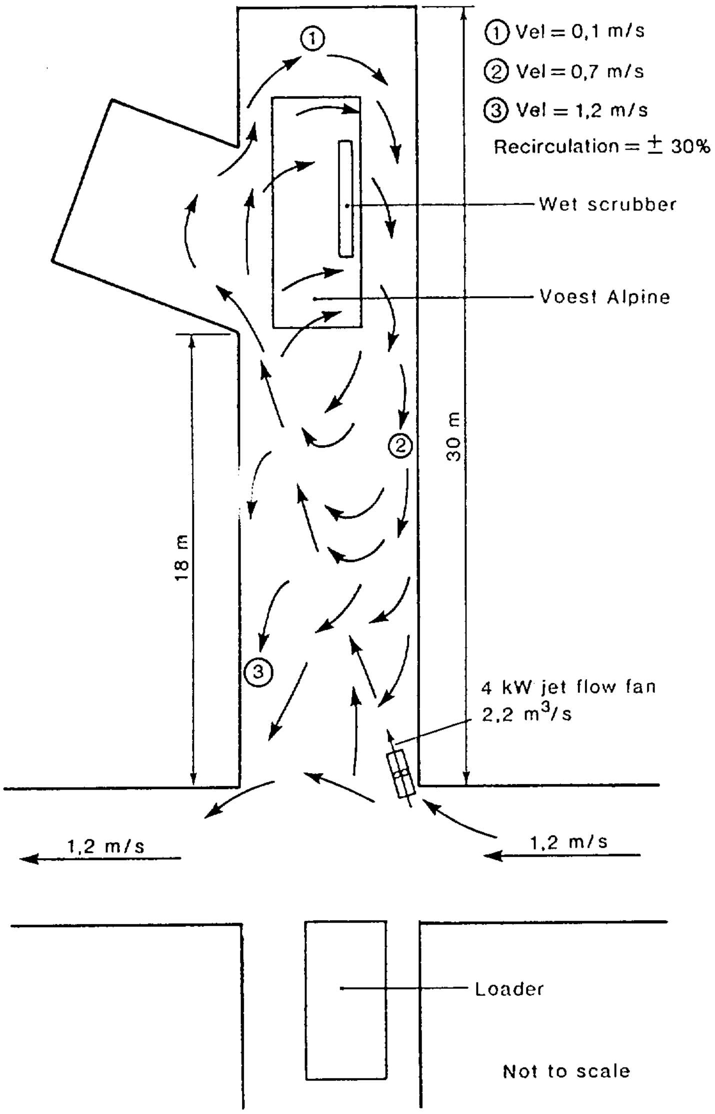

Figure 19: First test position of fan on upstream side of heading-machine not operating.

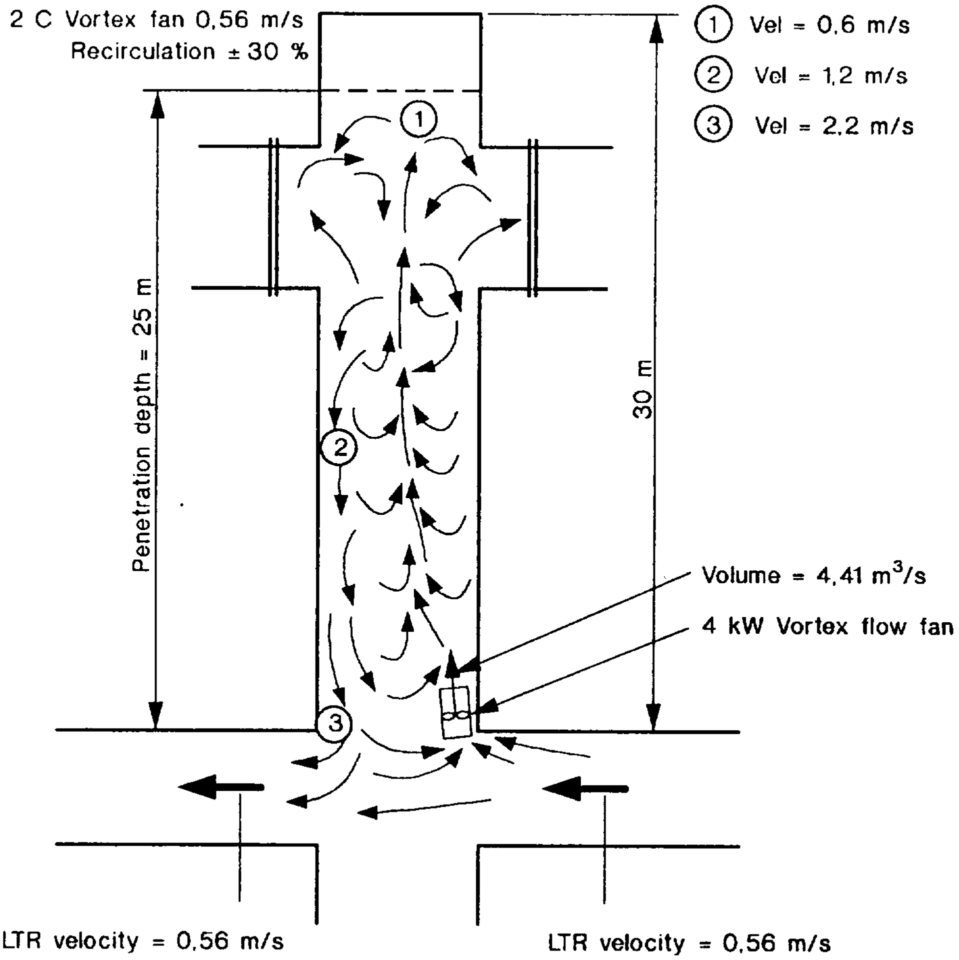

Figure 18(c): Second test position of vortex fan with last through road air velocity at 0,56 m/s.

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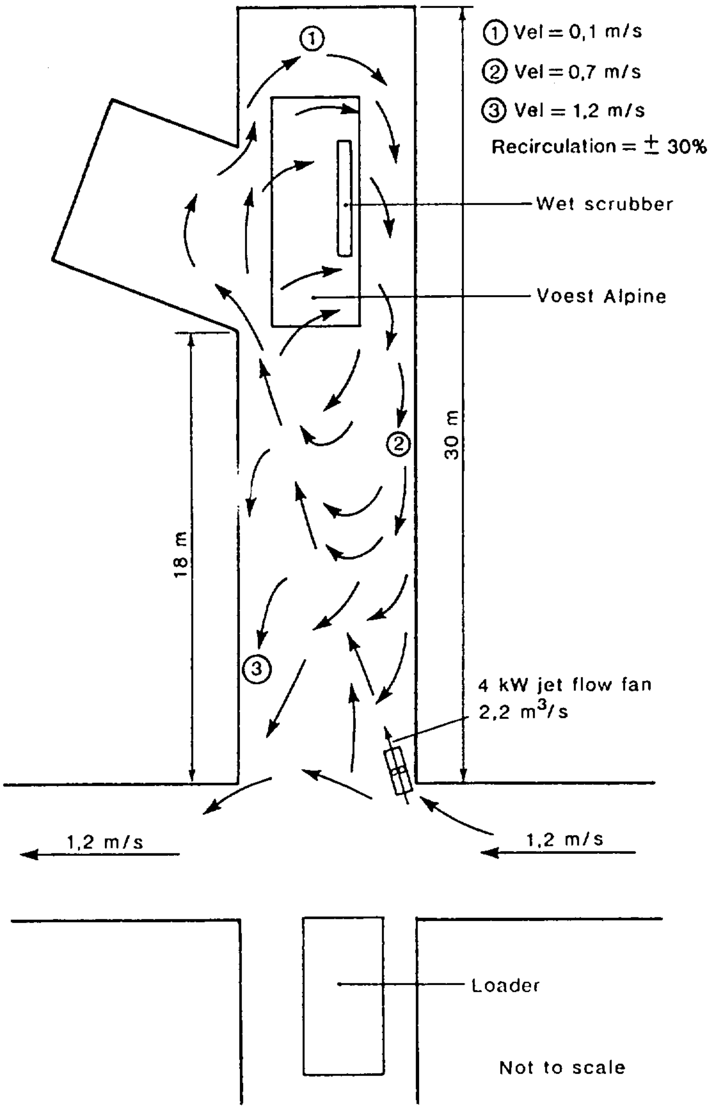


Figure 19: First test position of fan on upstream side of heading-machine not operating.

For the second test, the positions of the machine and the fan kept exactly the same, but the dust suppression systems on the machine were switched on. Figure 20 shows the large difference in the airflow patterns inside the heading. The effect of the watersprays and the scrubber system is causing a large amount of roll-back and turbulent flow around the machine and the amount of air recirculation has been increased to 60 %. Because the air volume of the scrubber is higher than that of the fan, the air in the top part of the heading appears to stay inside this area, causing the roll-back and recirculation. The ideal situation could be to have an air extraction system with the jet fan in order to balance the airflow inside the heading, but that possibility must still be investigated. It was found, however, that when the continuous miner was stopped, the dust seemed to clear out of the heading fairly quickly.

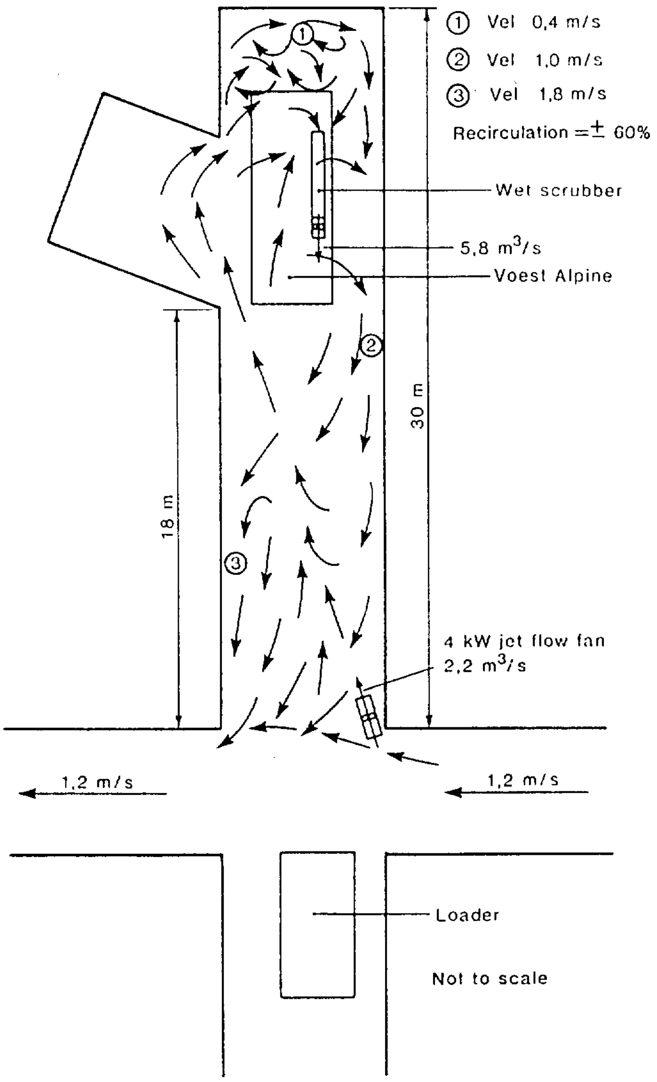


Figure 20: First test position of fan with dust suppression system in operation.

In the next scenario, the Voest Alpine was moved to the left of the heading, cutting the split. The fan was kept in the same position, but was turned to face directly into the split, blowing the air past the machine towards the face (Figure 21). At the same time, a loader moved into the heading to a position immediately behind the roadheader. With the dust suppression systems switched on and the fan assisting the movement of the air around the machine, the airflow patterns appeared to become more linear, with a small amount of recirculation behind the roadheader. Because of the fact that no air extraction system was in operation in the section, dust build-up and roll-back still occurred in the vicinity of the driver. Velocities on the face, however, were measured to be in the region of 0,8 m/s, showing that the possibility of a methane build-up was kept to minimum.

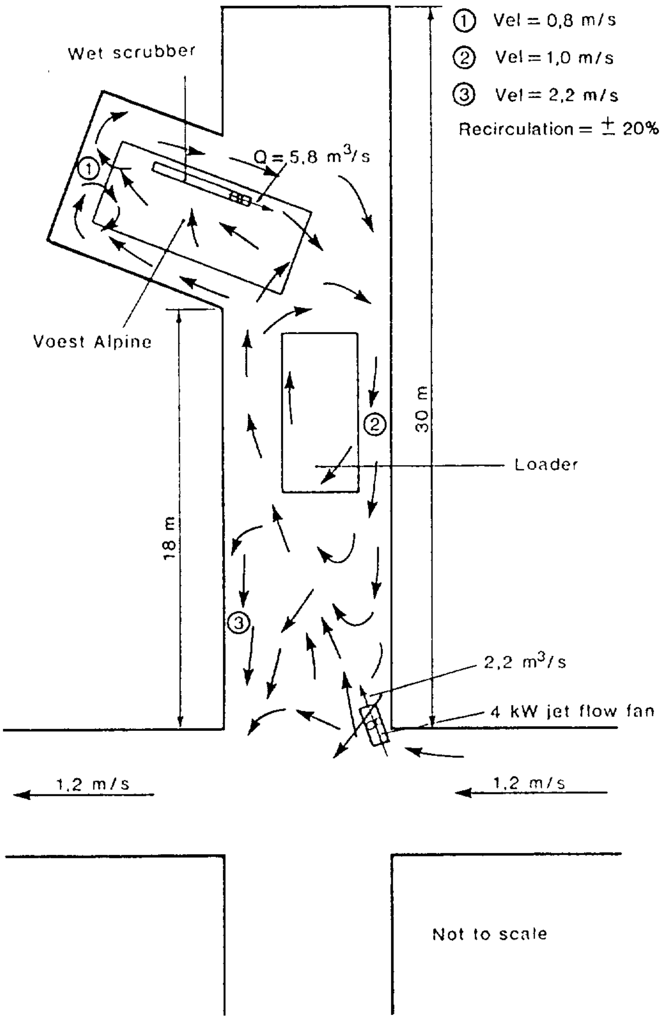


Figure 21: First test position of jet fan with Voest Alpine moved into split.

To illustrate that the correct positioning of the fan is very important, the fan was moved to the downstream side and about 4,0 m into the heading (Figure 22). By doing this, the effect of the air flowing in the last through road on the air inside the heading was minimized. The scrubber and the fan in this position caused a completely different situation inside the heading. The sweeping effect across the face has been minimized and the amount of air recirculation in the first part of the heading increased, due to the effect of the fan on the air inside the heading. This is obviously a very dangerous and unhealthy situation and should never be allowed to develop. This can be prevented by keeping the fan in the correct operating position with respect to the direction of airflow in the last through road and the position of the cutting machine.

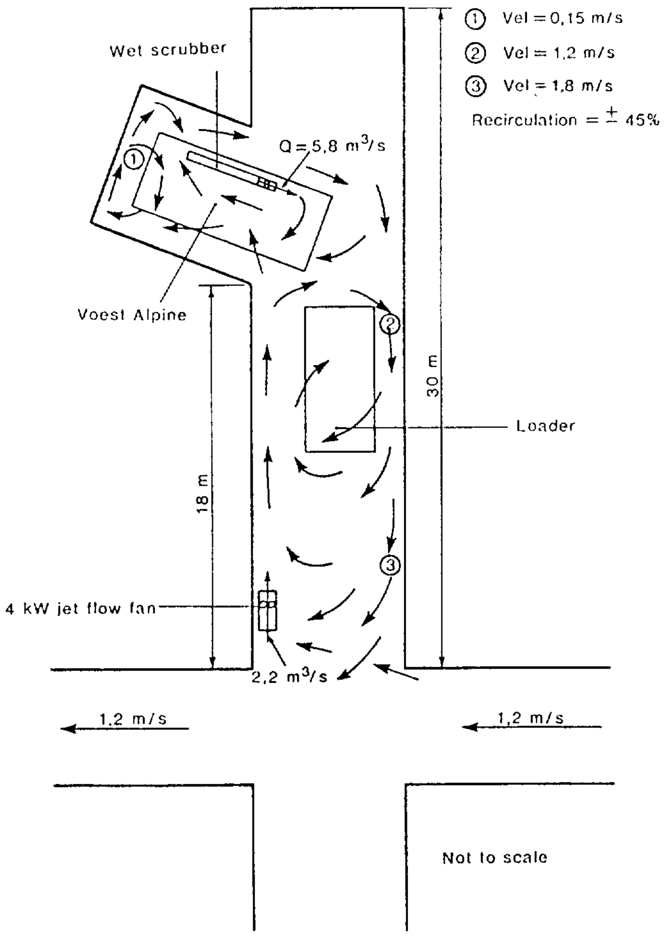


Figure 22: <u>Jet fan moved to downstream side and 4 m into heading.</u>

Interim Conclusions.

Based on these tests, the following important observations can be made regarding the use of jet fans.

- Reach of air into a heading is quite effective to a distance of 30 m.
- When used with dust suppression systems on the machine, good conditions can prevail if volumes are balanced and the fan is positioned correctly. It will, however, assist the airflow patterns if an air extraction system could be used in conjunction with these systems to prevent the apparent build-up of dust and uncontrolled recirculation of air. Tests regarding this matter are being addressed by other research parties with very positive results. These results should be published in the near future.
- The position of the fan with regard to the direction of airflow in the last through road is very important and should be adhered to at all times, regardless of the prevailing conditions inside the heading.

Test Results (cont'd).

The following are some results that were obtained from later tests carried out on the use of an electric driven jet fan. Figure 23 shows the layout of the area with the heading in which these tests were conducted. The sketch also shows the relevant airflow directions and airway dimensions.

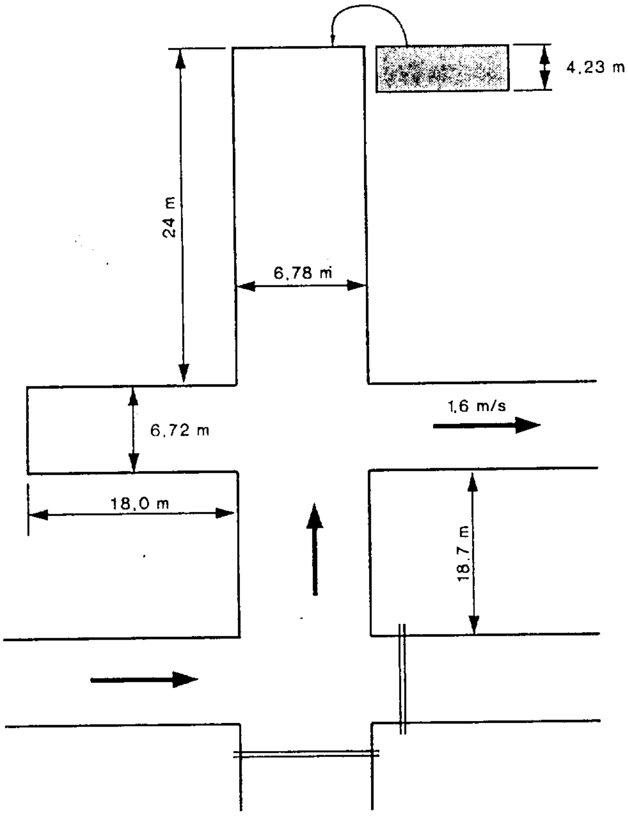


Figure 23: Layout of area in which second series of tests on jet fans was carried out.

An interesting aspect of this test scenario, is the fact that the heading was situated on the left hand side of the heading, directly opposite the main intake airway of the section. The jet fan used in these tests was exactly the same type of fan as used in the previous tests, but due to a difference in power supplys, the fan volume was slightly lower at 1,8 m^3/s. Despite the lower volume, it still created an entrainment volume of 4,0 m^3/s into the heading.

As can be seen in Figure 24, there is a heading to the left of the panel which was developed to a distance of 18,0 m. In the first test position, the fan was placed on the left hand side of the road, just before the entrance of the split to the left. The air velocity in the last through road was set at 1,6 m/s and was flowing from the left hand side of the panel to the right hand side.

The test heading was developed to a distance of 24 m which means that the fan was placed 30,7 metres from the face of the heading. A roofbolter was situated in the entrance of the test heading (Figure 24).

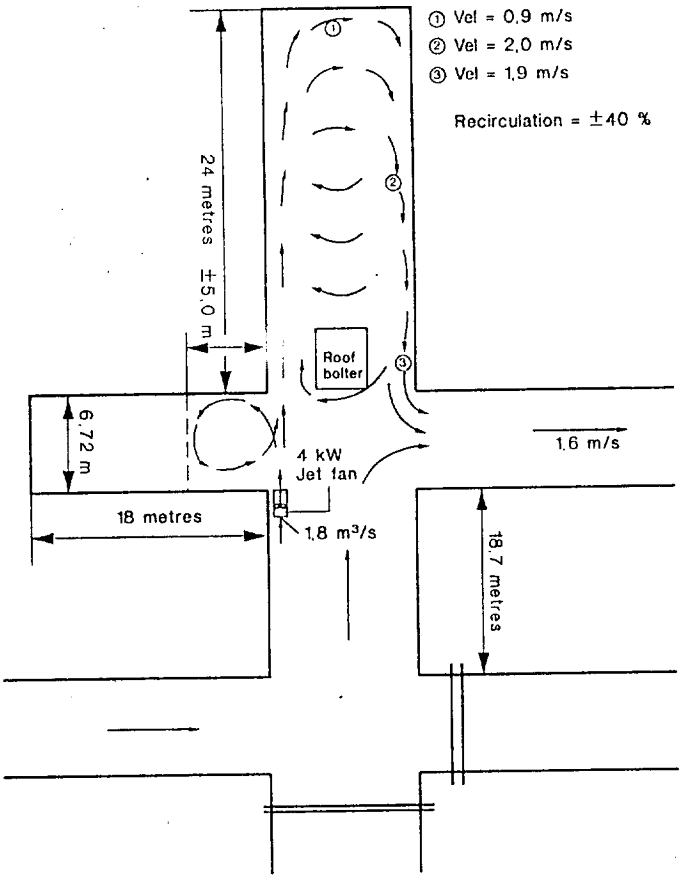


Figure 24: Airflow patterns with jet fan placed 30,7 m from face of heading.

With the fan in this position, airflow patterns were determined inside the split as well as in the test heading. Even with the fan volume being 1,8 m^3/s, an air velocity of 0,9 m/s was still measured at the face of the heading. Approximately 40 % air recirculation does occur inside the heading, because of the air entrainment caused by the fan, but still a good amount of air displacement is achieved inside the heading. The effective amount of air flowing out of the heading, was measured at point 3 to be 54,3m^3/s. With the fan operating in this position, air movement into the split was measured 5,0 metres, the split being 18 metres long.

For the next test, the fan was moved forward into the entrance of the test heading, now being 24 m from the face of the heading (Figure 25). Unfortunately, with the fan in this position, and the heading being situated on the side of the panel, air recirculation increased to 70 %. Because of the position of the heading relative to the airflow direction in the last through road, the air in the last through road has little effect on the amount of air entrained by the fan. This was also the reason for the high air recirculation figure. This might create a dust problem if a continuous miner were to operate inside this heading with the fan in this position.

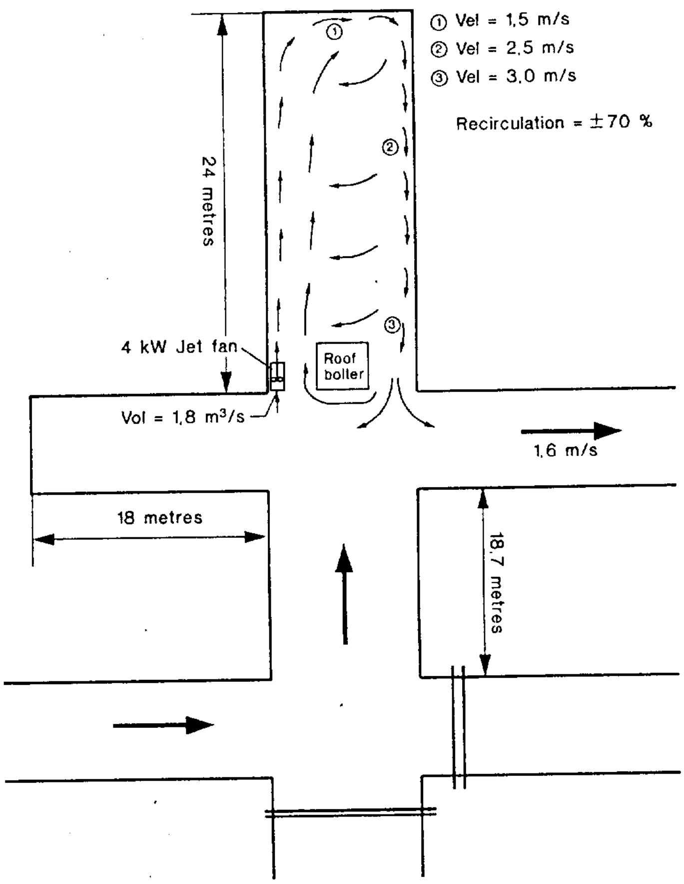


Figure 25: Airflow patterns with jet fan placed 24,0 m from face of heading.

On the positive side, the air velocities inside the heading have increased tremendously and the possibility of gas build-up or gas layering inside the heading is greatly reduced. This fan operating position will be effective if an exhaust system is used in conjunction with the fan. In this particular case, a ventilation curtain installed on the right hand side of the heading would be quite effective in assisting the airflow in the heading (Figure 25a).

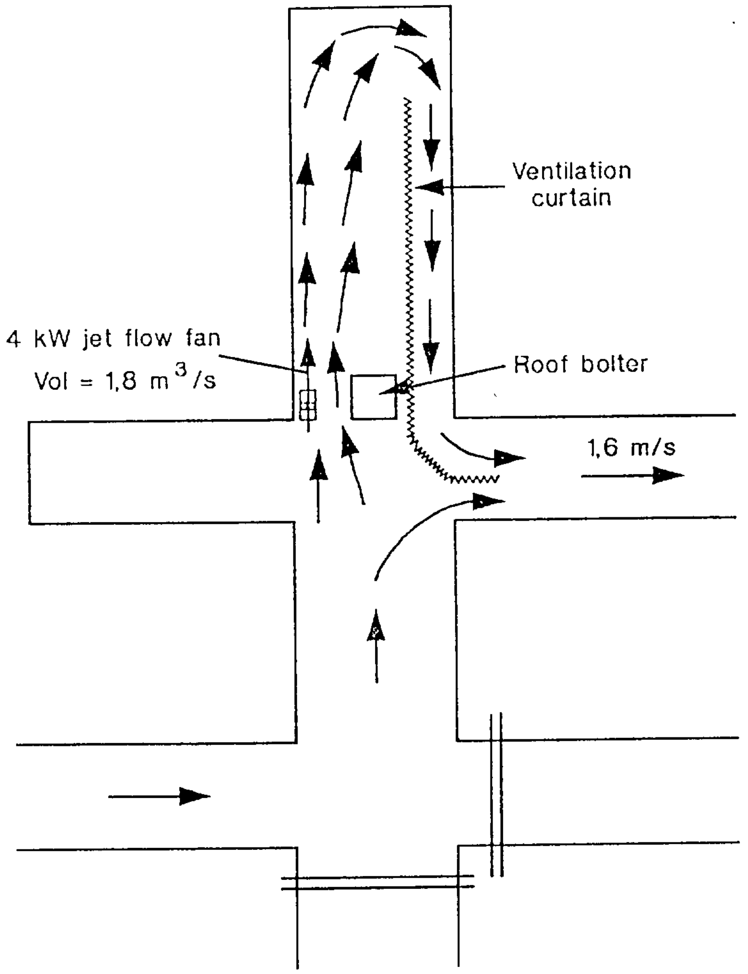


Figure 25(a): Possible airflow patterns if ventilation curtains were to be used with jet fan.

As an experiment to determine the effective reach of the air from the fan, the fan was moved back to a position 45,7 m from the face of the test heading (Figure 26). With the fan in this position, the air penetration into the split, was measured at 12,0 m, showing that in a limited way, the fan can be used to ventilate two headings simultaneously. The results show that with the fan at 45 m, positive air movement was still found at the face of the heading and that the heading was still ventilated effectively. Airflow out of the heading was measured to be 22,9 m^3/s. This situation is likely to change when a large production machine is operating inside the heading.

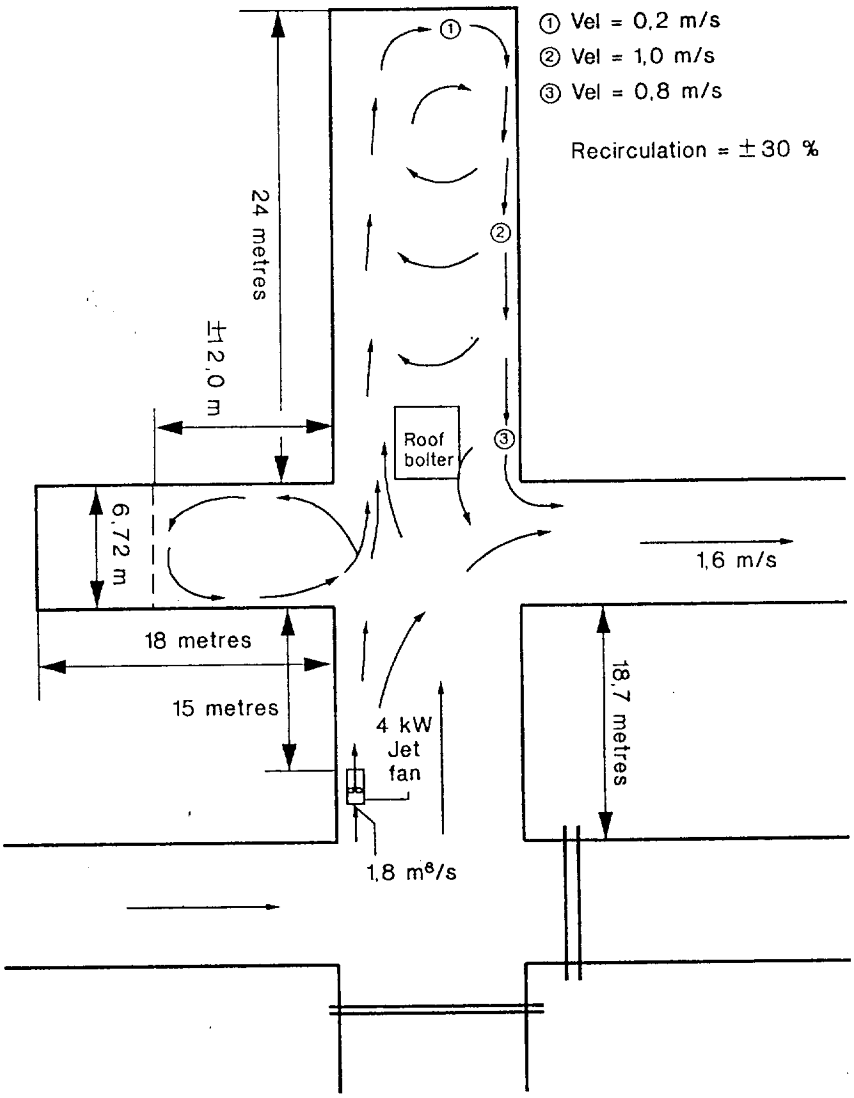


Figure 26: Airflow patterns with jet fan placed 45,7 m from face of heading.

In the previous tests it was already proven that the fan should be placed in the upstream position of a heading because of the high air recirculation figures when placed on the downstream side. The experiment was repeated with the fan placed in the downstream position (Figure 27). No velocities were measured in this particular instance, only airflow patterns, to determine the effect of the fan on the airflow when operating in this position. The sketch shows that air recirculation has increased to 90 % with the amount of air entrainment caused by the fan. Although the possibility of gas layering is small, unhealthy and dangerous situations could occur inside the heading.

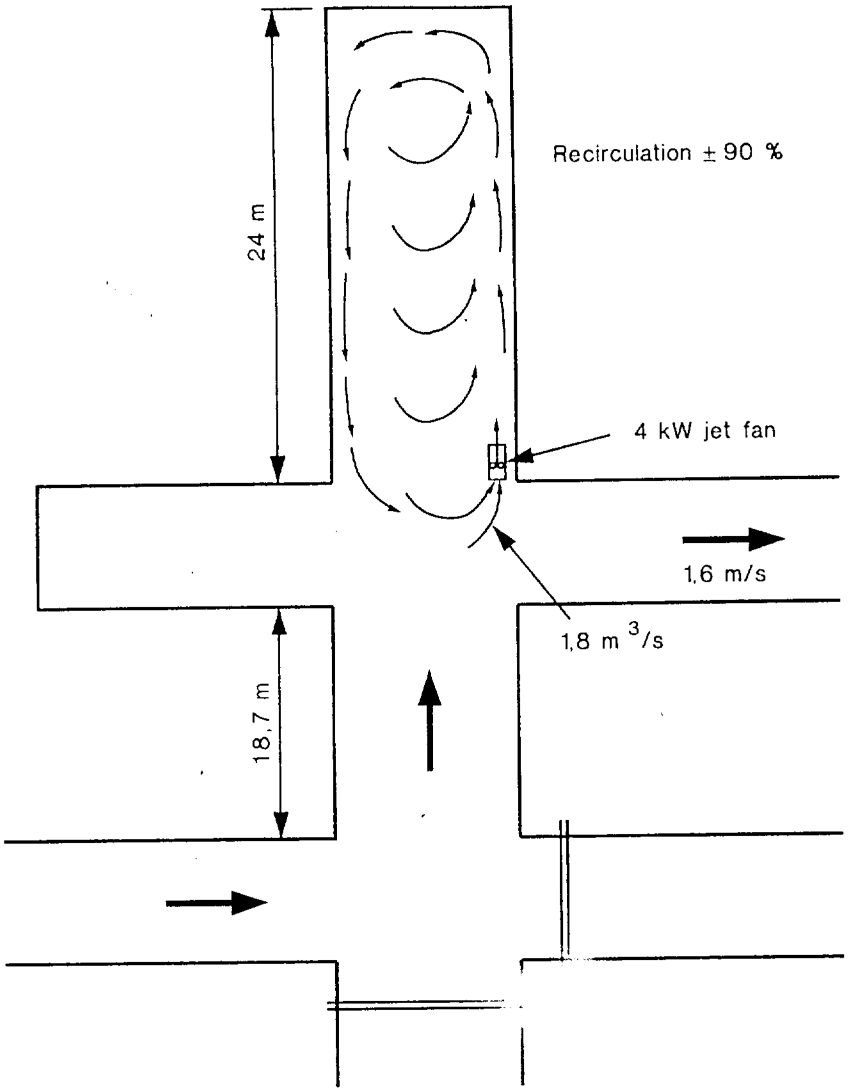


Figure 27: Airflow patterns with fan placed on downstream side of heading.

2.3.3 Recommendations.

From the tests conducted, it is possible to make a some recommendations regarding the use of ductless fans:

a) The jet fan is apparently the best alternative at this stage. The performance of the jet fan is better than the vortex fan and is more economical to use than the vortex fan.

b) The use of any ductless fan should always comply with the standards set out in the "Codes of Practice" of the individual mines dealing with the ventilation of bord and pillar headings.

c) When used with a continuous miner or any other production machine that is fitted with a dust suppression system, the volumes of the two systems should always complement each other in order to create the best possible airflow conditions inside the heading.

d) The fan should always be used in the upstream position of a heading, relative to the direction of airflow in the last through road.

e) If possible, the air velocity inside the last through road should always be more than 1,0 m/s and as close as possible to 1,4 m/s (critical velocity).

f) These fans are quite effective when used as force ventilation, but usually with a large amount of air recirculation in and around the heading. If possible, these fans should always be used with an exhaust system such as exhaust fans, ventilation curtains, ventilation ducting, etc.

It is advisable that some research work should still be carried out on the various uses of these fans, including:

- jet fans in exhaust systems
- jet fans mounted on continuous miners
- force\exhaust systems with jet fans

3. SECTION VENTILATION SYSTEMS.

3.1 Total Extraction Ventilation Methods (Meyer 1991)(4)

Stooping practices , which include pillar and rib-pillar extraction, form an integral part of mining the coal reserves in South African coal mines and is presently the second most popular method of mining after conventional bord and pillar development. Because the production rate of this mining method is much higher than other mining methods, the ventilation systems used to ventilate this type of section are very important. The importance of correct ventilation for these types of mining methods are underlined by the high risk of gas and/or dust related incidents that may occur during mining process. Because of the different geological and mining conditions present in mines, different ventilation systems are used to ventilate the pillar or rib-pillar extraction operations. The major consideration with the regard to the method of ventilation is whether a bleeder road system will be used to allow some air to "leak" through the goaf, or whether the airflow is only allowed to "sweep" the working faces and not forced across the goaf.

The different ventilation methods used by 11 collieries were investigated and reported. These included the ventilation process during development as well as during the extraction process. In this section of the report some attention will be given to the ventilation methods during the development stages and then some of the methods used during the extraction process will be described as well. It is apparent that no single method can be said to be appropriate for the ventilation of stooping sections and most mines adjust the system to suit their particular circumstances.

The purpose of these investigations was to inform the mining industry of the different ventilation methods in use in the coal mining industry with regards to pillar and rib-pillar extraction. It was also intended to give the mines that are considering stooping for the first time, and with no previous experience to assist them, some guidelines to the alternatives available.

3.1.1 Ventilation Methods During Development For Pillar Extraction.

The development of bord and pillar panels are usually done by either conventional methods or continuous miners. The amount of roads developed can differ between two roads and eleven roads depending on factors such as mine layout and conditions. Various methods are used by the mines to ventilate these panels during the development stages.

One of the methods that is used, is the well known electric driven axial flow force fan, usually connected to force ventilation ducting. The fans that are used, are in most cases 760 mm Ø , 37 kW fans that are fitted with flexible force ventilation ducting, ranging from 406 mm Ø to 760 mm Ø depending on conditions and application.

Figure 28 shows the layout of a typical 7 road bord and pillar development that will be used for pillar extraction after completion of the panel. The headings are ventilated with three 37 kW axial flow force fans with the aid of 570 mm Ø flexible force ducting. Each fan is capable of handling between 7 m^3/s and 10 m^3/s depending on factors such as duct length and the friction factors of the ducts used. The total volume of fresh air flowing into the section should be sufficient to supply the amount of fans used and to ensure a reasonable air velocity in the last through road.

In this particular panel, the coursing method of ventilation is used, where the intake air is flowing into the section through six roads, and after reaching the last through road, is flowing out via the return road. The air is directed through the section and the last through road by means of brick walls and line brattices.

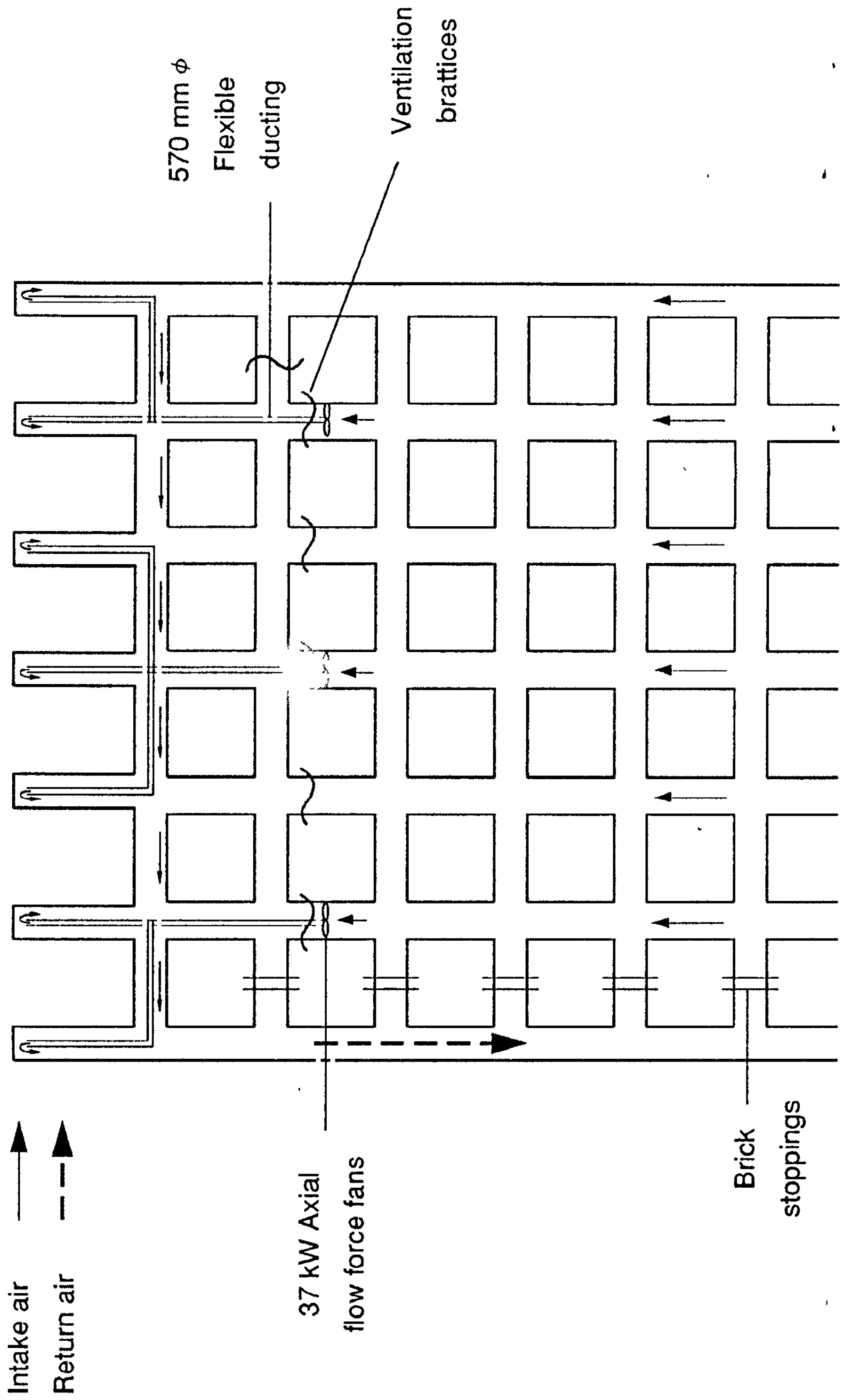


Figure 28: Ventilation layout for bord and pillar development using coursing ventilation.

A second method of ventilating this type of development, is by using the splitting method of ventilation (Figure 29). Axial flow fans are also used as was the case in the previous sketch, but with the difference that return airways are being established on both sides of the panel. This means that the five roads in the middle of the section are used as the intake airways and once the air reaches the last through road, the air splits both ways and flow towards the return roads. Again brick walls and line brattices are used to direct the airflow.

A third method that is used, is to ventilate the headings without using any form of auxiliary ventilation (Figure 30). The only time when fans will be used by this particular mine, is when in extreme cases the headings are developed further than 15 metres from the last through road. The air is coursed through the section from one side to the other and brick walls and line brattices are used to ensure that the maximum amount of air reaches the last through road. The air velocities in the last through road should be kept at a high standard to ensure a high air penetration into the headings. This type of ventilation is not recommended in headings where coal is being mined as the risk of any gas or dust related incident is greater than when auxiliary fans are used. This method is, however, sufficient in headings where no production is taking place, provided that the headings are not developed further than 10 m from the point of last through ventilation.

The use of line brattices is a popular method of ventilation in some of the mines. It is usually the practice in panels where the mining dimensions does not permit the use of auxiliary fans and ducting and where handgot mining methods are used. This means that the line brattices will not interfere with moving machinery and the air can be directed to the working place without problems.

Figure 31 shows a layout of a section where line brattices are used as a heading ventilation method. The splitting method of ventilation is used inside the section with three return roads being established and used. The amount of return roads that are used is not fixed and can vary from section to section. The sketch clearly demonstrates the mechanism of using the line brattices to direct the air from the last through road into the headings, creating in the process numerous intake and return roads on a small scale. For this system to work effectively, sufficient air should be provided in the last through road and air leakage through the brattices should be kept to a minimum.

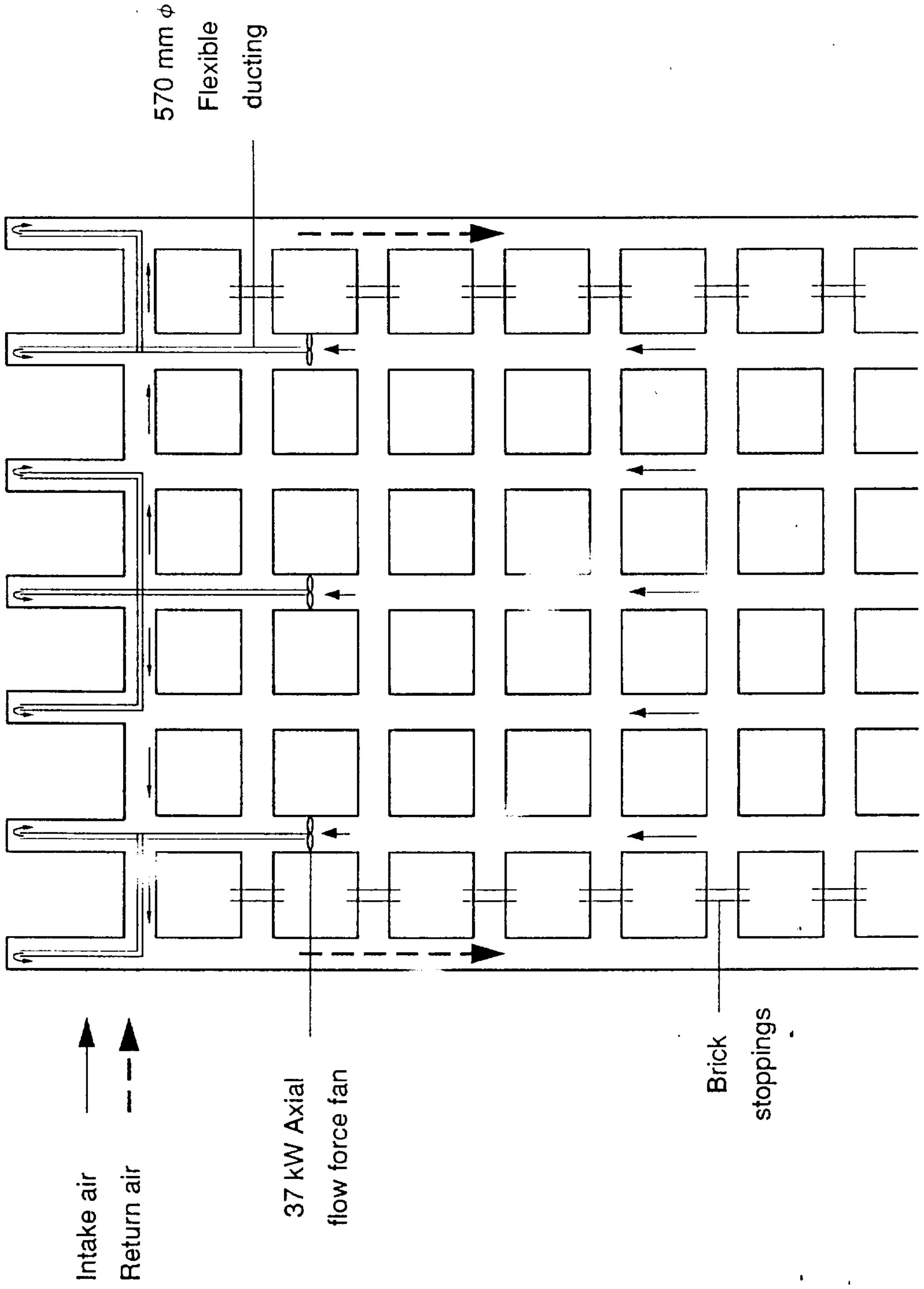


Figure 29: Ventilation layout for bord and pillar development using splitting ventilation.

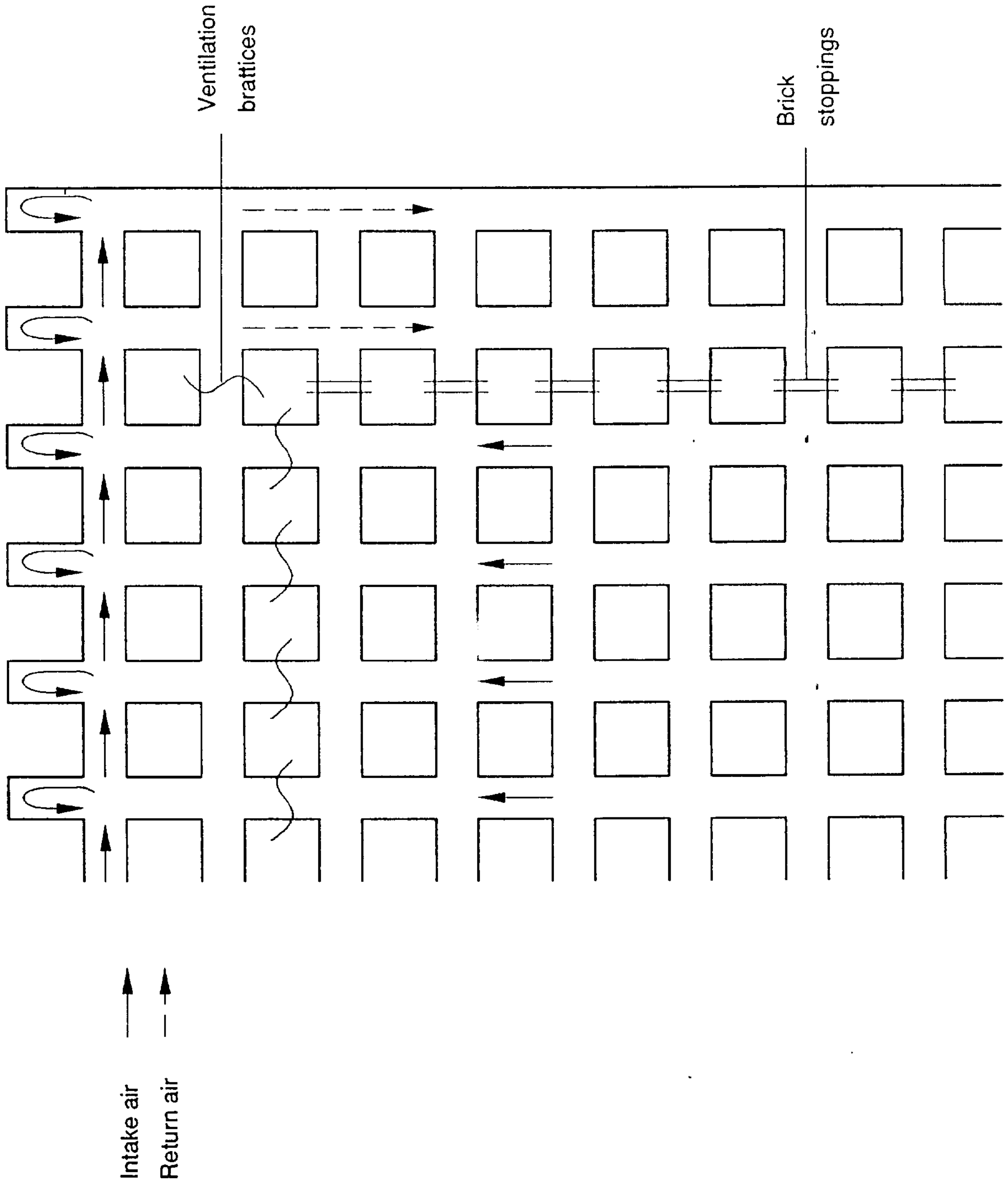


Figure 30: Ventilation of bord and pillar headings using no auxiliary ventilation.

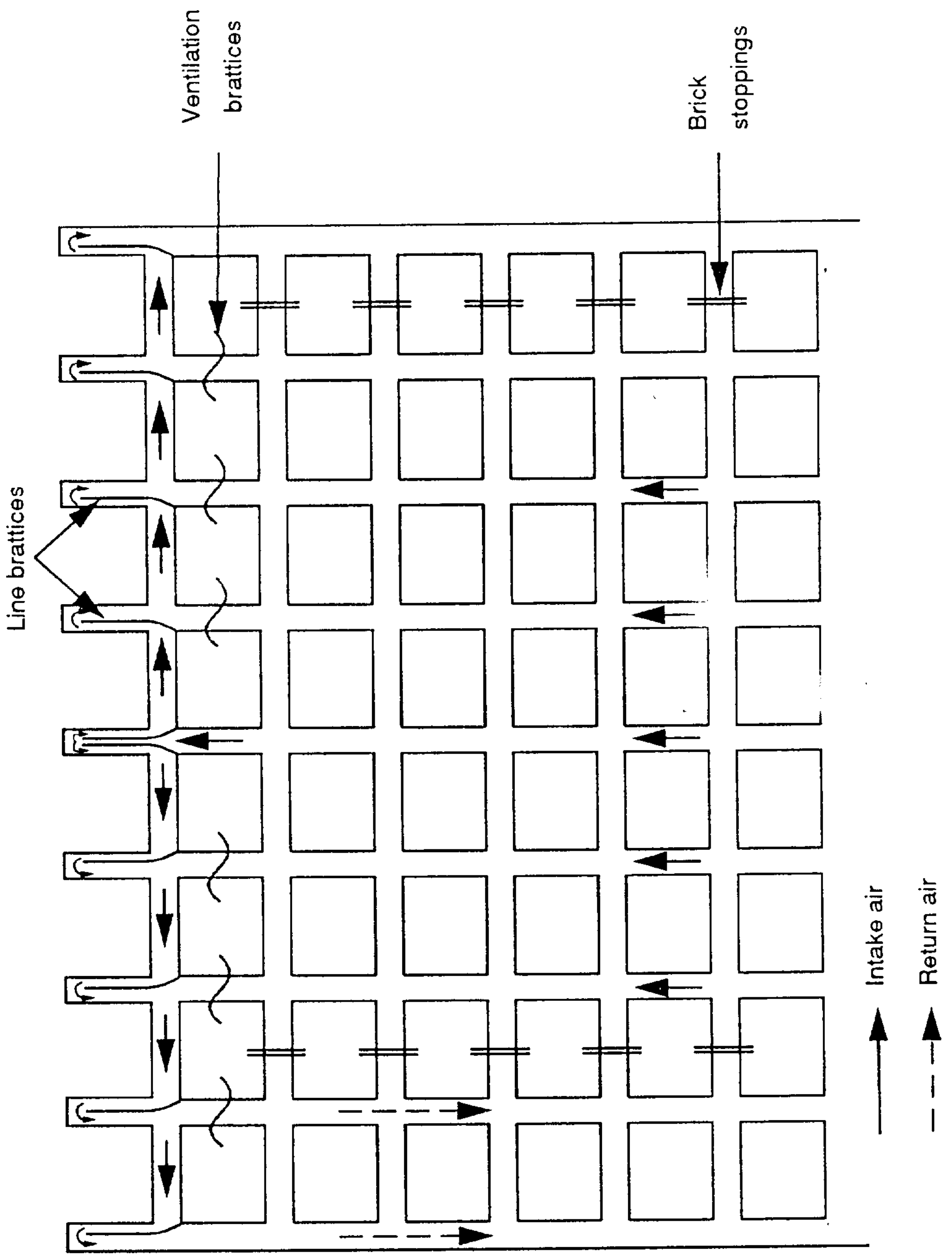


Figure 31: Ventilation of bord and pillar headings using line brattices.

In one of the previous sections of this report, the correct uses of air scoops were discussed, including some advantages and disadvantages of the system. One of the mines surveyed, has introduced air scoops to ventilate the bord and pillar headings (Figure 32). This particular mine is using handgot and conventional production methods and therefore the use of air scoops can be justified. The air is coursed through the section from left to right along the last through road. The scoops are all installed on the upstream side of the headings. They are installed in one third of the roadway width from the side of the heading as well as in the last through road, and extend to within 10 metres from the face of the leading (Figure 33).

The next method of ventilation that will be described, is unique in the sense that two types of fans are used without ducting to ventilate the headings. The section consists of eleven roads of which the five center roads are used as intake airways and the three roads on either side of the section are used as return airways. Line brattices are used to ensure that an even flow of air is maintained in the last through road. In the three center roads, just behind the last through road, three 11 kW axial flow fans, 570 mm in diameter and delivering between 5 m^3/s and 7 m^3/s of air, are used to course the air towards the three center headings. The other headings are ventilated by means of hydraulic driven vortex fans (Figure 34). The correct uses of vortex fans and their effects on airflow patterns inside headings have already been discussed in the previous section. Keeping the results from the tests done on vortex and jet fans in mind, it might be appropriate to suggest this time that the electric jet fans should be used for this particular system instead of the axial flow fans and the vortex fans.

Various other specialized ventilation methods are used by the mines for different development methods. These methods are described in detail in a COMRO reference report (Meyer 1991)(4).

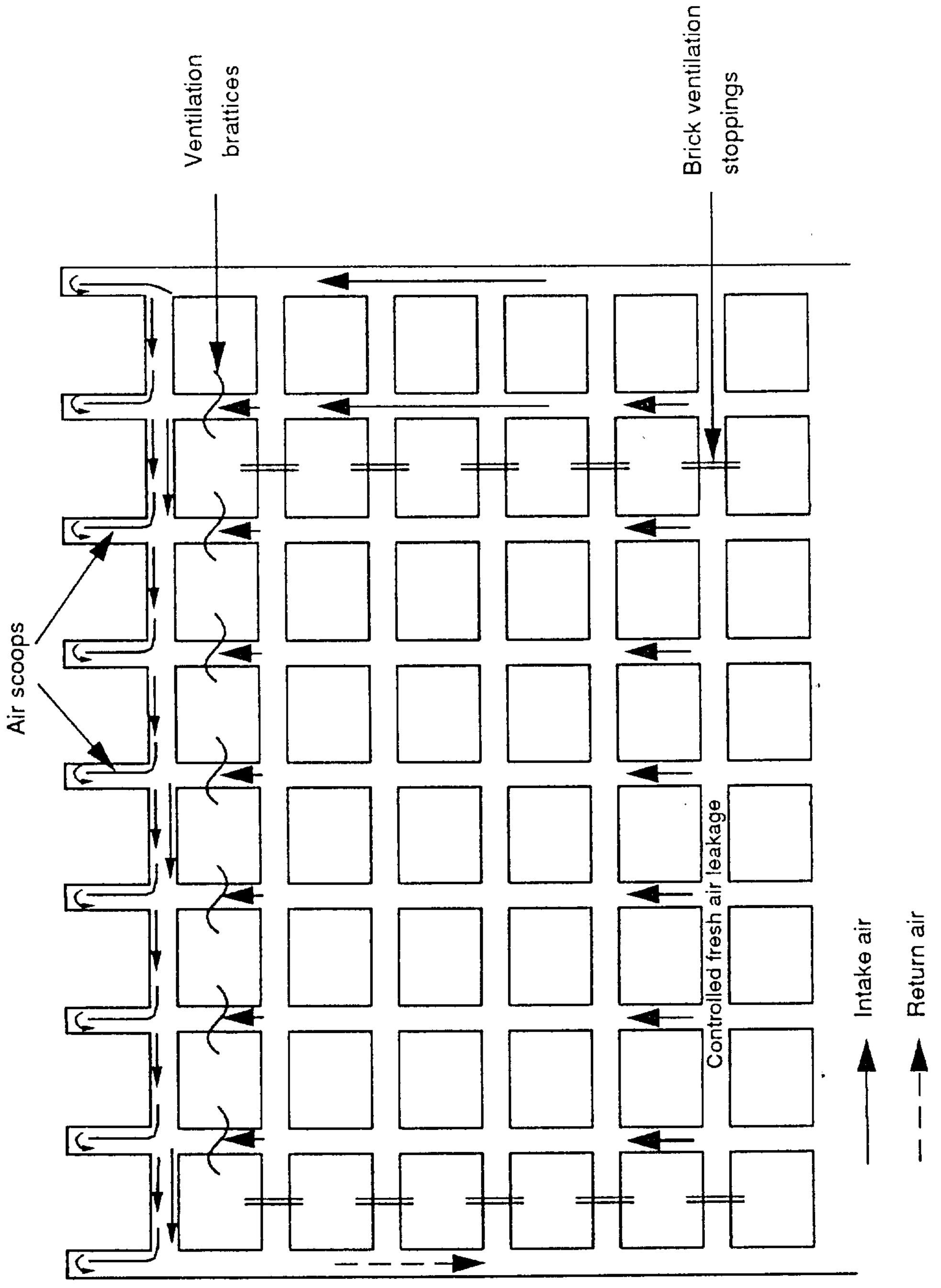


Figure 32: Ventilation of bord and pillar headings using air scoops.

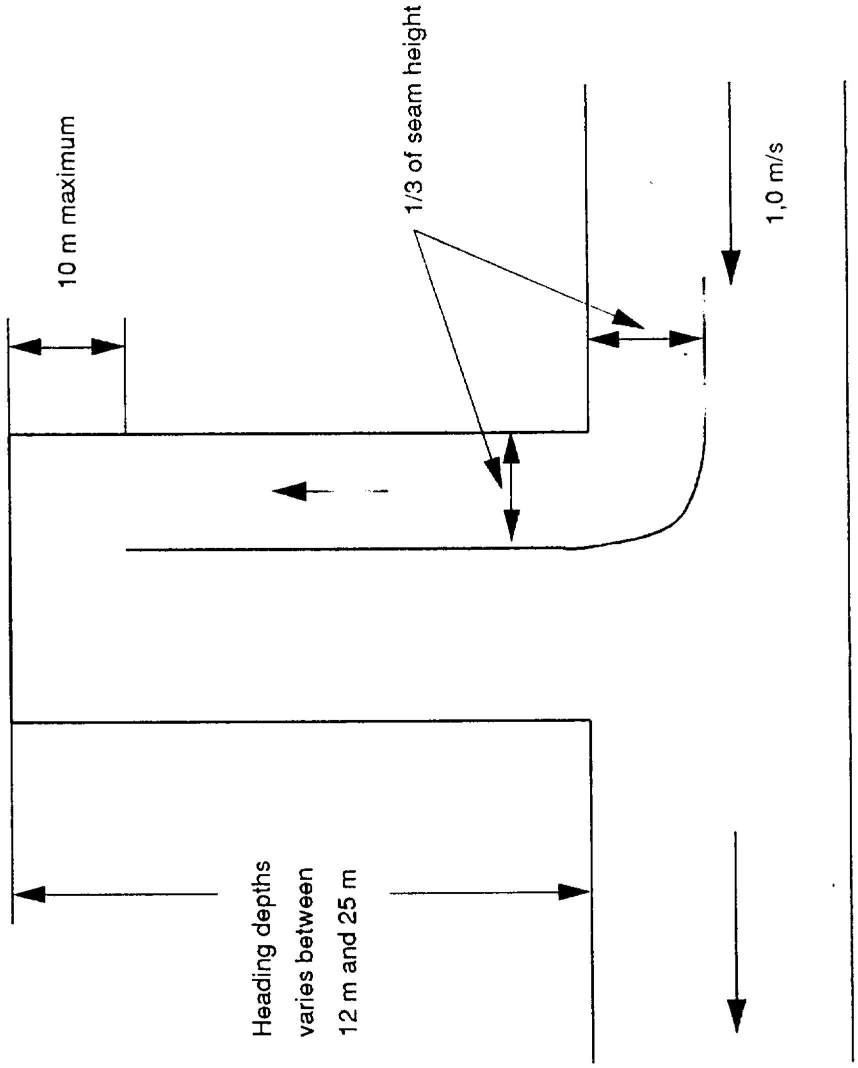


Figure 33: Correct method of installing air scoop inside heading.

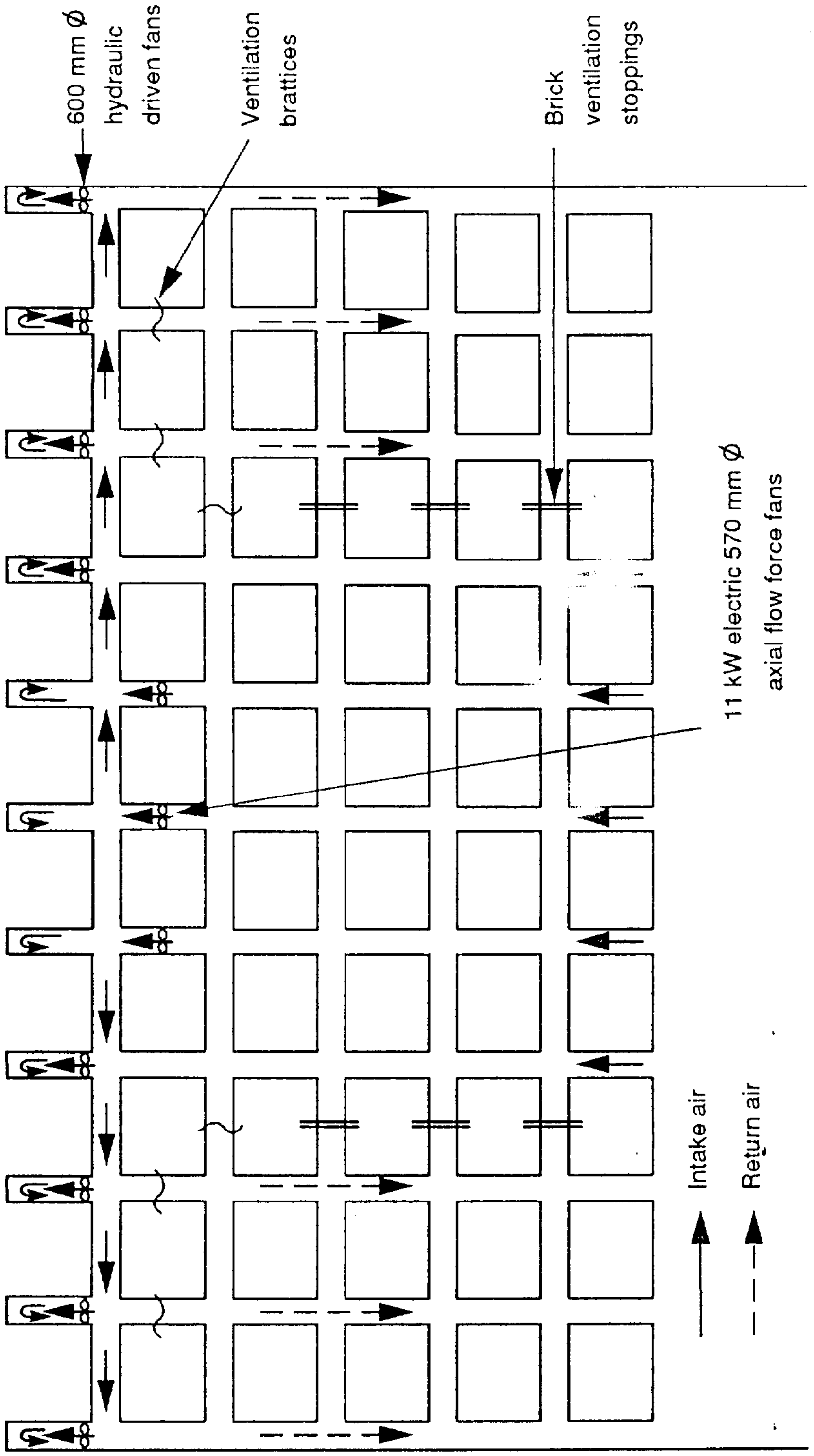


Figure 34: Ventilation of bord and pillar headings using auxiliary fans without ducting.

3.1.2 Ventilation Methods During Pillar Extraction.

The methods used for ventilation pillar panels, are concentrated around the criteria of a bleeder road system or not and whether or not to ventilate the goaf area. Some of the more important methods of ventilation will be discussed and illustrated.

The first scenario deals with the situation where the pillars are extracted in a straight line, starting with the pillars against one side of the panel, working to the other side of the panel. The following line of pillars are then mined in the opposite direction forming a criss-cross pattern across the section. The bleeder road is used in this section, was established during the development period of this panel (Figure 35). The air flows into the section through the intake roads to the working faces. By installing line brattices against the breaker lines, the air is concentrated along the working faces. From this point the air flows through the goaf area towards the bleeder road at the back of the goaf. The walls separating the intake and return airways, are kept intact and a 6,0 metre rib-pillar is left to protect the bleeder road. In the event of the goaf closing up, which would prevent or hinder the airflow, one or two of the walls are removed to rectify the situation.

The next ventilation method that is used during pillar extraction, is where an additional return airway is established on one side of the panel to return excess air from the section. This return airway handles the air that cannot flow through the goaf because of restrictions, but is necessary for keeping the total volume of air needed for the section to the required standard. The bleeder road is established by connecting it to the return road of an adjacent section allowing the air to flow over the goaf to the bleeder road (Figure 36). All the other roads in the section that were previously used as return roads, are converted to intake roads. The air is again concentrated along the working faces. This, incidentally, is common practice on all mines that are exercising total extraction.

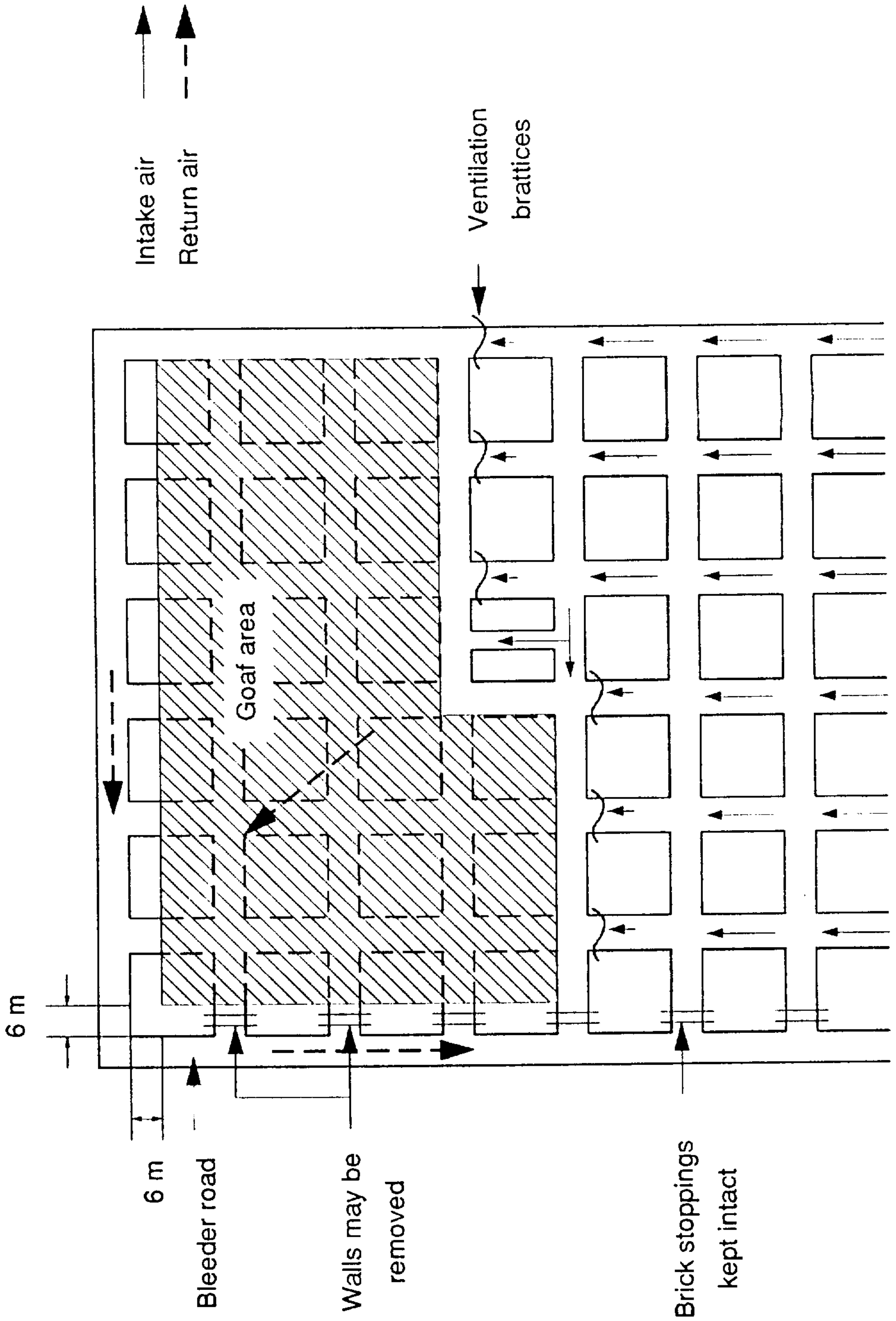


Figure 35: Ventilation layout during pillar extraction using bleeder road system.

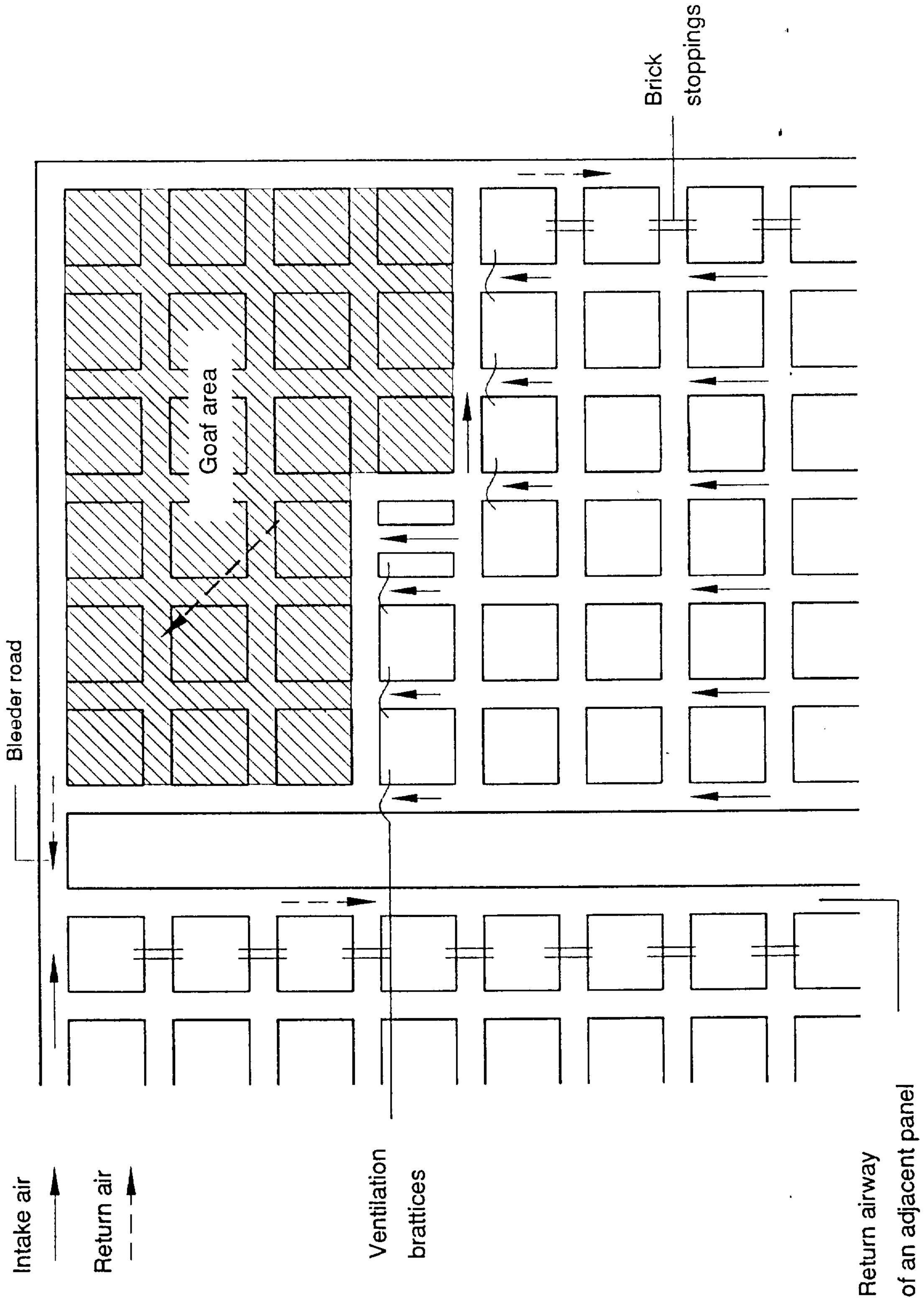


Figure 36: Ventilation layout during pillar extraction using return airway of adjacent section.

The next method of ventilation is different in the sense that no bleeder road is used and therefore no air is forced through the goaf. The reason for this method in this particular case, is that the overlaying strata is causing the bleeder road to collapse when the area is goafed. Spontaneous combustion is also a possibility as carbonaceous shale is present in the roof. This could present a problem if the air is forced through the goaf to a bleeder road. The air is flowing along the working faces and directly to the return airway on the side of the section, which consists of two roads (Figure 37). To assist in removing the dust and gases from the driver and the face, a 37 kW axial flow force fan is used with the aid of 570 mm Ø flexible ducting. The outlet of the column is positioned such as to ensure continuous flow of fresh air over the driver. This particular system works well, but a problem that does occur, however, is the large amount of dust that is pushed into the workings from the goaf whenever goafing occurs.

In the next case, pillar extraction is done on a 45° line, starting with the pillar in the right hand corner working down to the left hand side of the panel. Again all the roads are blocked with line brattices, leaving only one open road where the production process is taking place (Figure 38). The interesting fact is that although no "over the goaf" bleeder road system is used, the gas and dust migrating form the goaf, is still effectively removed by using the return roads of an adjacent section. The air flows behind the line brattices towards the return roads. When a special condition develops where an excess amount of gas is present in the goaf area or behind the brattices, an auxiliary fan is used to dilute the gas concentration.

Figure 39 shows a method where the pillars are mined in an arrow-head sequence. During development three return airways were established on both sides of the panel. These return airways are maintained throughout the extraction process and the air flows from the working faces to the return roads on the sides. The brick walls are removed with the pillars as the section progresses. Line brattices are again used to direct the air to the working position and to ensure that a strong flow of air is present behind the brattices against the goaf line. No bleeder road system is used and whenever a gas problem is encountered, the situation is being addressed by using a small vortex flow fan or a jet fan.

The other methods that are used by the mines are all fairly similar to the methods discussed in this report. The small differences occurring in the individual methods, are influenced by the difference in the mining methods and the different mining sequences used (Meyer 1991)(4). Full details on the different mining practices are described in a COMRO report and can be obtained from the MININGTEK information centre (Beukes 1989)(5).

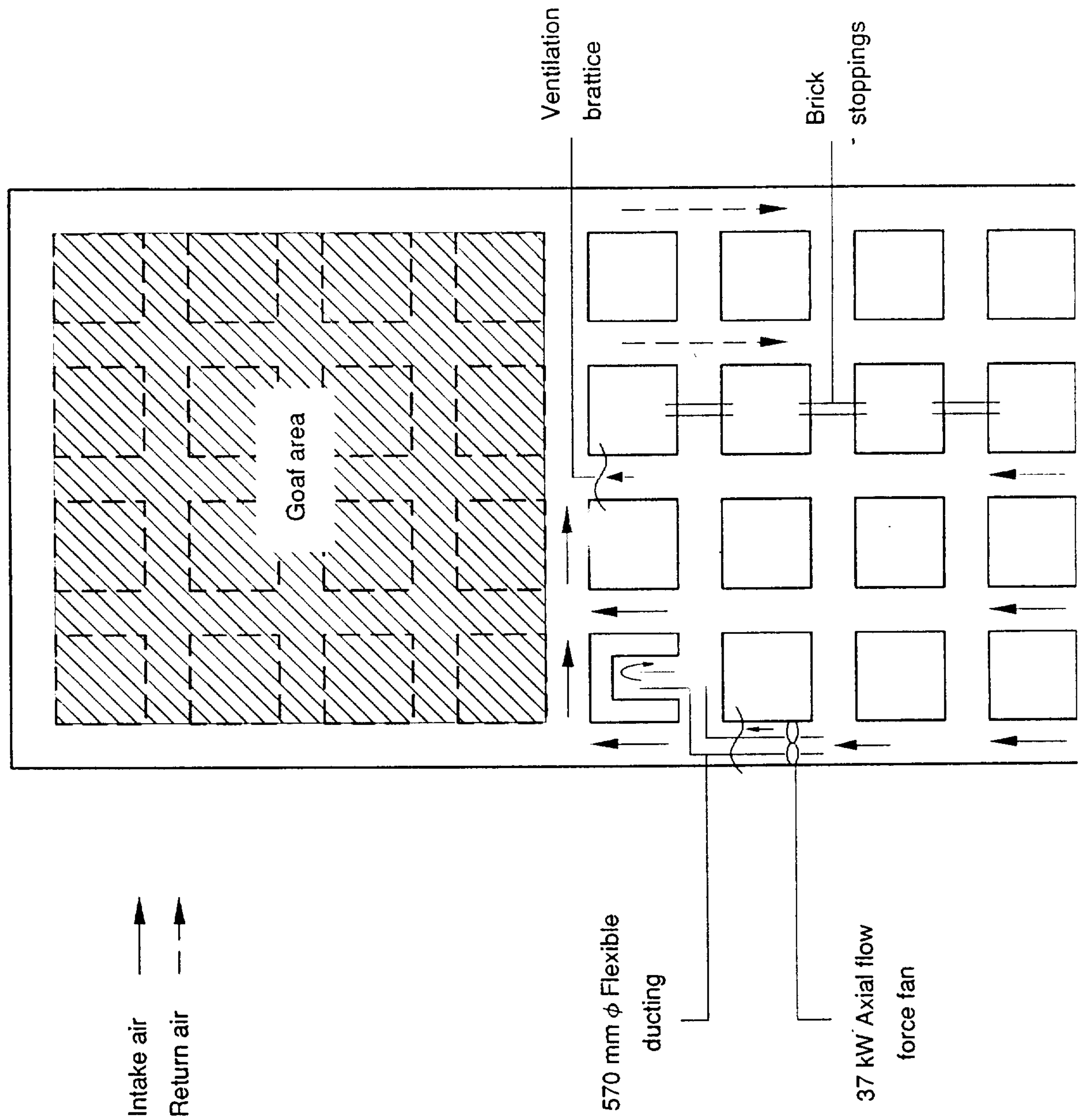


Figure 37: Ventilation layout during pillar extraction using no bleeder road.

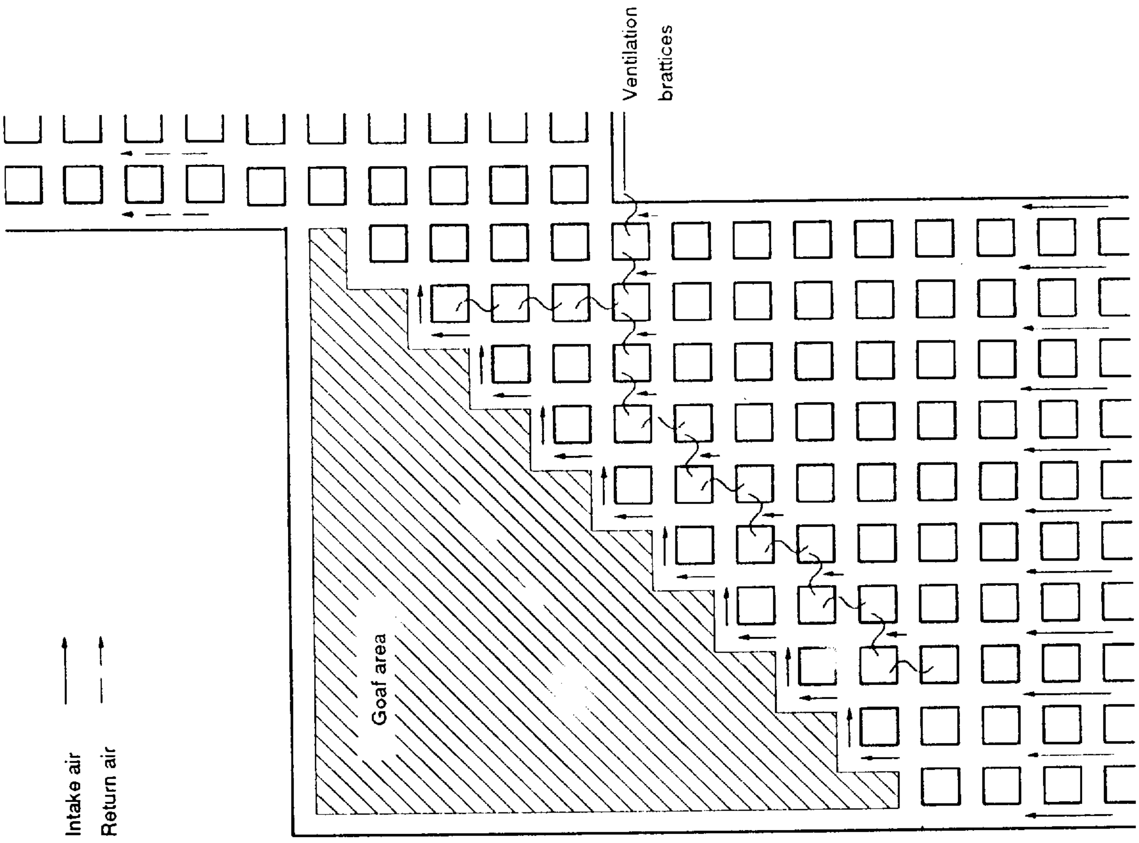


Figure 38: Ventilation layout during 45° angle mining method.

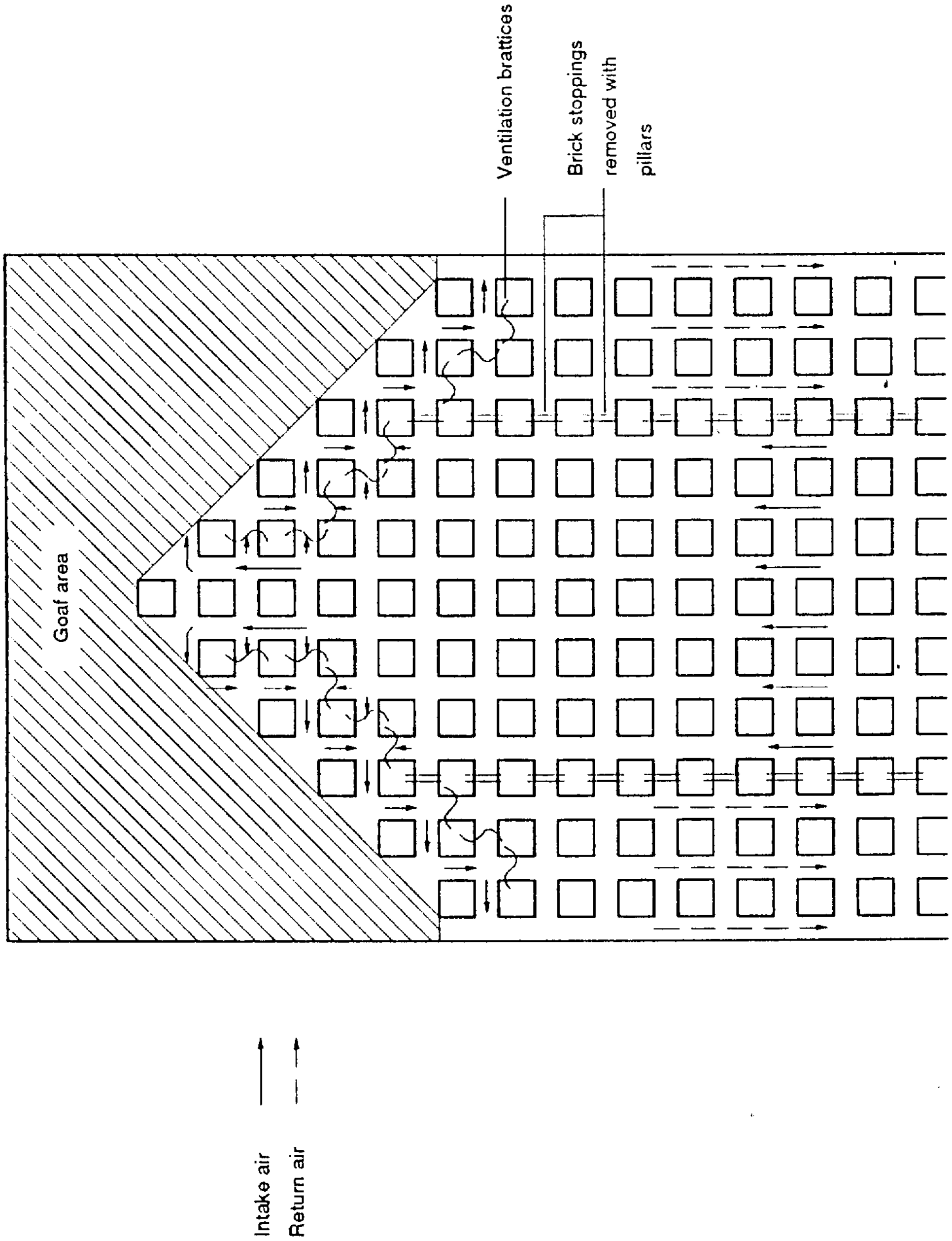


Figure 39: Ventilation layout during arrow-head mining sequence.

3.1.3 Ventilation Methods During The Develpment And Extraction Of Rib-Pillars.

The development of panels for rib-pillar extraction are much different than that of pillar extraction and although only a few mines still exercise this particular mining method, one or two examples will be given of a typical section ventilation layout during development and extraction. Development is largely done with continuous miners but one or two mines are using conventional mining methods as well. This development is usually ventilated with axial flow force fans connected to flexible force ducting.

Figure 40 shows a three road development into a block of ground (primary development) and from there two roads are developed into the virgin ground to establish a rib (secondary development). During this whole process, the headings are ventilated with a 760 mm Ø, 37 kW axial flow force fan using 570 mm Ø flexible force ventilation ducting. Of the three roads that were developed during the primary development, two were used as intake airways and one as a return airway. These airways are divided by brick walls to minimize air leakages. Of the two roads that were developed during the secondary development, one is used as an intake road and the other as the return airway. These two roads are temporarily divided by ventilation curtains which are installed properly and sealed around the edges.

On completion of the secondary development, a bleeder road is established at the back of the panel connected to an existing main return airway and both roads which forms the secondary development, are converted to intake roads (Figure 41). The establishment of the bleeder road and the method of ventilating can differ from mine to mine depending on the mining conditions. During the extraction process, the air is flowing through the two intake roads towards the mining area, and is concentrated to flow over the workers and the production machine into the goaf area, towards the bleeder road. The bleeder road is usually protected by leaving a 6 m protection pillar adjacent to the bleeder road.

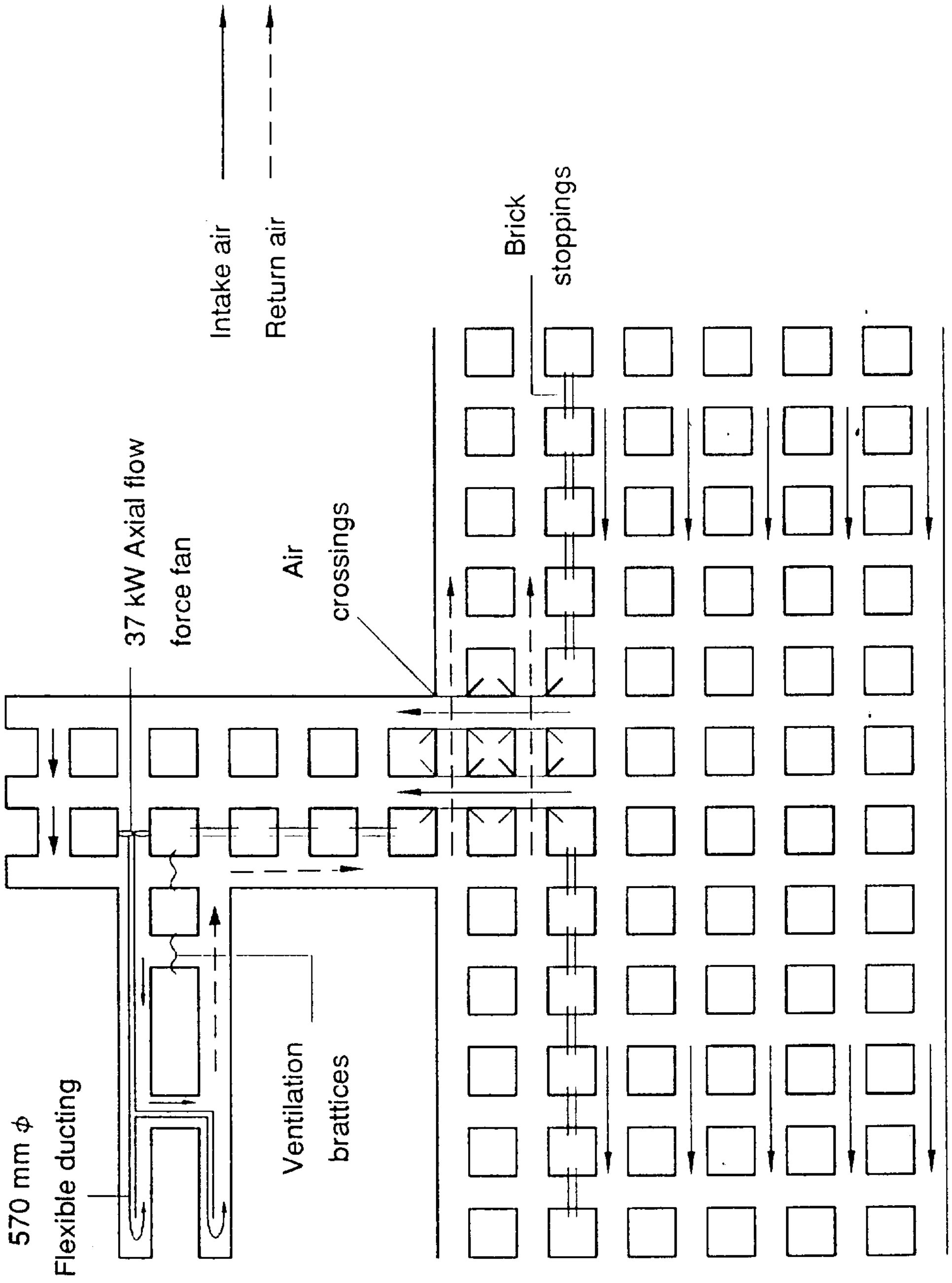


Figure 40: Ventilation layout during two road rib-pillar development.

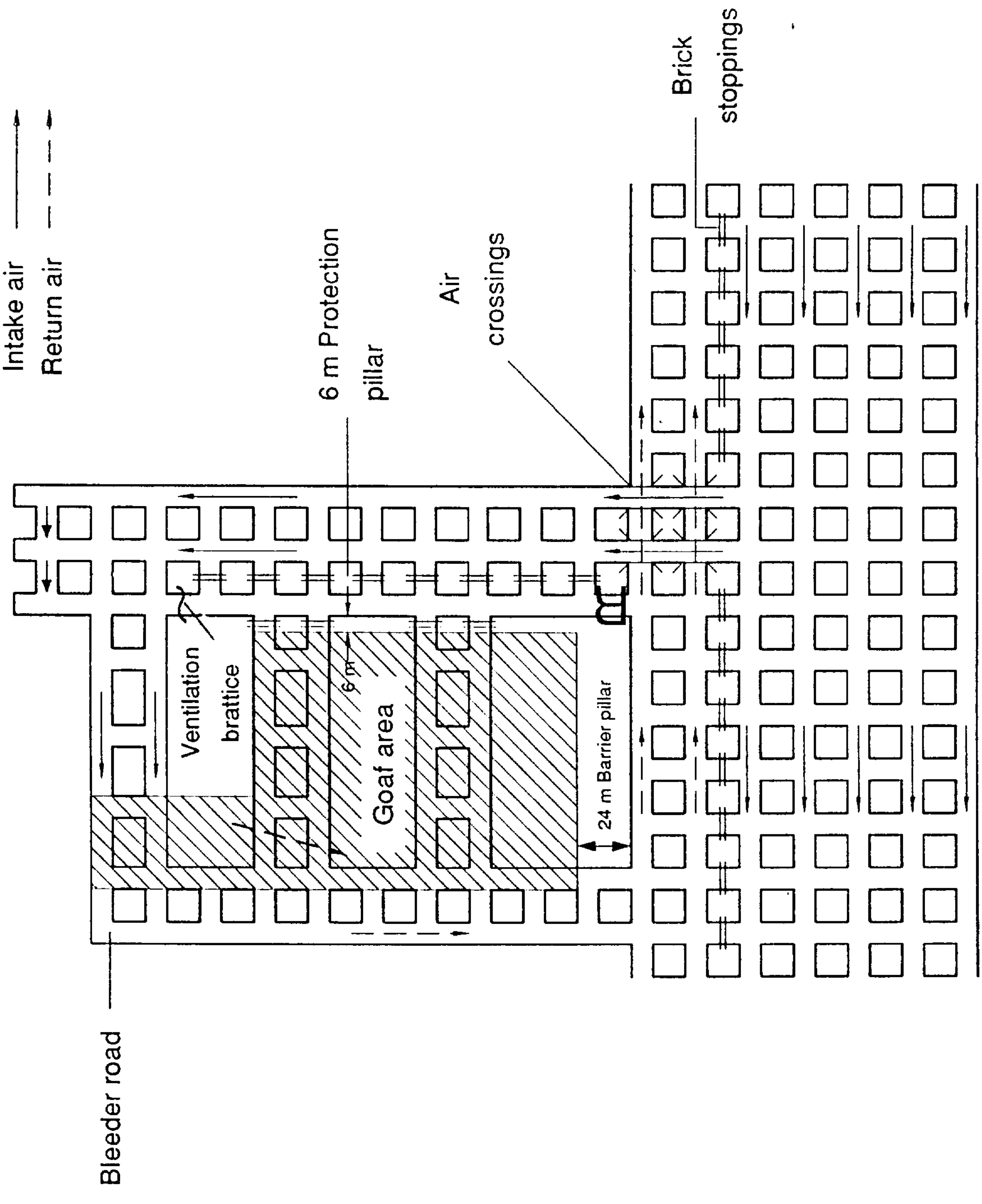


Figure 41: Ventilation layout during extraction of rib-pillars using bleeder road.

Another typical layout during the development of panels for rib-pillar extraction is shown in Figure 42. In this case the secondary development consists of four roads of which the two center roads are used for intake and two side roads for return airways. The headings are ventilated with 760 mm Ø, 37 kW axial flow force fans, connected to 760 mm Ø flexible force ducting. The intake and return roads are divided with brick walls to minimize leakages, but as soon as pillar extraction commences, one of the return roads is converted into an intake road, leaving one return road that could assist total airflow into the section and could act as an escape route as well. Most of the air is concentrated to flow over the workers and the production machines at the cutting position, into the goaf towards the bleeder road which is normally established at the back of the goaf (Figure 43). The main reason why all the air normally forced to flow over the workers and the machines, through the goaf area, is to remove the dust created by the production process. Secondly, the gas concentrations that is normally present and accumulating inside the goaf, is kept away from the workers and the production machine and to a large extent removed to the bleeder road from where it flows to the main return airways. By doing this the danger of gas related incidents are kept to a minimum. The bleeder road is usually established during the development period and in this case consists of two roads. One of this roads is protected by leaving the walls and one row of pillars intact.

3.2 Discussion.

As with the pillar extraction process, there are no fixed method for ventilating rib pillar extraction. Every mine must design and adjust its own ventilation system to suit its particular conditions and requirements. Many of the methods in use have evolved by trial and error and have been developed to overcome problems experienced with previous methods.

A number of ventilation methods are in use at present and are designed around certain factors which include gas occurrences, geological conditions and mine layout. Important aspects of the various ventilation methods will be discussed in general, and the important factors to be borne in mind when designing a ventilation system will be emphasised.

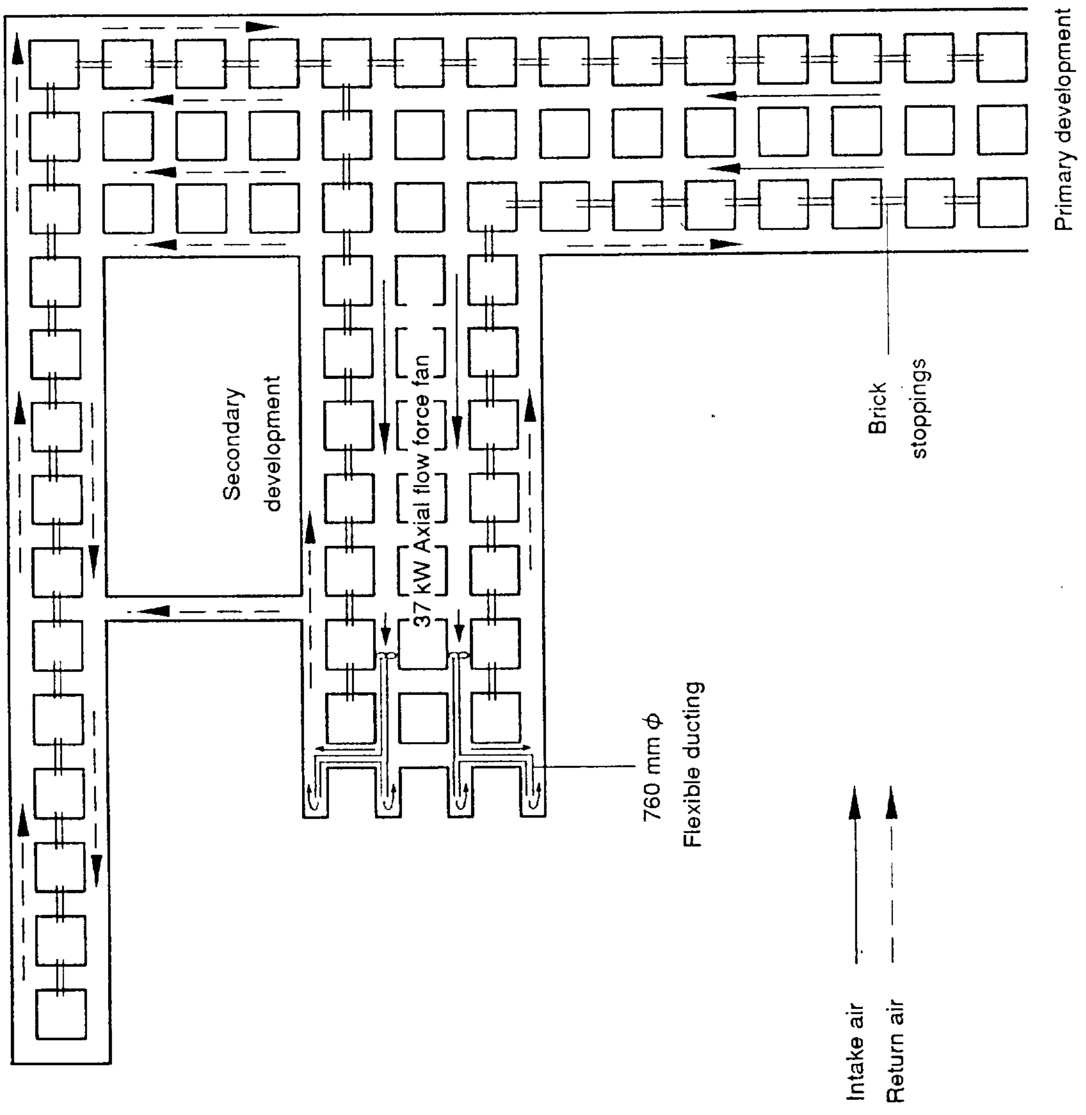


Figure 42: Ventilation layout during four road rib-pillar development.

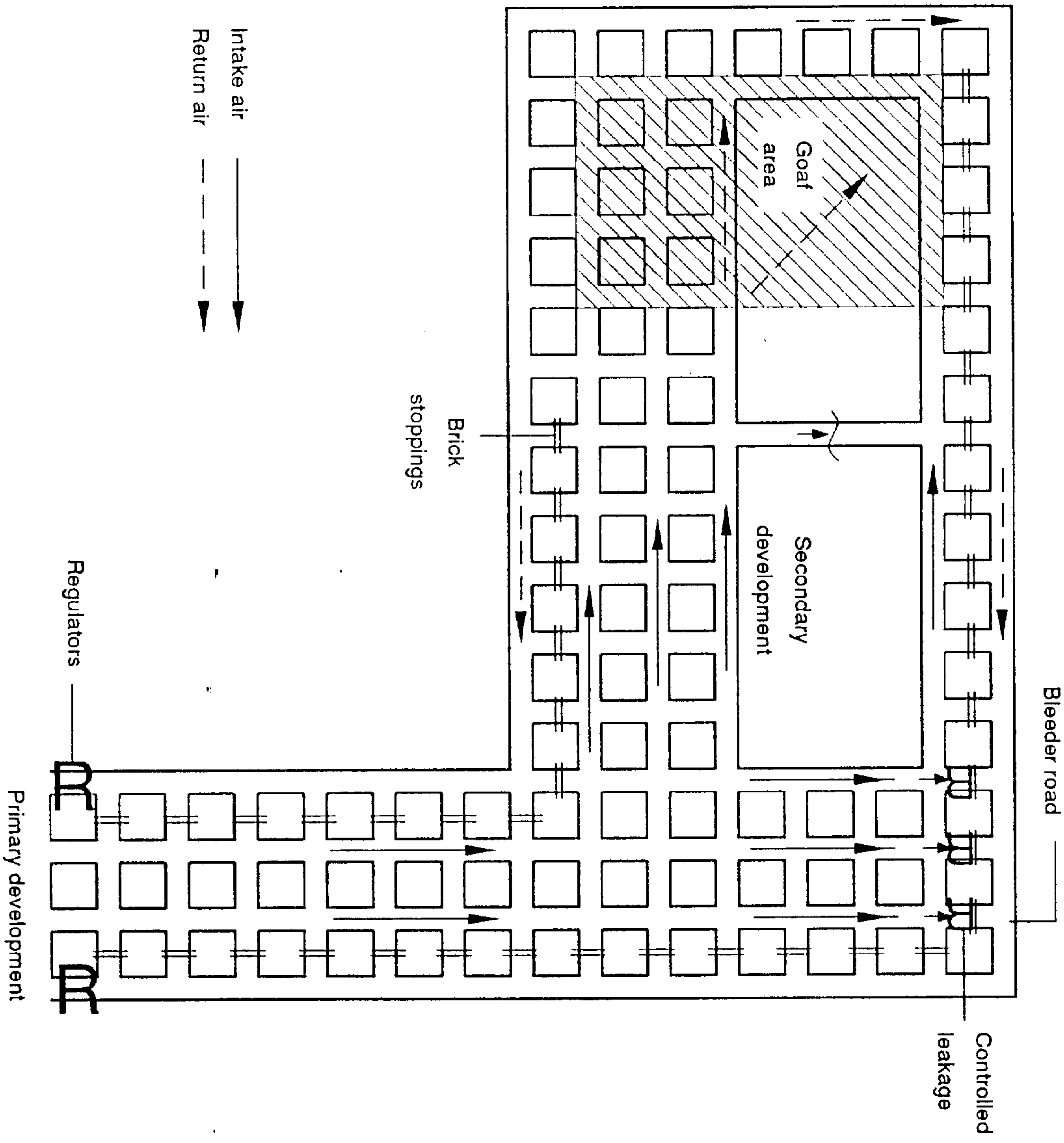


Figure 43: Ventilation layout during extraction of rib-pillar using bleeder road.

3.2.1 Pillar Extraction.

There are basically two methods of ventilating pillar extraction sections, with the goaf area being either ventilated or not ventilated.

Over the goaf ventilation (bleeder road system).

Most of the mines are opposed to the use of bleeder road system because of practical and economical reasons. The objective for using this ventilation method is to ventilate the goaf and to prevent any harmful gas from entering the section. A return airway is established at the back of the goaf which acts as a bleeder road for any gas present inside the goaf area. Difficulties that are experienced with this ventilation method include the following:

a) Establishing a bleeder road either on the side of the goaf or at the back of the goaf.
b) The loss of mineable coal reserves, by having to keep pillars intact for the protection of the bleeder road.
c) Restriction to airflow caused by extensive caving in the goaf area.
d) Potential for spontaneous combustion in the goaf due to low airflow rate through the caved area.

Various methods are used to establish a bleeder road and some mines even utilize return airways of adjacent section where previous planning and section layouts permits. To assist in removing gases and dust from the driver of the machines during the splitting of the pillars, some mines use auxiliary fans with the aid of ventilation ducting.
The bleeder road system has the following advantages:

a) The goaf is kept under constant pressure, preventing gas from the goaf from entering the working area.
b) Fresh air is concentrated on the machine or the extraction position and all dust and blasting fumes are immediately removed into the goaf.
c) Gas concentrations from the goaf, which includes methane gas and carbon monoxide gas, can effectively be monitored in the bleeder road.
d) Depending on the nature and force of the incident, methane occurring inside the goaf may be kept away from the section.
e) Depending on the layout of the section, substandard ventilation walls and structures do not influence face airflow to any great extent.

The volume flows involved in this method of ventilation vary from mine to mine depending on individual circumstances. It is obvious that the more air is flowing through the goaf, the smaller the possibility of any methane related incident in the goaf area or section. However, not all mines have the amount of air available to ventilate such a section in a satisfactory kind of way, and therefore every mine uses its own criteria to determine ventilation requirements. For example, some of the mines supply the minimum allowable volume, others use an approved formula for determining the ventilation requirements, while other mines use the last through road air velocity and the number of auxiliary fans used in the section during development as criteria. Whatever the method used, a few important aspects must be kept in mind when determining the ventilation requirements for any section.

a) Volumes, air utilization figures and air velocities must always equal or exceed the requirements of the regulations as prescribed in the Mines and Works Act, or the standards set in the approved Codes of Practice.
b) Ventilation conditions must create a healthy and safe environment for the workers in the section. This normally ensures high motivation among the workers, which results in higher productivity.
c) Personal experience regarding previous methane related incidents or explosions, must also play a deciding role in determining the ventilation requirements or ventilation system.
d) The ventilation system in use must be easy to control and maintain by production personnel. A system that is difficult to control, will result in no control at all.

Coursing or Splitting Ventilation.

These methods are normally used by mines not using the bleeder road system or over the goaf ventilation methods. From the position of cutting, the air flows alongside the goaf line towards the return roads. The air is either coursed from the one side of the section to the other side, or it splits both ways towards the return airways. Mines exercise this option in different ways and planning is done to suit individual conditions and requirements. Interesting to note that this method is used whenever the pillars are extracted in a 45° angle or when the arrow-head sequence is used. This makes the ventilation aspect easier, because the air always flows against the goaf line towards the return airways, reducing the possibility of gas from the goaf entering the section. Some mines use one or two auxiliary fans to assist in ventilating problem areas.

The advantages and disadvantages of coursing or splitting ventilation:

Advantages

a) No loss of reserves due to the protection of the bleeder roads.
b) Less restriction to airflow, which means that less air might be needed in the section to satisfy the ventilation requirements.
c) Reduced possibility of spontaneous combustion inside the goaf area.
d) No difficulty in establishing a bleeder road and no excessive planning to utilize the return airways of adjacent panels.

Disadvantages

If a methane ignition should occur in the goaf area, the possibility that the flame and\or gases will enter the section, is greater than is the case for the bleeder road systems, endangering the lives of the workers. Special precautionary measures will have to be taken to prevent this from happening.

b) Methane gas or any other harmful gas can flow into the section and accumulate in the section if any of the ventilation structures and controls are not well maintained. This increases the possibility of a methane related incident.
c) Care must always be taken to ensure that sufficient air is flowing across the workers and the machine.
d) The additional use of auxiliary ventilation is sometimes necessary to ensure effective dust suppression and methane control.

3.2.2 Rib-Pillar Extraction

The only difference between ventilating a rib-pillar extraction section and a normal pillar extraction system, is the mining method and layout. This type of section is easier to ventilate because of the flexibility of the section and the way in which the ventilation system can be adjusted to suit changing conditions. There are also two basic methods of ventilating these sections, either with a bleeder road or without.

Over the goaf ventilation (bleeder road system)

In the case of rib-pillar extraction, it is sometimes much easier to establish a bleeder road at the back of the goaf, or to utilize the return airways of another section. As the section and the pillars are developed, the bleeder road is developed simultaneously, or the planning is done in such a manner that a connection can be established into the return airway of an adjacent section. It does unfortunately mean that, in all cases, protection pillars must be left for the protection of the bleeder roads or the return airways. It is, however, much easier to ventilate towards and through the goaf area with this type of section, because of the small areas involved at any one time. This section is divided into small areas and the pillars inside these areas are split and removed, resulting in small goaf areas that have to be ventilated. With every new set of pillars, the bleeding point is moved closer to the cutting positions and in most cases the previous goaf is sealed off.

Most of the mines doing rib-pillar extraction prefer to use this method of ventilation, because of the small amount of ventilation structures involved to direct the air to the required position. The number of roads involved at any one time during the extraction ranges between two and four, depending on the layout of each individual section. Because of this, the air volume flowing over the workers and the machine is sometimes higher than is the case during normal pillar extraction. The air flows freely in these roads towards the goaf and the bleeder road, without requiring extensive ventilation control measures. The other advantages and disadvantages are similar to those mentioned under pillar extraction.

No goaf ventilation

Some mines prefer not to use the bleeder road system for various reasons, including the possibility of spontaneous combustion in the goaf area. When not using a bleeder road or "over the goaf" ventilation, the air flows from the cutting position directly to the return roads. This method is fairly easy to execute, although it means that the ventilation walls have to be kept up to date with the section, as a return airway is required. Because of the number of roads involved, the velocity in the last through road is still reasonably high, which means that any gas emission will be diluted effectively. In the event of methane related incidents in the immediate goaf area, potential problems can be prevented by using auxiliary fans and ventilation ducting to address the problem area. This is also a safe and effective way of ventilating, but it does mean that strict ventilation measures and control must be carried out.

3.2.3 Goaf Related Incidents

Over the past years, numerous incidents which were methane related, or related to spontaneous combustion, occurred in sections exercising pillar or rib-pillar extraction. It was therefore decided to determine whether there is a relationship between the number of incidents that occurred in the goaf areas and the ventilation methods used. Unfortunately it was impossible to obtain all the relevant information, because of incomplete record keeping over the years. Some information was obtained for the period 1986 to 1989 and was of some assistance in establishing a relationship.

According to the reports, 67 % of all reported incidents, were reported by mines using "over the goaf" ventilation or the bleeder road system. The remaining 33 % was reported by mines that were not ventilating the goaf area at all. These incidents include occurrences of spontaneous combustion and methane related ignitions and explosions to blasting or friction. According to these statistics, it appears as if it is safer not to ventilate the goaf area or to use a bleeder road at all, but there could be other explanations for this.

- It is possible that not all the incidents have been reported by the mines, or that record keeping has been neglected, which means that the statistics could be quite different had the records been complete.

It is true, however, that by ventilating the goaf area, sufficient oxygen is supplied to this area to create an explosive air\gas mixture, which could easily ignite when caving occurs. During the caving process, friction might cause sparks which might then ignite the mixture. The fact that the air movement through the goaf is sometimes very slow, can also be the cause of spontaneous combustion because of the supply of oxygen and the inadequate removal of heat. It is evident, however, that even though most cases reported use goaf ventilation systems, very few cases were reported where the ignition or explosion entered the section, causing danger to the workers. Because of the positive flow of air through the goaf, the flame tends to stay inside the goaf or move towards the bleeder road away from the workings, burning up all the available methane in the process.

The situation is different in sections not utilizing the bleeder road option. In a large number of the reported cases, the workers had to be evacuated because of the danger created by the incident and the flame that entered the section. Although the goaf is not positively ventilated, a small amount of oxygen still enters the goaf area and incidents still occur during the mining process.

3.2.4 Recommendations

Mines that carry out total extraction, do so because of various factors such as better utilization of reserves and higher productivity. Increasingly more mines are progressing towards different kinds of stooping and therefore the environmental control officer must have references to assist in planning the ventilation layout of such a section. It is therefore necessary to consider a few points that are essential for the effective ventilation of a stooping section.

In any ventilation design, there are basic rules that apply to ventilation and airflow:

a) For air to flow between two points, there must be a difference in ventilation pressure.
b) The bigger the difference in pressure between these two points, the higher the volume of air that will flow.
c) Air always flow from the high pressure side to the low pressure side.
d) Any resistance to airflow will result in a reduction in the air volume. Restrictions include regulators, ventilation walls, falls of ground, and the natural closure of goaf areas.

Another basic rule, is the fact that air will always follow the shortest route. This is probably the most important rule to remember in the case of stooping ventilation.

Requirements of a ventilation system that should be considered are dust control, gas dilution and control and the prevention of ignitions and explosions. These can only be achieved if ventilation conditions and control are kept up to standard and air volumes supplied comply with or exceed legal requirements.

For mines that prefer to use the bleeder road system, there are certain considerations that should be kept in mind and included during the planning stage.

- The possibility of spontaneous combustion in the goaf area, because of the slow supply of oxygen through the goaf area.
- The availability of an alternative air return route in the event of the goaf closing up during extensive caving.
- Advance planning for the establishment of a suitable bleeder road or the utilization of the return road of an adjacent section. This will make the development process of the section much easier for the mining personnel and will save valuable time.
- The installation of a continuous monitoring system in the return airways that can monitor gas such as methane and carbon monoxide.

Mines that decide not to use the bleeder road system should keep the following aspects in mind during the planning stage.

- Good ventilation flow towards the goaf is essential to prevent any inflow of gas from the goaf area.
- Ventilation control must be well managed to ensure good ventilation flow. One of the mines that was surveyed, is making use of a so called "gas-prefect". This "gas-prefect" is responsible for monitoring the ventilation and the gas conditions in the section on an hourly basis and to take immediate steps if necessary.

An alternative that is worth considering and has worked well on some mines in the past, is the spraying of large amounts of stonedust into the goaf area on a daily basis. This is additional to the installation of stonedust barriers in the section, but it may assist in quenching the flame from an ignition, and thus prevent it from entering the section.

4 PRIMARY VENTILATION

4.1 Controlled Recirculation Of Mine Air.(Meyer,1992)(6)

In this last chapter of this report, a project that was performed on controlled recirculation of mine air is discussed. This project was initiated by one of the South African underground collieries and it involves the recirculation of air inside a ventilation district opposed to the installation of additional costly ventilation systems. Because the re-use of air in an underground coal mine is prohibited by the Mines and Works Act and Regulations, special permission was obtained from the Government Mining Engineer (GME) who included some provisions and rules that had to be adhered to.

After extensive planning, a booster fan was installed at a strategic point in the ventilation district which was supplying six sections with fresh air. The booster fan recirculates 65 m^3/s of return air into the main intake airways, increasing the total volume for this district from 170 m^3/s to 235 m^3/s (Figure 44). Most of this air is carried to the individual sections inside the ventilation district, resulting in an increase in available air volumes.

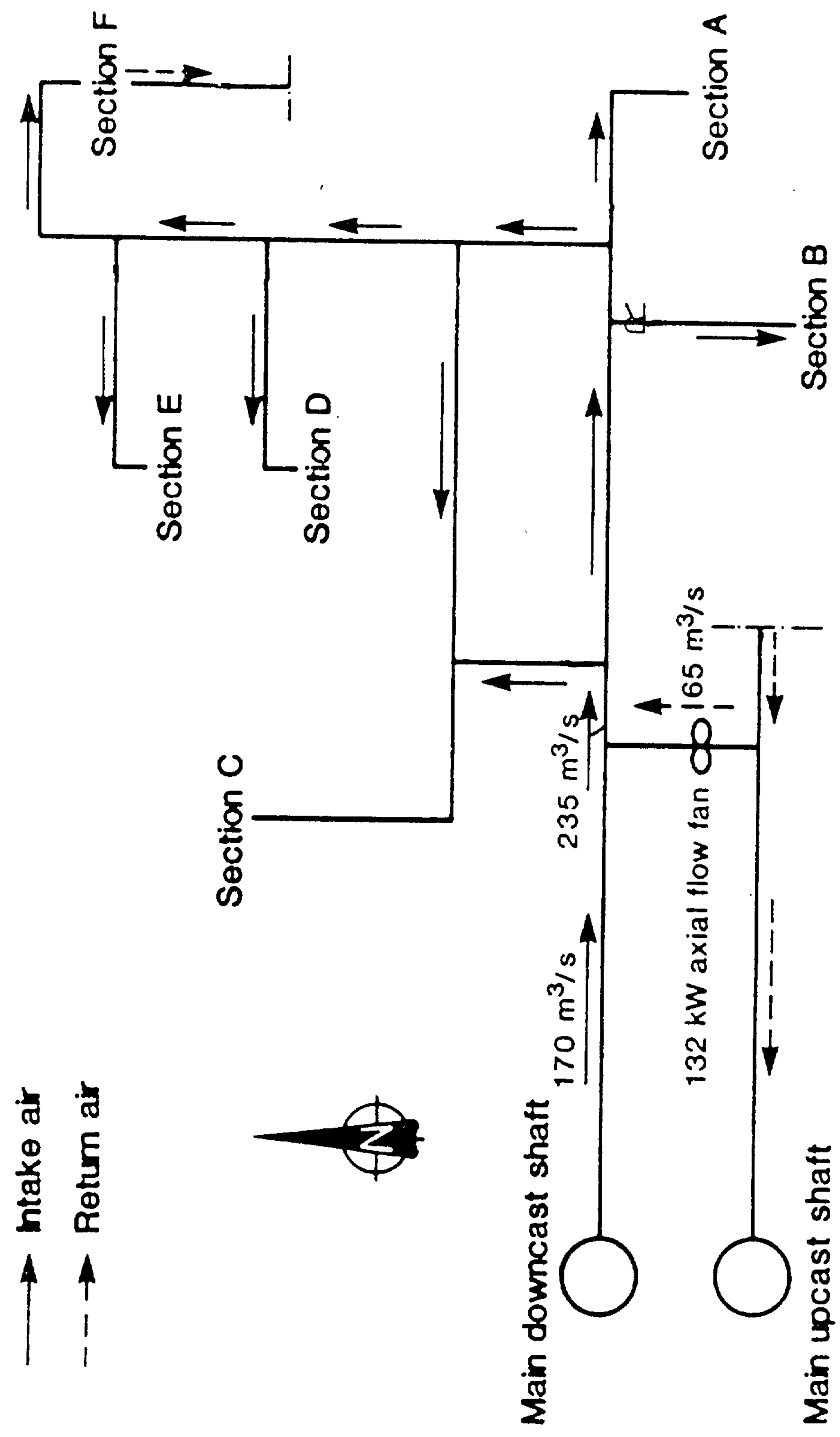


Figure 44: Layout of ventilation district in which air is being recirculated

4.2 Initial Planning

The initial planning of the project consisted of discussions held with the mining and engineering departments, who were responsible for the preparation of the installation site for the booster fan, as well as approving the capital expenditure. Approval from the GME required lengthy discussions and proposals containing certain precautionary measures. Details regarding the underground ventilation conditions and the fan that was to be used, comprised an important part of the proposals. In granting permission for the project, the GME included a few alternative precautionary measures that had to be taken by the mine.

- The air recirculation factor was not to exceed the figure of 37 %.

- A continuous gas and ventilation monitoring system had to be installed in the surface control room, backed-up by a "watchdog" system underground at the recirculation fan to monitor the following conditions:

a) Main intake airways

- Methane and other flammable gases	(%)
- Carbon monoxide	(ppm)
- Air velocities	(m/s)

b) Intake air at the fan (recirculation air)

- Methane and other flammable gases	(%)
- Carbon monoxide	(ppm)

c) Mixture: Fresh air and recirculation air flowing to the sections

- Methane and other flammable gases	(%)
- Carbon monoxide	(ppm)
- Air velocities	(m/s)

Before the project was commissioned, air samples had to be taken by the Air Quality Division of the Department Of Mineral and Energy Affairs to determine whether any radioactive gases were present in the underground atmosphere.

4.3 Safety Measures Taken By The Mine

Apart from the safety measures stipulated by the GME, the mine also introduced a number of safety measures for the safe working of the fan and the project. Apart from several engineering functions which included tripping mechanisms on the fan in case of emergency, the environmental control department initiated the following safety measures:

- The installation of access doors (tunnel doors) to provide access to the fan for inspection purposes. These doors were to be kept locked and only appointed persons were authorized to use this entrance.
- Self closing doors installed in front of the fan in the intake air. These doors would close automatically in the event of the failure of the fan, preventing any air leakage from the intake airways into the return airways.
- As a back-up arrangement, a set of ventilation doors was installed on the intake side of the fan in the return airway. These doors were to be closed if the self-closing doors on the intake side of the fan failed to close in the event of a fan failure.
- The recirculation fan was never to be stopped manually without special permission and without prior arrangements with the environmental control department.
- A printout of the readings from the continuous monitoring system, was to be given to the environmental control department on a daily basis.

These measures as well as other instructions, were compiled into a special standard instruction prepared by the mine for the project.

4.4 Commissioning Of The Fan

After a planning stage of approximately 18 months, a fan (132 kW, shaft driven, axial flow force fan, 1530 mm in diameter) was ordereds from Airtec Howden and installed and commissioned after 16 weeks by the same company. The total cost for the fan and the installation was R205 000. The recirculation fan was installed inside a holing through the barrier pillar, between the main intake and main return airways. The floor of the fan chamber was covered with concrete with a strength of 30 MPa and the surrounding walls consisted of double walls spaced at 200 mm filled with concrete inside the two walls. The motor of the fan was placed in fresh air and the shaft of the fan passed through a wall towards the impeller of the fan (Figure 45). The fan motor was connected to an alarm system which is activated when the fan stops.

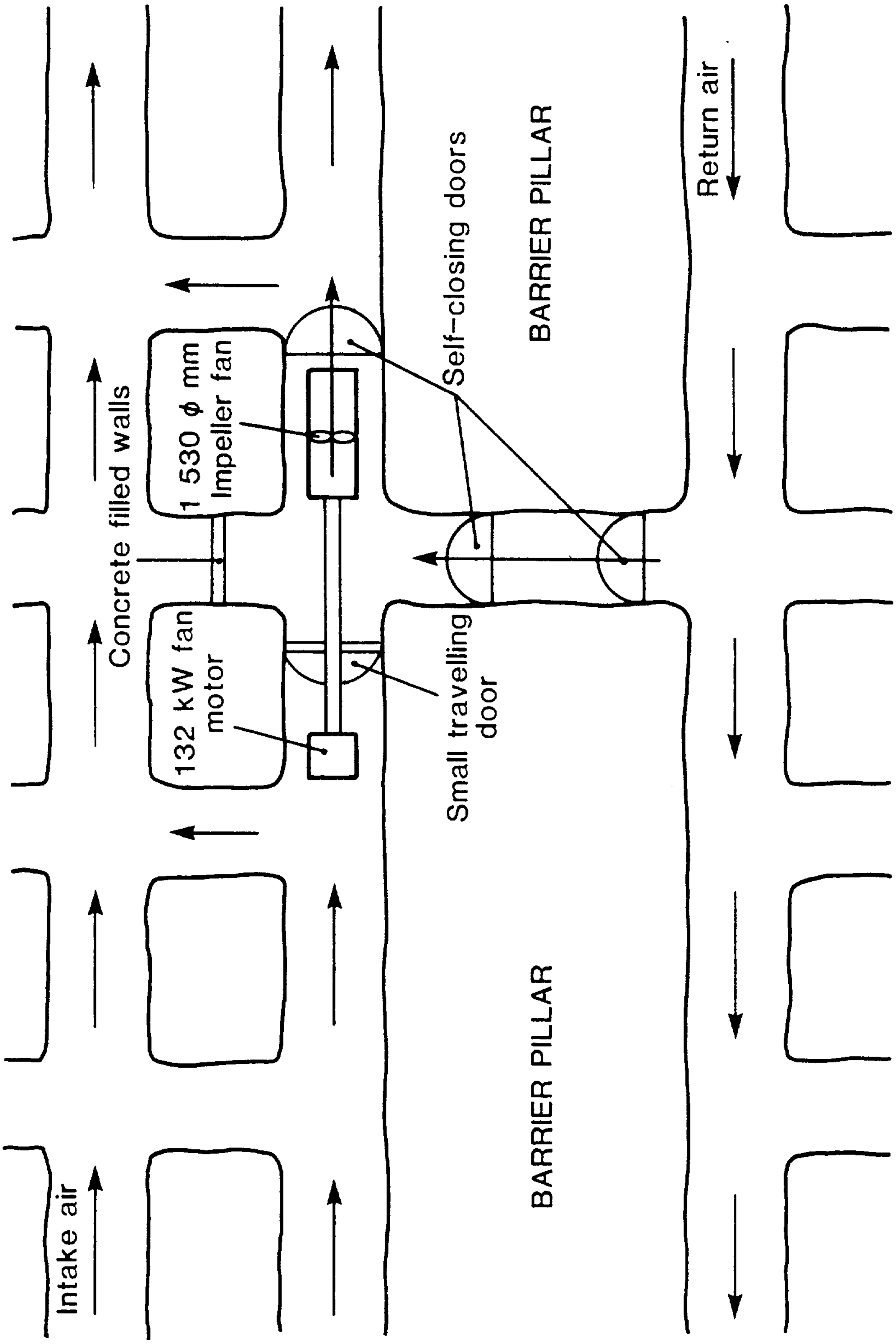


Figure 45: <u>Layout and position of recirculation fan.</u>

4.5 Initial Problems Encountered And Gas Readings Monitored.

During the initial period of the operation of the fan, some problems were encountered, which could be expected with a project of this nature.

- Excessive vibration caused the fan to trip out on four occasions. The necessary adjustments were made and the problem solved.
- The alarm on the Carbon monoxide monitor in the main intake air was activated on a few occasions and caused the fan to trip. Investigations showed that a diesel machine was working in the vicinity and the fumes activated the Carbon monoxide monitor.
- The fan also tripped twice because of high temperature readings from the bearings. It was found that there was an excessive amount of grease inside the casings.

To date, no increase in the gas levels has been monitored by the continuous monitoring system situated around the fan position. Additional gas surveys using different instrumentation, are being conducted on a regular basis to check the reliability of the continuous monitors, and results are consistent for all surveys to date.
Surveys that were carried out by the Air Quality Division of the DEMA office, showed that there were no radioactive gases present in the underground workings. Follow-up tests are done on a regular basis by the department.

The introduction of the booster fan had a significantly positive influence on the available air volumes, but also had a negative influence on the ventilation structures and walls as the pressure exerted on the walls increased. The actual effectiveness of the booster fan had to be determined, as well as the influence of the recirculated air on the quality of the air for health purposes. COMRO (now the Division Of Mining Technology of the CSIR) was involved in determining airborne dust levels and the possible accumulation of dust due to the recirculation of air. Tracer gas techniques was also used to determine the distribution and utilization of the recirculated air using SF_6 as the tracer gas.

4.6 Determining Airborne Dust Levels In Recirculation Circuit.

A dust survey was carried out to measure the respirable dust concentrations in the air recirculation system, to determine the effect on the quality of the intake air to the sections. During the survey, three sections were producing: a short wall of 125 metres where a shearer was operated, and two bord and pillar sections, one using conventional mining equipment and the other a Joy continuous miner (CM). The short wall and the CM bord and pillar development sections were 2500 metres from the recirculation fan and the conventional bord and pillar section 900 metres.

4.6.1 Instrumentation

Eight Hund TM Data samplers were used to measure real time respirable airborne dust concentrations, and a Gillian personal gravimetric sampler in parallel with one of the Hunds to enable the Hund readings to be converted to mg/m^3. This was necessary as it has been found that the Hund does not give the equivalent of the gravimetric dust concentration on a 1:1 basis (Appelman, 1991)(7).

4.6.2 Method

All dust samplers were started simultaneously in the return air near the recirculation fan and operated in parallel for 10 minutes to determine their bias (Appelman, 1991)(7).

The Hunds were then moved to different positions to measure the concentrations in the intake to the area, intake to the recirculation fan, the mixed intake air to the sections near the fan and near one of the sections, as well as in the return air from two of the sections (Figure 46).

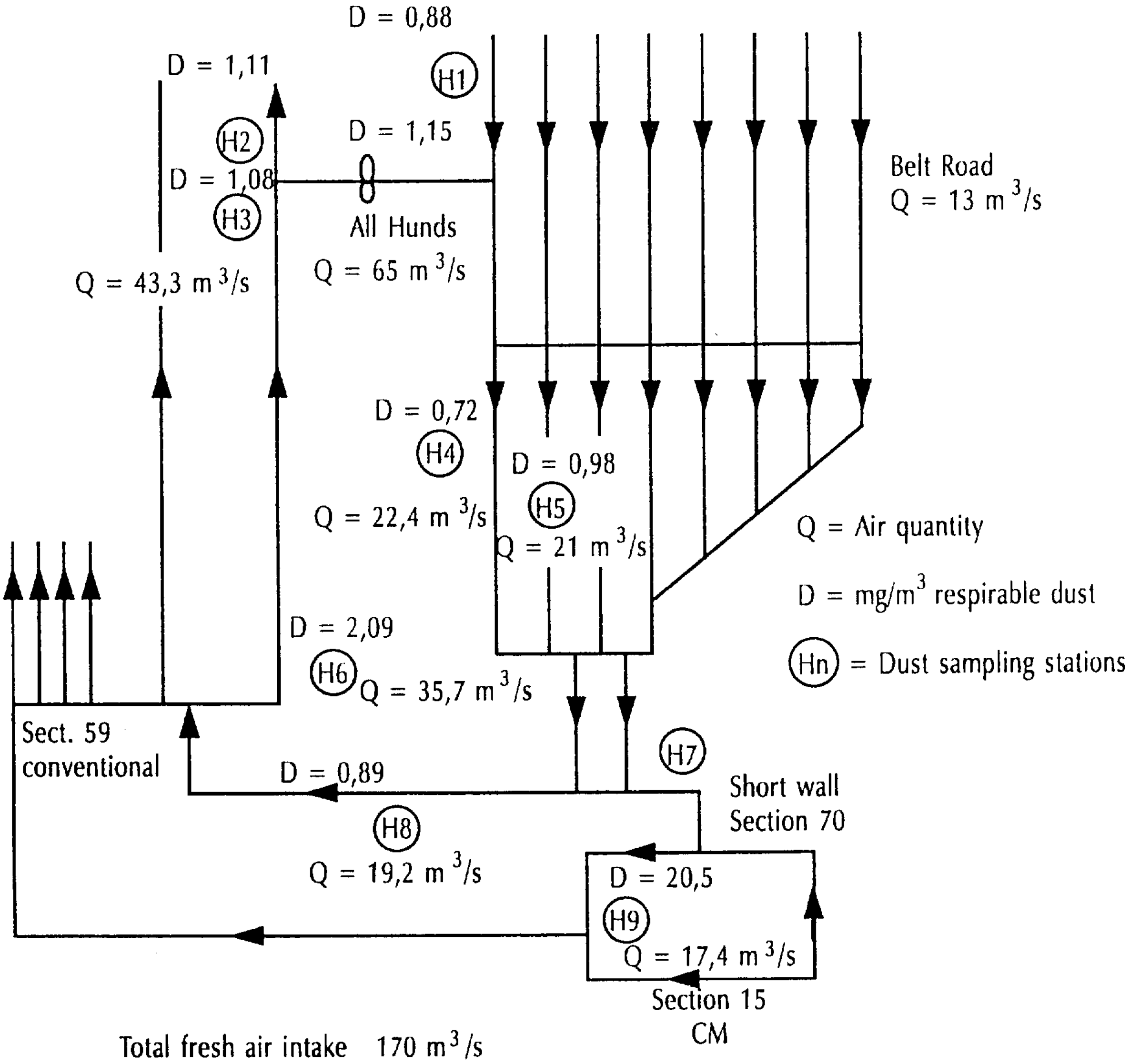
Dust samples were taken for between 30 to 70 minutes, after which all instruments were operated for seven minutes in the return of the fan where the air had not yet mixed with fresh air, leaving one Hund in the intake to the fan.

The last seven minutes were sampled to determine the possible effect of the recirculation fan on the dust concentration.

Air quantities were measured at the sampling positions by the mine's Environmental Control Department. The sampling positions are described in Table 11 and shown in Figure 46.

TABLE 11: Dust sampling stations

H1 = Fresh air intake to sections.
H2 = Return air past the intake to the recirculation fan.
H3 = Intake air to recirculation fan.
H4 = Mixed air in nearest roadway.
H5 = Mixed air in second roadway.
H6 = Return from conventional development. Section 59 (approximately 900m from recirculation fan).
H7 = Intake to section 70.
H8 = Mixed air intake to sections after dust decay for approximately 900m (@ 2 m/s = 7,5 mins).
H9 = Return from shortwall, Section 70 (approximately 2500m from the recirculation fan).



Total fresh air intake 170 m^3/s

Total mixed air 235 m^3/s

Total return air 210 m^3/s

Leakage 25 m^3/s (difference between intake and return air)

Recirculated air 28 % of the mixed air (65 m^3/s of 235 m^3/s)

Figure 46: Sampling positions of all dust samplers.

4.6.3 Results

Hund 2 sampled parallel with the gravimetric sampler and its results are therefore used as the basis for the other Hunds, according to the bias determined during the initial parallel sampling of the Hunds. The readings were then normalized to Hund 2, and the average concentrations for each of the positions surveyed are given in Table 12, using a factor of 1,5 to convert Hund readings to mg/m^3.

TABLE 12: Dust sample results.

INSTR. NO	SAMPLING POSITIONS	HUND READINGS	EQUIVALENT mg/m^3
H1	:FRESH AIR	0,6	0,9
H2	:RETURN AIR AT FAN INTAKE	0,7	1,1
H3	:INTAKE TO FAN	0,74	1,1
H4	:MIXED AIR 1	0,5	0,7
H5	:MIXED AIR 2	0,7	1,0
H6	:RETURN SECTION 59	1,4	2,1
H7	:INTAKE SECTION 70	DATA LOST DUE TO MALFUNCTION	
H8	:INTAKE SECTION 59	0,7	1,0
H9	:RETURN SECTION 70	13,7	20,5
6 HUNDS	:RETURN FROM FAN	0,77	1,2

4.6.4 Discussion

For this discussion, the worst case is assumed initially, where each of five sections simultaneously discharge 20 mg/m^3 of respirable dust into 19 m^3/s of ventilating air.

Without recirculation, the dust concentration in 170 m^3/s of intake air is 0,9 mg/m^3.

Assuming no settling of dust, the weighted average respirable dust concentration in the return air theoretically is:

$$\frac{75\ \text{m}^3/\text{s} \times 0{,}9\ \text{mg/m}^3 + 95\ \text{m}^3/\text{s} \times 20\ \text{mg/m}^3}{75\ \text{m}^3/\text{s} + 95\ \text{m}^3/\text{s}} = 11{,}57\ \text{mg/m}^3$$

With 65 m^3/s recirculated, the dust concentration in 235 m^3/s of mixed air is then:

$$\frac{65\ m^3/s \times 11{,}6\ mg/m^3 + 170\ m^3/s \times 0{,}9\ mg/m^3}{65\ m^3/s + 170\ m^3/s} = 3{,}9\ mg/m^3$$

During the survey, however, the activities in the sections surveyed generated 20,5 and 21,5 mg/m^3 respectively, while one section was not monitored and the other sections were not in operation. In spite of occasional concentrations exceeding 100 mg/m^3 in the return from the short wall, the dust concentrations at the intake to the recirculation fan showed a steady 1,1 mg/m^3, indicating that most of the dust created in the sections settled out or was diluted in the return airway system.

Dust concentrations measured in the mixed intake air in the two roads near the recirculation fan were adjusted for the other six roads, which carried fresh air, to arrive at an average concentration for the total air intake.

In this case the average was, however, still 0,9 mg/m^3, due to the low dust concentration in the recirculated air (1,1 mg/m^3).

One of the major factors contributing to the decay of the dust created in the sections was probably the distance between the dust source and the recirculation fan, which was approximately 2500 m for Section 70 and 900 m for Section 59.

The test to determine the effect of the fan on the dust concentration shows no significant difference between the dust concentrations before or after the installation of the fan (1,1 mg/m^3 and 1,2 mg/m^3 respectively).

4.7 Determining The Distribution Of The Recirculated Air Using Tracer Gas Techniques.

To determine the effectiveness of the controlled recirculation project with regard to air utilization, tracer gas techniques were used to measure the actual distribution of the recirculated air. By doing this the amount of airflow increase to the individual sections as a result of the recirculation, could be determined.

4.7.1 Instrumentation

The instrumentation used for these tests consisted of a 450 ml gas bottle filled with SF_6, 10 ml glass vac-u-tainers, plastic plungers fitted with hypodermic needles and stopwatches to time the sampling intervals. An SF_6 analyzer situated in a surface laboratory was used to analyze the samples.

4.7.2 Sampling and test Procedure

The SF_6 was sampled by inserting the 10 ml vac-u-tainers into the plastic plunger. The hypodermic needle inside the plunger punctured the rubber stopper on one end of the test tube. As the stopper was punctured, the ambient air entered the test tube and sampling was complete. Withdrawing the test tube from the plunger resealed the stopper, preventing the sample from escaping. Samples were taken at predetermined intervals and the test tubes were marked with information pertinent to the sampling procedure. The samples were brought back to the laboratory for analysis.

The ventilation district that was affected, was divided into small areas. Each area was treated individually, with gas being released on the intake side of the recirculation fan for a certain period of time. Sampling positions were determined beforehand and the sampling of the ambient air proceeded at predetermined times. Because SF_6 is colorless, odourless and behaves in a similar manner to normal air, the air travel times had to be determined very accurately, to ensure that contaminated air was sampled. After four weeks of field work, sufficient information had been obtained for calculations to determine the effect of the recirculation on the airflow volumes (Meyer, 1992)(6).

4.7.3 Results

Figure 47 shows the schematic layout of the ventilation district with the individual volumes of SF_6 flowing into the sections, and also indicates the various SF_6 sampling positions used. The results from position (1) indicated that none of the recirculated air was spreading into this branch. Three checks were subsequently carried out giving the same results. This sampling position is therefore not discussed further in this report.

Table 13 gives a summary of the results calculated for all the sections that was involved in the exercise. The final recirculated volumes are compared with total air volumes flowing into the sections at the same position as measured by the environmental control personnel.

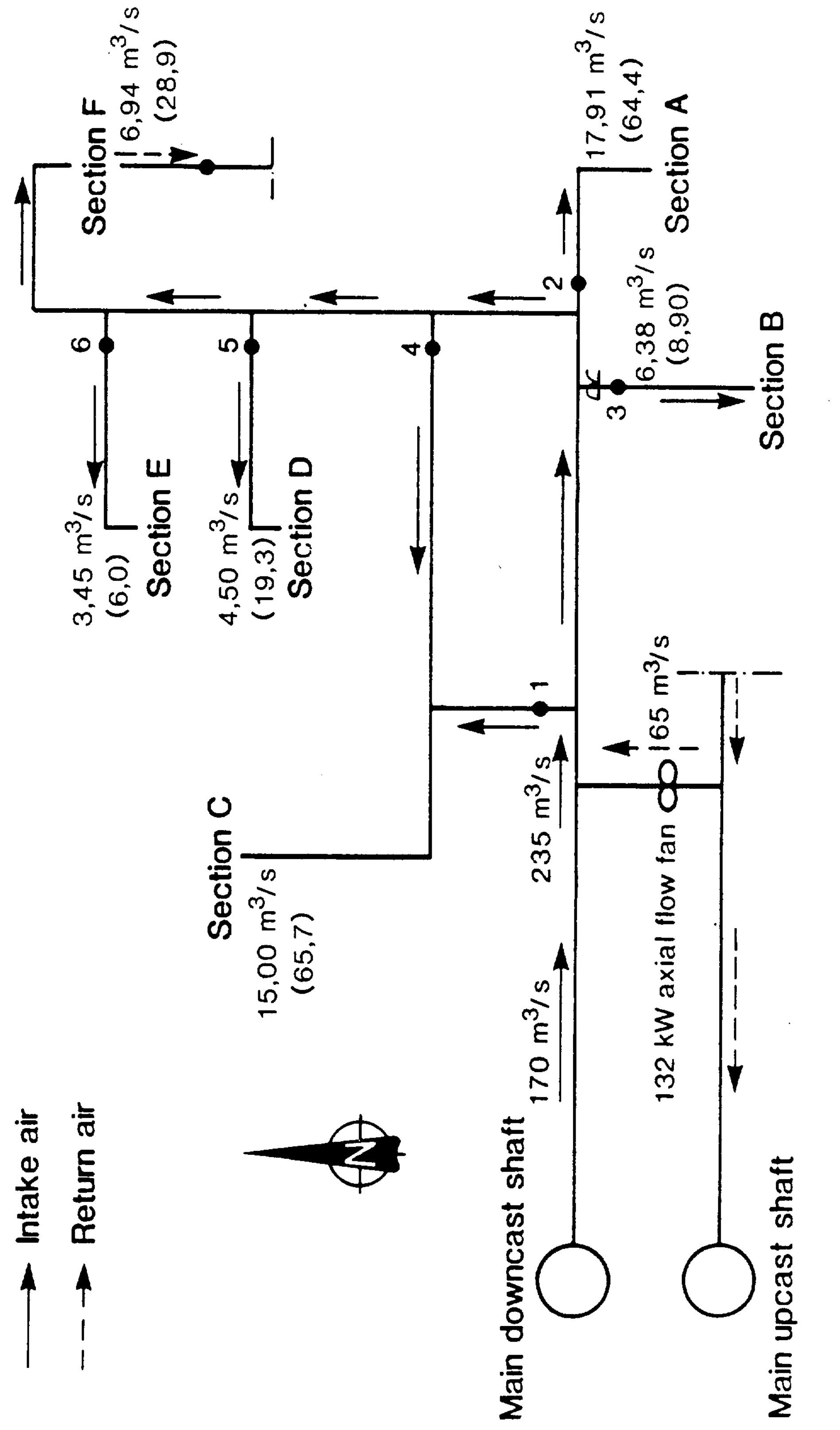


Figure 47: Distribution of recirculated air to various sections.

TABLE 13: Summary of SF_6 sampling results.

SECTION NUMBER	RECIRCULATION AIR VOLUME m^3/s	TOTAL MEASURED AIR VOLUME m^3/s
SECTION A	17,91	64,4
SECTION B	6,38	8,90
SECTION C	15,00	65,7
SECTION D	4,50	19,3
SECTION E	3,45	6,0
SECTION F	6,49	28,9

4.7.4 Discussion of results

The objective of recirculating the mine air was to increase the available air volumes to the sections without any changes to the existing airways. By using the tracer gas techniques, the utilization of the recirculated air could be determined and therefore be expressed as a percentage.

With the introduction of the booster into the system, the pressure differences across the ventilation structures increased, resulting in a higher leakage factor. From the 65,0 m^3/s of air recirculated by the fan, a total of 54,18 m^3/s reached the intake airways of the sections. This means that 10,82 m^3/s of the 65,0 m^3/s was lost due to leakage across the structures and due to airway resistances. This gives an air utilization figure of 83,35 per cent, which is high, considering the large number of ventilation structures involved as well as the long air travel distances.

The dust investigations showed that a project of this nature does not create a health hazard for the underground workers. The continuous monitor systems had not recorded any increase or accumulation of gases found in the underground workings as a result of the recirculation of air.

This project proved to be very successful and it showed that the use of recirculated air can be a very feasible and economical short term solution for ventilation flow problems, as opposed to the use of additional ventilation shafts.

5 CONCLUSIONS

The information in this report covers the basis of all ventilation systems used in the coal mining industry. The basic principles and answers that were highlighted in the research work can be used to a great extent to develop a ventilation system that will be suitable to combat dust and methane inside a heading.

The results described in this report only cover a very small aspect of heading and section ventilation and show that more work is necessary to determine the optimum ventilation system. It is also true that since each mine has its own circumstances and conditions, ventilation systems must be adapted for particular mines.

Areas requiring further investigation, either by a research institute or the mines themselves, include the use of freestanding fans with different kinds of extraction systems on the production machines. Another area is the use of controlled recirculation of mine air. While some work has already been done, additional work should be done to investigate the viability of recirculating air inside a coal heading.

It is hoped that this report will assist Environmental Control and mining personnel on the mines in that all useful research information is available in one document and that this information can be used as guidelines when designing new, or modifying current ventilation systems.

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