A Survey of Booster Fan Use in Underground Mines.

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INTRODUCTION

Booster fans are used extensively in underground mines throughout the world. Indeed, a number of mining organizations have indicated that there is no other practicable means of ventilating their mines. In the United States, many metal and non-metal mines employ booster fans. The conditions under which these fans may operate are governed by the Code of Federal Regulations 30, Sections 57.5 and 57.21. The latter section refers to gassy metal and non-metal mines, and distinguishes clearly between main fans, which must be installed on surface and booster fans. For underground coal mines, the corresponding regulations are contained in CFR 30, Sections 75.300 through 75.330 (Subpart D). Here again, main fans are required to be installed on surface, but no reference is made to booster fans. This is interpreted widely as disallowing the use of booster fans in American coal mines.

One of the overall aims of this project is to investigate the manner in which booster fans are used in U.S. metal and non-metal mines, and in all forms of underground mining internationally. The rationale behind the effective ban on booster fans in U.S. coal mines is to be examined, together with the advantages and potential hazards that may be associated with the use of such fans in coal mines.

As an initial phase of the project, a major survey of booster fan usage was undertaken involving 13 countries, 758 mines and 1252 booster fan installations. This paper reports the results of the survey and the inferences that may be drawn from its findings.

SCOPE OF SURVEY

A questionnaire was designed in such a way as to elicit not only where booster fans were in use, but also how and why they were used, or not used, by the respondent companies. The questionnaire is reproduced in Appendix I. It contained four main sections. Section A requested general information concerning the type of mining and whether or not booster fans were used. Section B was to be completed only by companies who used booster fans, and sought technical information for the fans in addition to details of any monitoring equipment that was used. This section also enquired into the reasons for installing booster fans and the factors influencing the choice of fan location. Section C was completed only by those companies who did not use booster fans, and sought to establish the reasons for not employing such devices. Section D was to be completed by all companies and was intended to monitor the perception of the respondents to the application of booster fans.

In order to provide a common understanding of the term, the front cover of the questionnaire gave the definition of a booster fan as ...one that handles the through-flow ventilation circulating around one or more districts of a mine, and should be distinguished from auxiliary fans that are used in conjunction with duct systems to ventilate headings.

RESPONSE TO SURVEY

A total of 502 questionnaires were sent out. Of these, 43 were returned from mines that were no longer fully operational. Of the 459 remaining, 163 were returned, properly answered. A few others were disregarded because of inadequate completion. Hence, the response rate was 163/459 or 35.5 per cent. This was considered satisfactory for a technical survey encompassing a number of countries.

Some of the responses gave duplicate data. This occurred when the head office as well as individual mines of a company returned questionnaires. All of the returns were screened carefully to avoid such duplication. This brought the number of effective returns down to 127, representing 758 mines and 1252 booster fan installations.

A breakdown of the returns in terms of country of origin and mineral type is given in Table 1.

The countries denoted as "Others" are those from which an insufficient number of questionnaires were returned to form a separate grouping. However, they represented a total of 227 mines or 30 per cent of the mines reported and could not be ignored. They have, therefore, been grouped together. The countries represented in this category were Austria, India, Ireland, Mexico, New Zealand, Turkey, West Germany and Zimbabwe.

ANALYSIS OF RESULTS

Each question and alternative choice on the questionnaire was given a code number and the complete set of data keypunched into a computer file. This file then provided a base data bank that could be searched for each category requiring analysis. It should be understood that the data reported in this paper have been extracted from the questionnaires that were returned and, in no way, purports to represent all of the mines in any one category or country.

Section A

The data from Section A of the questionnaire was used to compile Table I. The number of mines in each category using booster fans is illustrated on Fig. 1 as a percentage of mines in that same category. None of the 92 coal mines who responded from the U.S. nor the 28 coal mine respondents from Australia reported the use of booster fans. In contrast, the 5 coal mines reported from Canada and the majority of the 170 coal mines in the United Kingdom employed booster fans.

For most of the analyses, the metal and non-metal groups have been combined. Figure 1 shows that although 40 per cent of the metal and non-metal mines reported in the US employ booster fans, this still lags behind Canada (85 per cent), South Africa (100 percent), Australia (50 percent) and other countries (65 per cent). There were no significant differences in the range of stoping methods between the mines of the U.S. and those of most other countries. Hence, this analysis seems to indicate a reluctance by American metal and non-metal mine operators to employ booster fans as freely as other countries.

Section B

This section, in the main, was concerned with the planning and technical data of booster fans currently in operation. Fan specifications reported by the respondents are reproduced in Table 2 and in Figures 2 through 6. Where any country does not appear on the histograms, the information from that country was considered inadequate for separate analysis.

Booster fan pressures:

Figure 2 indicates the average pressures developed by booster fans for coal and metal/non-metal mines. Table 2 gives the lowest and the highest fan pressures reported in each group. The logic of the algorithm used to determine the mean fan pressure for each group was as follows

(i) For each individual return find the arithmetic mean of the reported pressure range.
(ii) Multiply that mean value by the number of booster fans reported in the same questionnaire.
(iii) Sum the weighted means for all the mines in that category.
(iv) Divide the sum by the total number of booster fans in that group.

Figure 2 shows that coal mines in the U.K., South Africa and other countries report excellent agreement in the average booster fan pressures at 3000Pa (approximately 12 inches w.g.) The U.S. and Australia do not appear in this comparison as neither country reported any booster fans in their coal mines. However the Canadian coal mines reported significantly lower booster fan pressures, giving a weighted average of 1890Pa (7.6 in w.g.)

For metal and non metal mines, the U.S., Canada and Australia all produced average booster fan pressures lying between 700 and 1200 Pa (2.8 and 4.8 in w.g.). However, the gold mines of South Africa dominate Fig. 2 with an average booster fan pressure of almost 3,500 Pa (14 in w.g.).

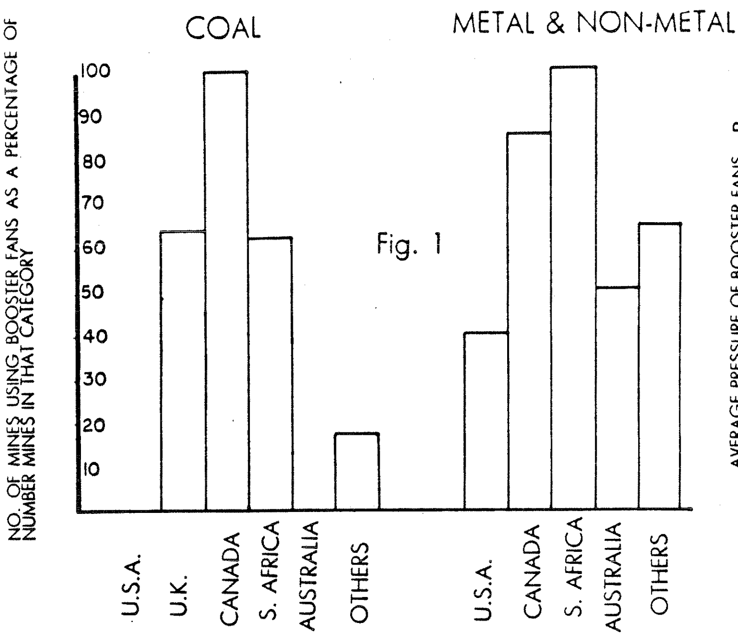
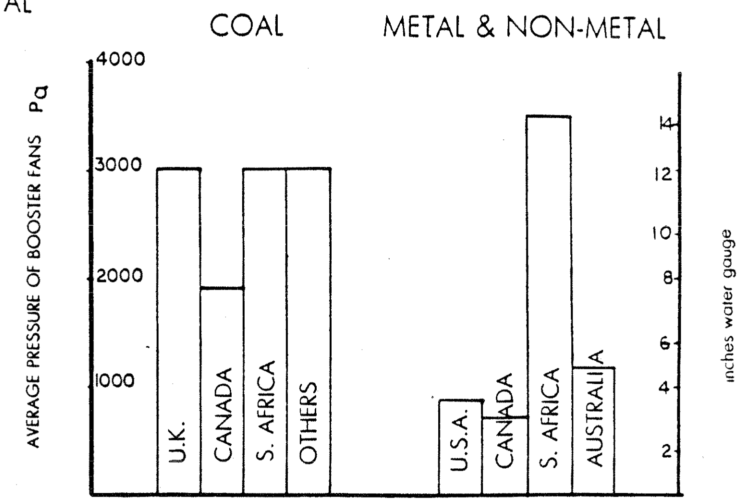


Fig. 1

Fig. 2



COUNTRY	COAL	METAL	NON-METAL	TOTAL
United States	92	65	30	187
United Kingdom	172	2	1	175
Canada	5	48	6	59
South Africa	24	40	4	68
Australia	28	14	0	42
Others	207	2	18	227
TOTALS	528	171	59	758

TABLE 1. Number of mines represented in returned questionnaires.

	No. of Mines	Mines using boost-ers	% mines using boost-ers	No. boost used	Pressure Range		Average Pressure		Airflow Range		Average Airflow		Diam. Range		Average Diameter	
					Pa	in.w.g.	Pa	in.w.g	m^3/s	kcfm	m^3/s	kcfm	m	inches	m	inches
U.S.A. coal metal non-met	92 65 30	0 30 8	0 40.0	0 122 34	125-4980 25-2988	0.5-20 0.1-12	978 877	3.93 3.52	3.5-132 3.7-35.1	7.4-280 7.8-74.4	22.8	48	0.30-2.0 0.25-2.1	12-79 10-83	0.96 1.04	38 41
U.K. coal metal non-met	172 2 1	110* 1 1	64.0 67	135 5 4	210- 900 500-1500	0.84-3.61 2.0- 6.0	3000	12.0	10 -55 10 -40	21.2-116 21.2 -85	75	159	1.20-1.50	47-98	1.85 1.5 1.2	73 59 47
S.Africa coal metal non-metal	24 40 4	15 40 0	62.5 100 0	100 231 0	850-7500	3.4-30	3000 3481	12.0 14.0	100-300 10-300	21.2-636 21.2-636	155 110	328 234	0.75-3.0 0.75-3.0	30-118 30-118	1.85 1.88	73 74
Canada coal metal non-met	5 48 6	5 40 6	100 85.2	5 293 65	622-2988 25-2490 125-1494	2.5-12 0.1-10 0.5- 6	1892 715	7.6 2.9	47-188 2-118 2- 34	100-398 5-250 4- 74	96.4 240.5	204 52	1.2-1.5 0.3-2.1 0.4-1.7	47-59 13-83 14-66	1.36 1.06	54 42
Australia coal metal non-met	28 14 none reported	0 7	0 50	0 134	249-2000	1.0-8	1172	4.7	5-220	11.7-466	38.6	82	0.6-3.6	24-142	1.28	50
Others coal metal non-metal	207 2 18	35 2 11	16.9 65	78 10 36	187-5881 196-1892 392-3431	0.7-24 0.8-7.6 1.6-14	2998	12.0 2.2 7.7	2-200 12- 68 17- 83	3.4-424 26.5-145 35.2-177	19.5	41	0.8-2.5 0.9-1.9 0.4-0.9	33-98 37-77 35-16	1.11	44 66 26
TOTALS	758	311	41	1252												

Table 2. Fans Specifications Reported

Booster fan airflows:

The average airflows passed by the booster fans were also weighted according to the number of fans reported in each return. The results are shown on Fig. 3. In both coal and metal/non-metal mines, South Africa reported the largest airflows through booster fans. In the metal/non-metal category, the US and Canada again report the lowest booster fan airflows, in the range 23 to 25 m^3/s (49 to 53 kcfm), compared to South Africa's average value of 110.5 m^3/s (234 kcfm).

Diameters of booster fans:

Figure 4 shows the weighted mean diameters of the impellers of booster fans. In coal mines, the booster fans of the U.K. and South Africa have the same average diameter of 1.85m (73 inches), with Canada producing an average value of 1.36m (54 inches)

In the metal category, South Africa again dominates, giving a mean booster fan diameter of 1.88m (74 inches), compared with U.S. and Canadian values of slightly over 1m (39 inches).

It is clear from Figs.2,3 and 4 that the booster fans used in the metal/non-metal mines of North America are smaller and have considerable lower duties that in the mines of other countries. This suggests a different strategy in the planning and utilization of booster fans in the U.S. and Canada. This is confirmed by comments written on a number of returned questionnaires. It would appear that in North America, booster fans tend to be employed very locally for the control of airflow through individual stopes. However, booster fans in other countries are also planned as an integral part of the overall ventilation system, and enhance airflows in complete districts or sections of the mine.

Monitoring:

Figures 5 and 6 indicate the level of monitoring on booster fans in coal mines and metal/non-metal mines respectively. Booster fans in the coal mines of the United Kingdom are fitted with all the monitors listed in the questionnaire, namely airflow, fan pressure, vibration, temperatures of bearings, smoke and mine gases, - the monitors providing signals both locally and at remote control centers. Three out of the five coal mines reported from Canada have boosters fitted with a full range of monitors.

Figure 6 shows the comparison of booster fan monitors in metal/non-metal mines. Most boosters in the gold mines of South Africa are fitted with transducers for fan pressure, vibration and bearing temperatures. Surprizingly, there were very few smoke detectors and no airflow monitors reported on South African booster fans.

The degree of booster fan monitoring on American and Canadian metal/non-metal mines is dismally low. Indeed most of the returns from these countries reported no monitors of any kind on booster fans, apart from an occasional manual measurement of airflow. This confirms the conclusions of the previous section - that is, booster fans in North America tend to be utilized merely as airmovers to enhance airflows very locally, while booster fans in the coal mines of the U.K. and the gold mines of South Africa are carefully planned and engineered installations. As the overall ventilation systems in those countries are more dependent on boosters, it is required that they have a high degree of reliability and that any malfunctions or conditions that may develop into a hazard are detected at an early stage - hence, the high level of monitoring.

Location of booster fans.

The primary factor in selecting a site for a booster fan is, of course, that is must achieve the required enhancement of airflow within the ventilation system. Network analysis programs may be used to investigate alternative locations for the fan and the corresponding airflow distributions and operating costs.

Having chosen the general location within the ventilation network, other factors such as minimizing leakage or avoiding transportation routes must be taken into account before selecting the precise site for the fan.

Figures 7 and 8 illustrate the replies to question 6 on the questionnaire. The respondents were asked to prioritize three factors to be considered during site selection for a fan, using 1 as the highest priority. For the analysis of the response to this question, and others that required orders of priority, no weighting on the basis of number of mines or boosters was carried out. The reason for this was that 'order of priority' questions were more subjective and dependent upon the experience of each individual. However, many respondents left some boxes empty indicating that those corresponding choices were of little relevance at their mine or group of mines. To handle this situation, the following algorithm was employed for each alternative, and for each category of mines:

(i) find the arithmetic mean of the priorities chosen by the respondents for each alternative choice, ignoring the blanks.

(ii) Determine a "relevance factor", defined as the

$$\frac{\text{number of responses to that choice}}{\text{no. of returns in that category}}$$

(iii) A "Priority Rating" was then calculated as

Fig. 3

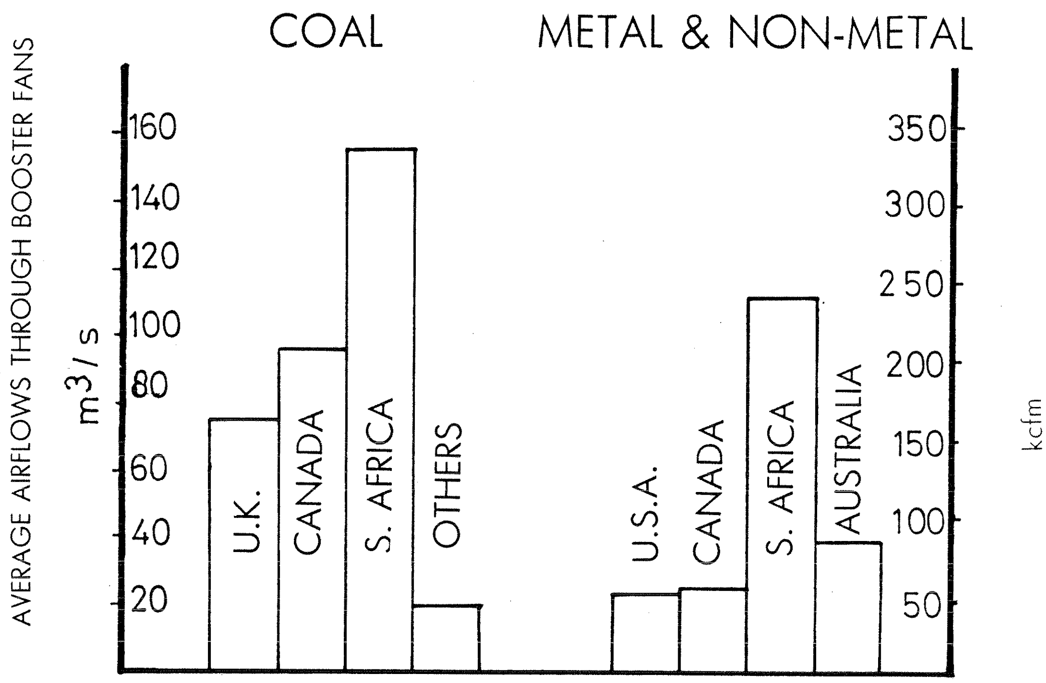

COAL
METAL & NON-METAL
AVERAGE AIRFLOWS THROUGH BOOSTER FANS
m3/s
160
140
120
100
80
60
40
20
U.K.
CANADA
S. AFRICA
OTHERS
U.S.A.
CANADA
S. AFRICA
AUSTRALIA
350
300
250
200
150
100
50
kcfm

Fig. 4

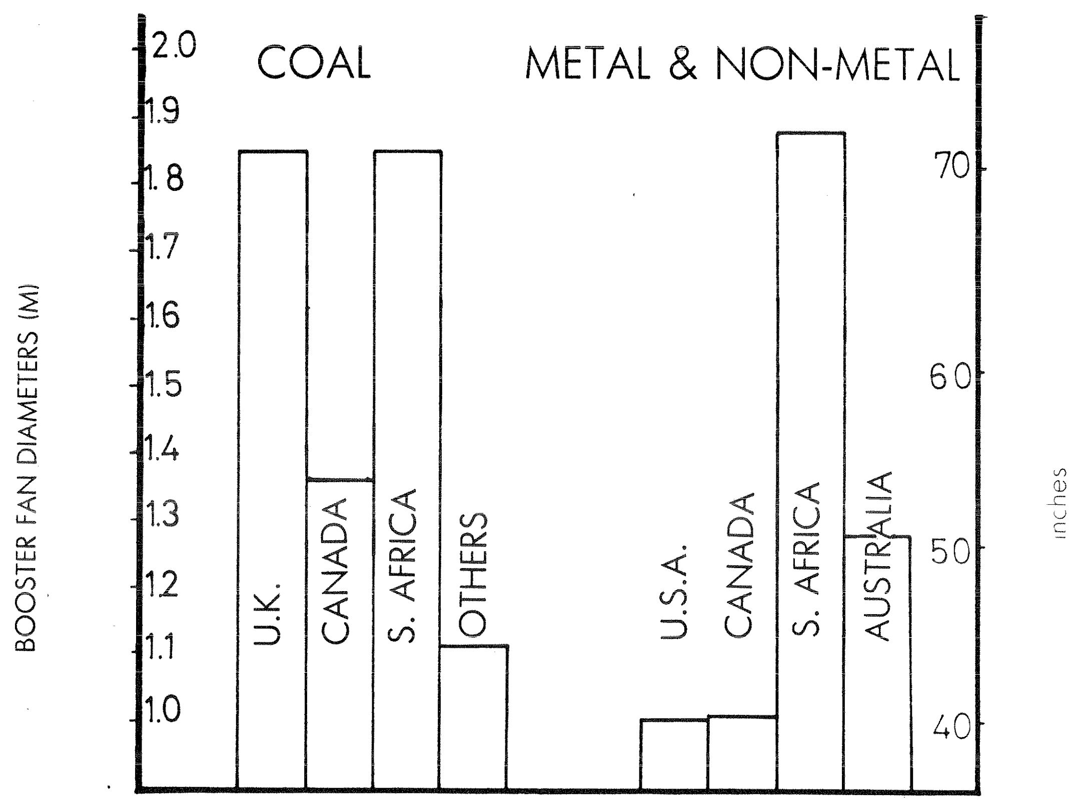

COAL
METAL & NON-METAL
BOOSTER FAN DIAMETERS (M)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
U.K.
CANADA
S. AFRICA
OTHERS
U.S.A.
CANADA
S. AFRICA
AUSTRALIA
70
60
50
40
inches

Fig. 5 MONITORING OF BOOSTER FANS IN COAL MINES

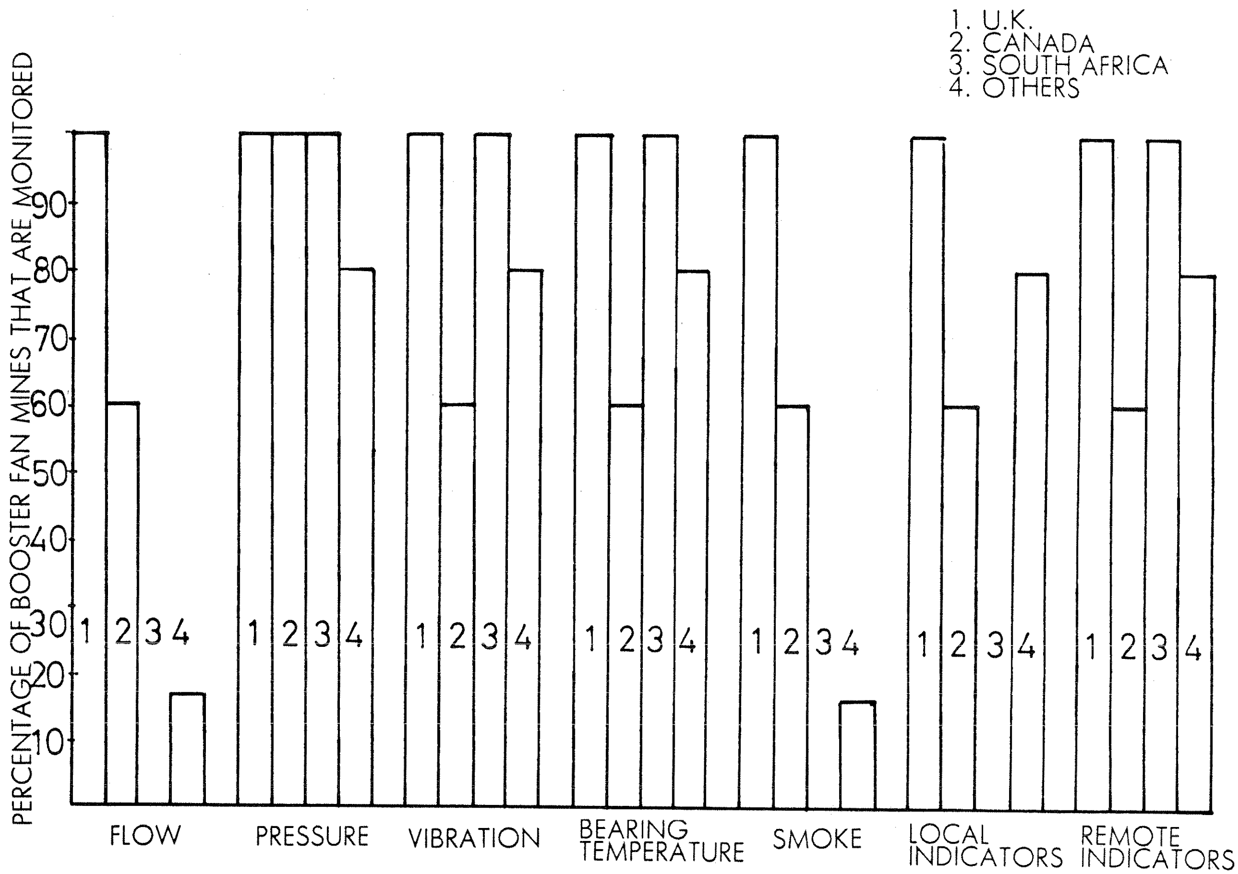


Fig. 6 MONITORING OF BOOSTER FANS IN METAL & NON-METAL

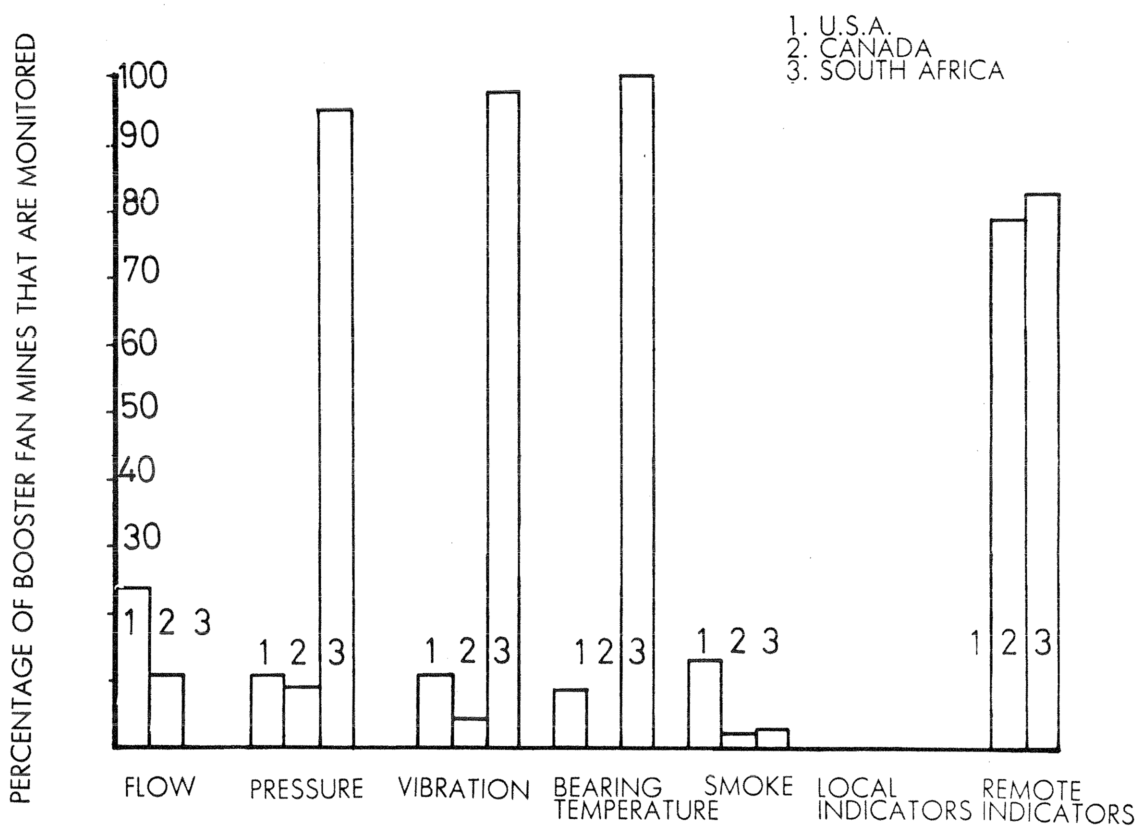


Fig. 7
SITE SELECTION PRIORITIES IN COAL

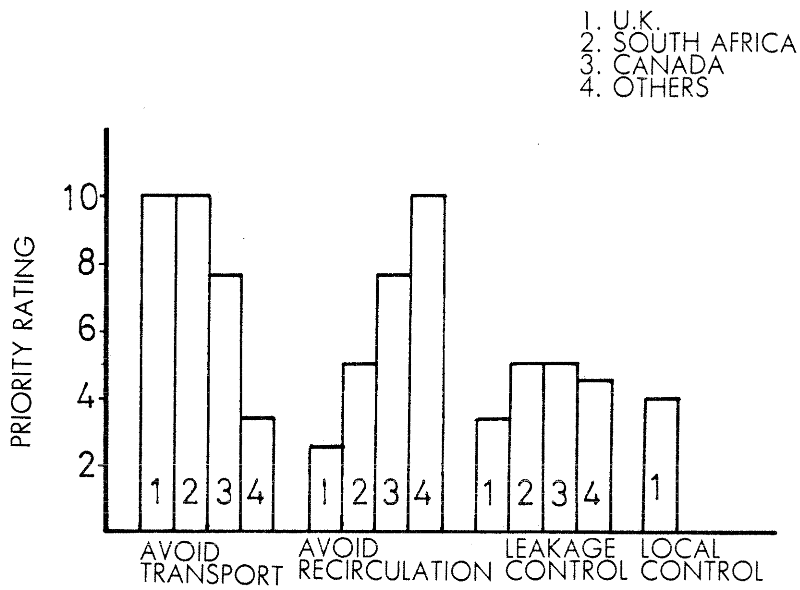
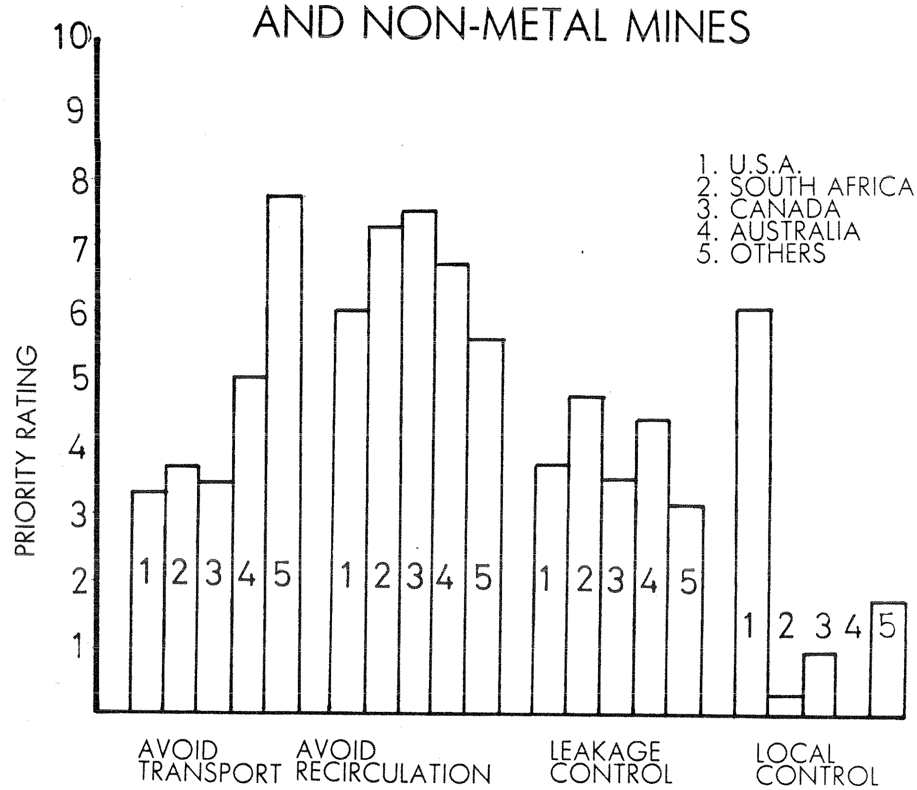


Fig. 8
SITE SELECTION PRIORITIES IN METAL AND NON-METAL MINES



$$\frac{\text{relevance factor}}{\text{arithmetic mean}} \times 10$$

Hence a Priority Rating of 10 would indicate that all respondents had answered and given highest priority to that particular choice.

Figure 7 shows that for coal mines the most important local factor in siting a booster was the avoidance of conveyors or other mineral transport routes. The coal mines in Canada and other countries also gave a high priority to minimizing recirculation. Significantly, the United Kingdom considered recirculation to be of secondary importance. In that country controlled recirculation is practiced for the improved control of dust, gas accumulations and heat, in addition to the reduction of total fan operating costs.

In metal/non-metal mines, the picture is rather different. Figure 8 shows that avoidance of recirculation is considered to be important, with the location of mineral transport routes and leakage control being of less concern in the United States, United Kingdom, Canada, Australia and South Africa. The one exception is the group of other countries who placed the avoidance of mineral transport routes to be a primary concern in siting booster fans in metal/non-metal mines.

Reasons for installing booster fans:

Figure 9 shows the priority ratings for coal mines, computed from the responses to question 7 on the questionnaire i.e. the reasons for installing booster fans. There is considerable diversity between countries on this matter. In the U.K. the outstanding reason for booster fans was to support concentrations of workings distant from shaft bottoms. In South Africa, however, all respondents gave the control of airflow as their primary need for boosters. In both of those countries, the second most important reason for installing booster was operating costs - the enhancement and control of airflow by boosters being more economic than replacing or upgrading main fans.

Figure 10 gives the corresponding histogram for metal/non-metal mines. Here every country gave airflow control as the main reason for installing booster fans. However, the corresponding priority ratings on Fig. 10 reach a maximum of no more than 5.6. This indicates differences of opinion among the respondents in each category of mines. The second most important reason for installing booster fans in metal/non-metal mines of all the named countries was high resistance airways or workings. One mine reported the installation of a booster fan in order to introduce a system of controlled recirculation.

Section C

This section was to be completed only for mines that did not use booster fans. The questions in Section C were designed to give an indication of attitudes towards booster fans by those who, for whatever reasons, did not utilize them. The results are given in Table 3.

For the majority of categories, booster fans were unnecessary because the current ventilation systems were already satisfactory - a result that might clearly have been expected. However, the U.S. coal mine returns produced very different results. First, the American coal mining industry is the only major group included in this survey that is effectively banned from using booster fans. Of the 92 U.S. coal mines for whom questionnaires were completed, 39 of them (42 per cent) indicated that they would install booster fans were they permitted to do so. Furthermore, 52 of the American coal mines (57 per cent of the 92 mines) indicated that they would not use booster fans because of the danger of uncontrolled recirculation. Although current users of booster fans were conscious of potential recirculation when siting booster fans (Fig. 8), Table 3 shows that for non-users of boosters the American coal mining industry is far more concerned about recirculation than any other group.

Section D

All recipients of the questionnaire were requested to complete Section D. This was intended to determine a priority list of the benefits of booster fans, as perceived by industrial personnel. Figure 11 shows the returns from coal mines. The U.S.A., U.K., Australia, South Africa and other countries chose ventilation efficiency as a main benefit accruing from the use of booster fans, although neither American nor Australian coal mines reported the use of booster fans. The ventilation efficiency is defined as the percentage of total main fan airflow that reaches the working places. The reduction in leakage is, therefore, related to ventilation efficiency and was chosen by Canadian coal mines as the most important benefit of booster fans.

The corresponding returns for metal/non-metal mines are illustrated on Figure 12. In this case, ventilation efficiency was chosen by all groups as the number one benefit of employing boosters, with airflow control coming second. In the U.K. and South Africa, the use of booster fans for pressure control was recognized although the matching leakage reduction did not receive as high a priority.

Fig. 9

REASONS FOR INSTALLING BOOSTER FANS IN COAL MINES

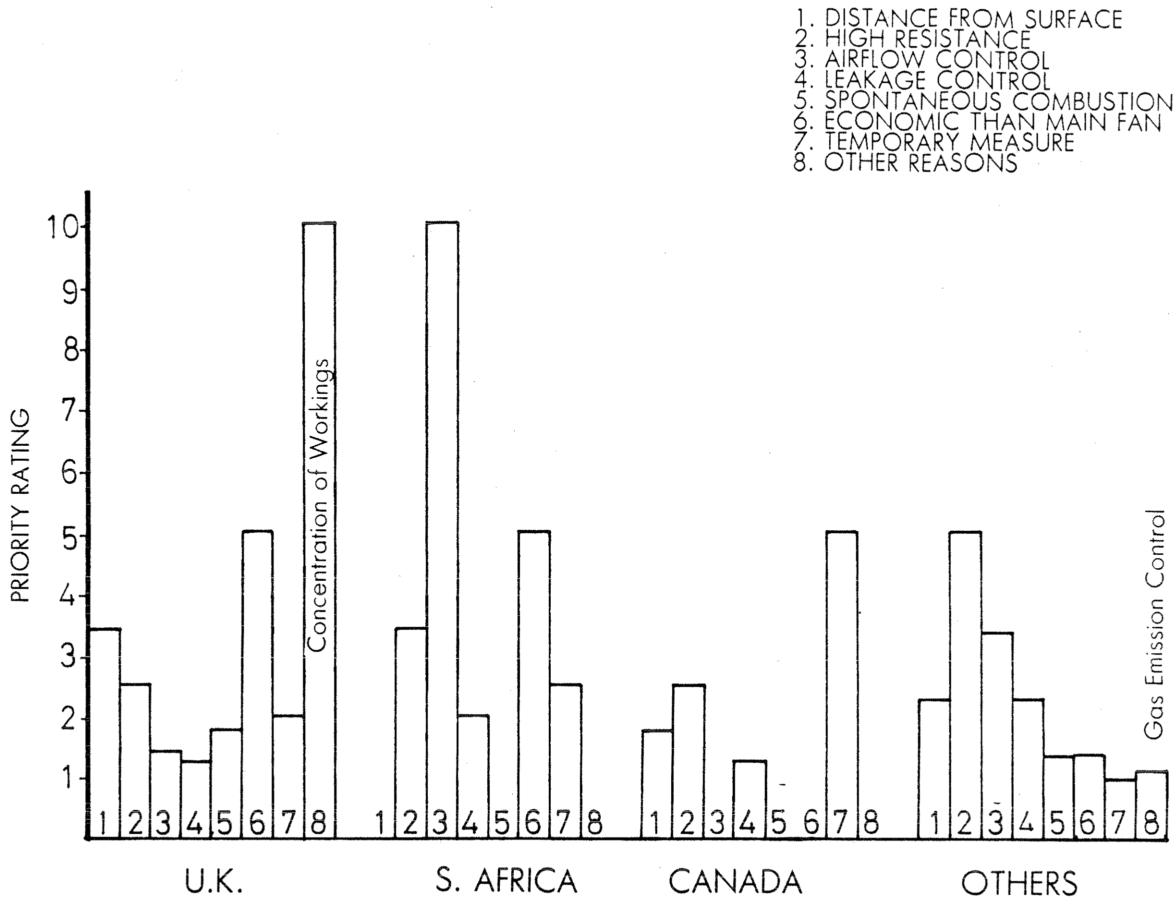
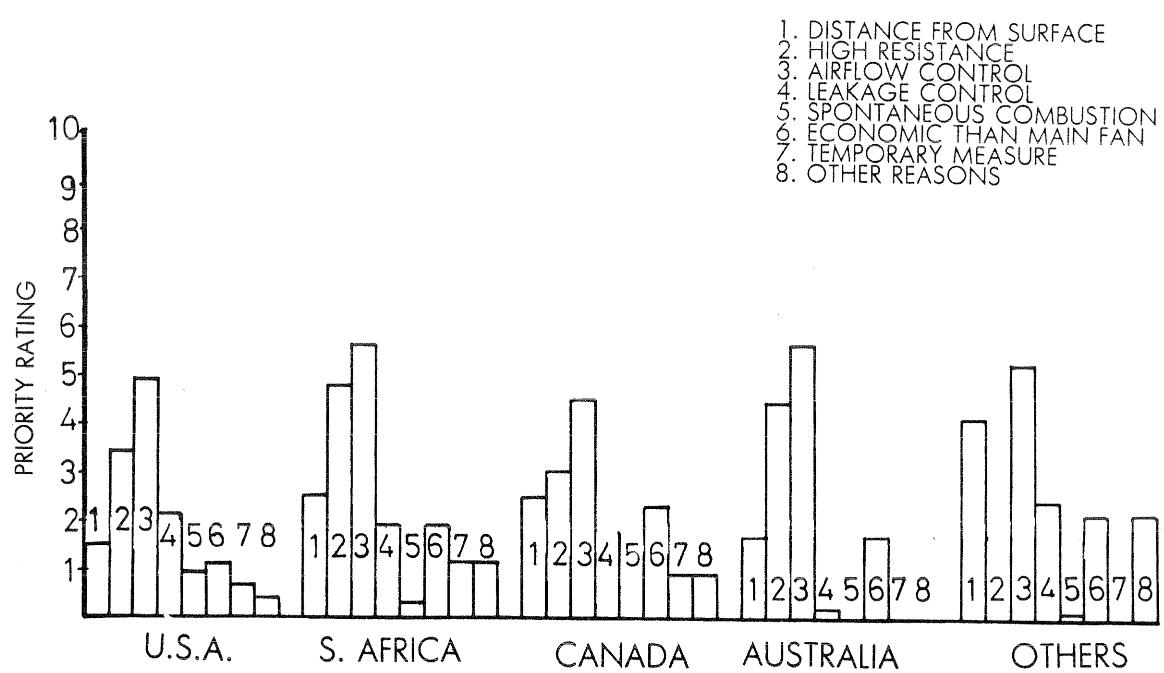


Fig. 10

REASONS FOR INSTALLING BOOSTER FANS IN METAL & NON-METAL MINES



	No. of mines NOT using booster fans	Prohibited by law?		Would you use booster fans if permitted?		Apart from legislation, give other reasons for not using booster fans			
		Yes	No	Yes	No	Insufficient knowledge	Uncontrolled recirculation	Ventilation already satisfactory	Cost of installation
USA									
Coal	92	62	30	39	53		52		25
Metal/Non-metal	56	1	55	1			1	48	
U.K.									
Coal	62		62					62	
Metal/Non-metal	1		1				1		
South Africa									
Coal	9							9	
Metal/Non-Metal	4							4	
Canada									
Coal	0								
Metal/Non-metal	8		8					6	
Australia									
Coal	28		28				2	28	
Metal/Non-metal	6		6				3	6	
Others									
Coal	17		17					17	
Metal/Non-metal	7		7			7	7	7	

Table 3 : Reasons given for NOT using booster fans

Fig. 11 PRIORITIES OF BENEFITS FROM BOOSTER FANS IN COAL MINES

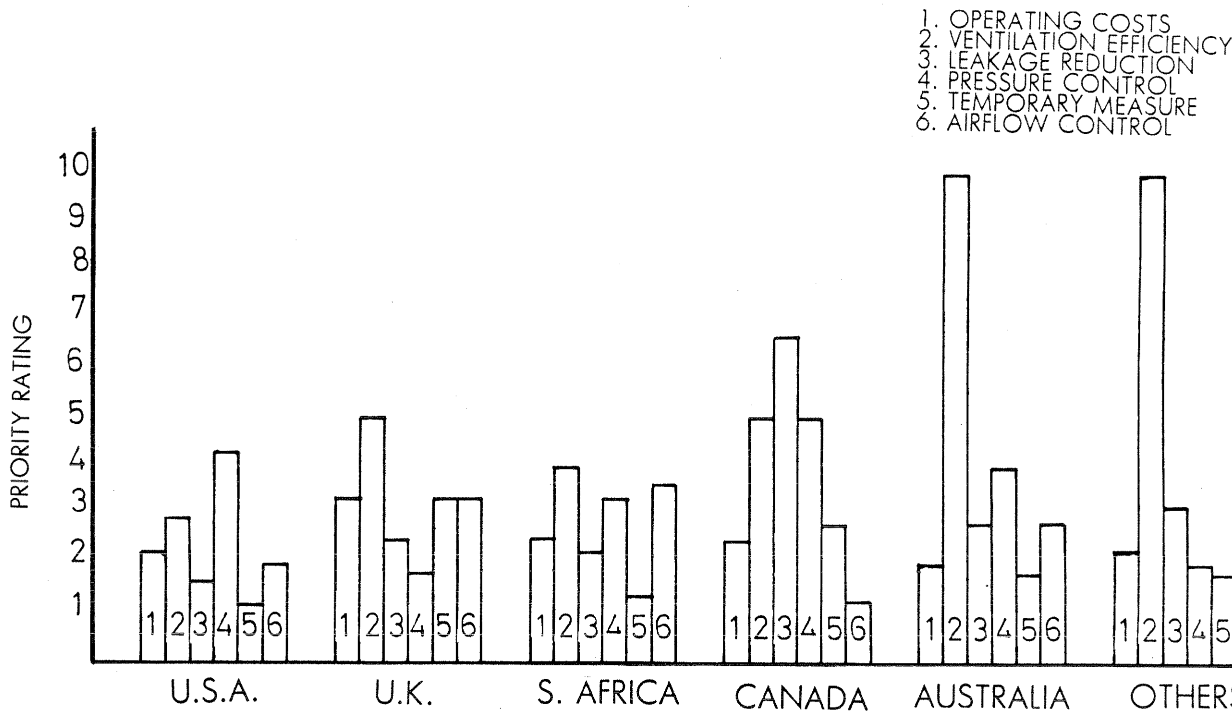
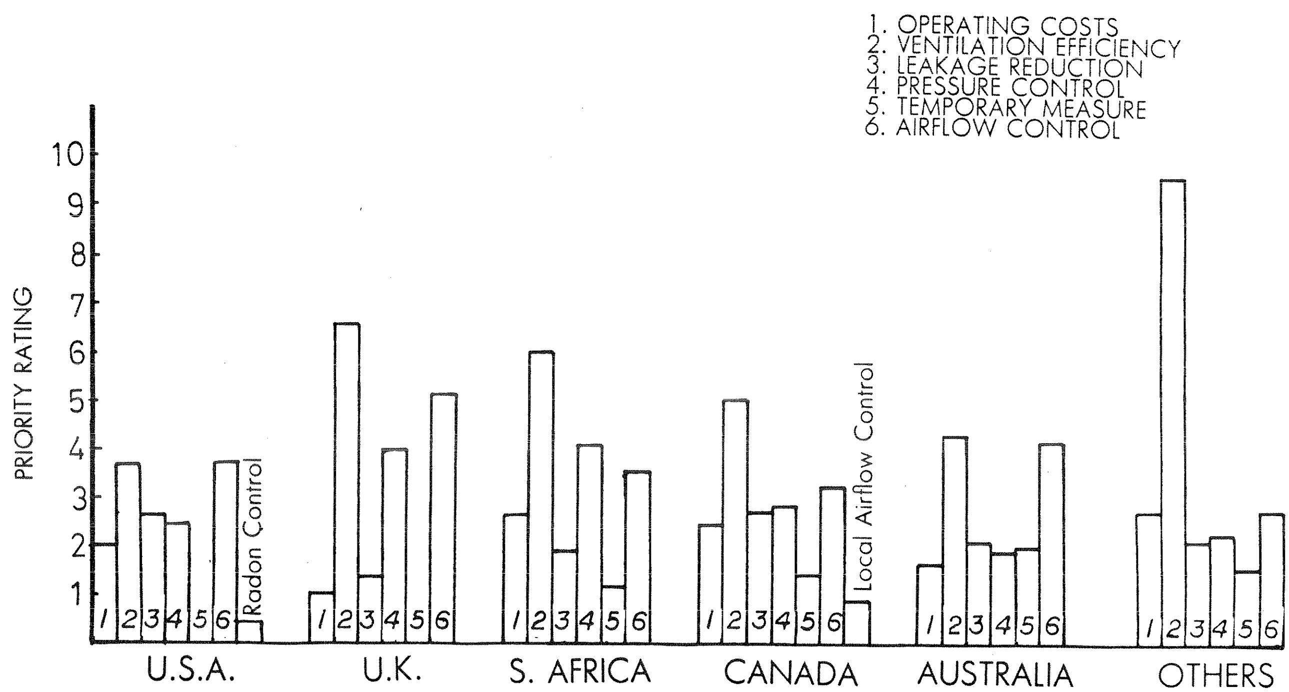


Fig. 12 PRIORITIES OF BENEFITS FROM BOOSTER FANS IN METAL AND NON-METAL MINES



CONCLUSIONS

The survey of booster fan usage described in this paper encompassed coal, metal and non-metal mines in thirteen countries. The response from five of them was sufficient for individual analysis. Those countries were the United States, United Kingdom, Canada, South Africa and Australia. The total number of mines covered in the survey was 758 and involved 1252 booster fan installations.

Although not specifically prohibited by CFR 30, Section 75, the requirement that main fans must be located on surface is interpreted as an effective ban on booster fans in U.S. coal mines. In the room and pillar system that is predominant in U.S. coal mines, the large number of openings gives rise to low resistance workings. Hence, substantial total airflows can be maintained by low pressure main fans. Booster fans are unnecessary to promote greater total airflows. However, the large number of airways inevitably results in greater leakage. In such cases the leakage could be reduced and face airflows increased by small booster fans located near the inbye end of a panel.

Where the longwall method is predominant, such as in the United Kingdom, there are far fewer airways. Booster fans are used extensively in that country in order to combat the relatively high resistances of both the faces and the airways. Many British coal mines could not reach their production targets without employing booster fans. As the coal mining industry of the United States continues to move towards greater use of the longwall system, the operating costs of maintaining satisfactory airflows to high production faces will require either more surface connections or the promotion of additional airflows by underground devices.

Some 42 percent of the American coal mines represented in the survey indicated that they would install booster fans if they were allowed to do so. However, another 52 percent quoted the danger of recirculation as a reason for not employing boosters. This is in contrast to some other countries where booster fans are being installed intentionally to create controlled recirculation.

In the metal/non-metal categories, booster fans are permitted in American mines. However there are fewer of them, pro-rata, than in other metal/non-metal mining countries. The results of the survey indicate that booster fans in the U.S. are utilized primarily for the very local control of airflow in, or close to, working sites - rather than to enhance the total air supply to the district. The booster fans in North American metal/non-metal mines are smaller and have lower duties than in other countries. Continuous monitoring at booster fan sites, as practiced in the coal mines of the United Kingdom and the gold mines of South Africa, are virtually non-existant in North American metal/non-metal mines.

The results of this survey seem to suggest that in the U.S. and Canadian metal/non-metal mines, small booster fans are sited on the basis of local knowledge and experience, as a means of controlling the distribution of available air. In other major mining countries, installations of larger booster fans are used to enhance the total air supply to one or more districts, and are preceded by planning exercises on the location, performance and continuous monitoring of the fans.