IMPROVING THE ENERGY EFFICIENCY OF MINE FAN ASSEMBLAGES

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ABSTRACT

Energy associated with ventilating an underground operation comprises a significant portion of a mine operation's base energy demand and is consequently responsible for a large percentage of the total operating costs. Ventilation systems may account from 25–40% of the total energy costs and 40–50% of the energy consumption of a mine operation. Fans are the most important mechanical devices used to ventilate underground mines and the total fan power installed in a single mine operation can easily exceed 10,000 kW. Investigations of a number of mine main fan installations have determined their assemblage to be, in general, very energy inefficient. The author has found that 40–80% of the energy consumed by a main fan is used to overcome the resistance of fan assemblage components. This paper presents how engineering design principles can be applied to improve the performance and efficiency of fan installations, resulting in substantial reductions in power consumption, operating cost and greenhouse gas emissions. A detailed case study is presented to demonstrate that, by designing fan assemblages using proper engineering concepts of fluid physics and industrial ventilation design, main fan systems will operate at efficiencies well above 80–90% (compared to common operating efficiencies of between 20 and 65%), resulting in a drastic reduction in a mine's overall costs and base electrical and energy loads.

KEYWORDS

Mine ventilation, Mine fans, Fan assemblage design, Ventilation energy, Fan efficiency, Operating cost

INTRODUCTION

Global awareness of potential problems with the long-term availability of resources has encouraged a world-wide re-evaluation of energy consumption. The recent problems experienced with the electricity supply in North America have resulted in a more urgent emphasis being placed on energy efficient design and operation of all energy consuming equipment. Electricity is a main mode of energy supply and the mining industry is affected by the increasing cost of this commodity.

One of the main electricity consumers in operating mines is ventilation. To address this high consumption, this paper presents how one can optimize main fan system assemblage designs, which have been measured to be, in many installations, extremely energy inefficient. With use of proper engineering procedures for the design and operation of main mine fan systems based on energy efficiency and cost effectiveness, the overall base electrical and energy loads of such systems would be drastically lowered and a reduction in overall operating costs would be achieved. This paper also demonstrates how the common problems with the design and commissioning of main fan systems can be analysed and corrected. With appropriate design modifications (retrofitting) of existing systems, substantial reductions in power consumption, cost and greenhouse gas emissions would result.

A case study is presented to analyse the design of a main fan exhaust air system, with two fans operating in parallel in two stacks, illustrated in Figure 1. A series of analysis are performed to design each component of the complete fan system: plenum, collar, elbow, airway split, transition sections, fan cones and accessories (backdraft dampers, joints, screens).

For all cases the following requirements or conditions are considered:

- design flow rate - 189 m^3/s

- fans (2 in parallel) - 8400-VAX-5150, full bladed, 60 Hz, 1800 rpm
- power cost - $0.084/kW.hr
- operation - 24 hours/day, 365 days/year
- shaft diameter - 4.35 m
- plenum dimensions - 2.29 m x 4.55 m and 2.95 m x 5.03 m
- shaft resistance pressure - 1120.9 Pa
- accessories resistance pressure - 124.50 Pa

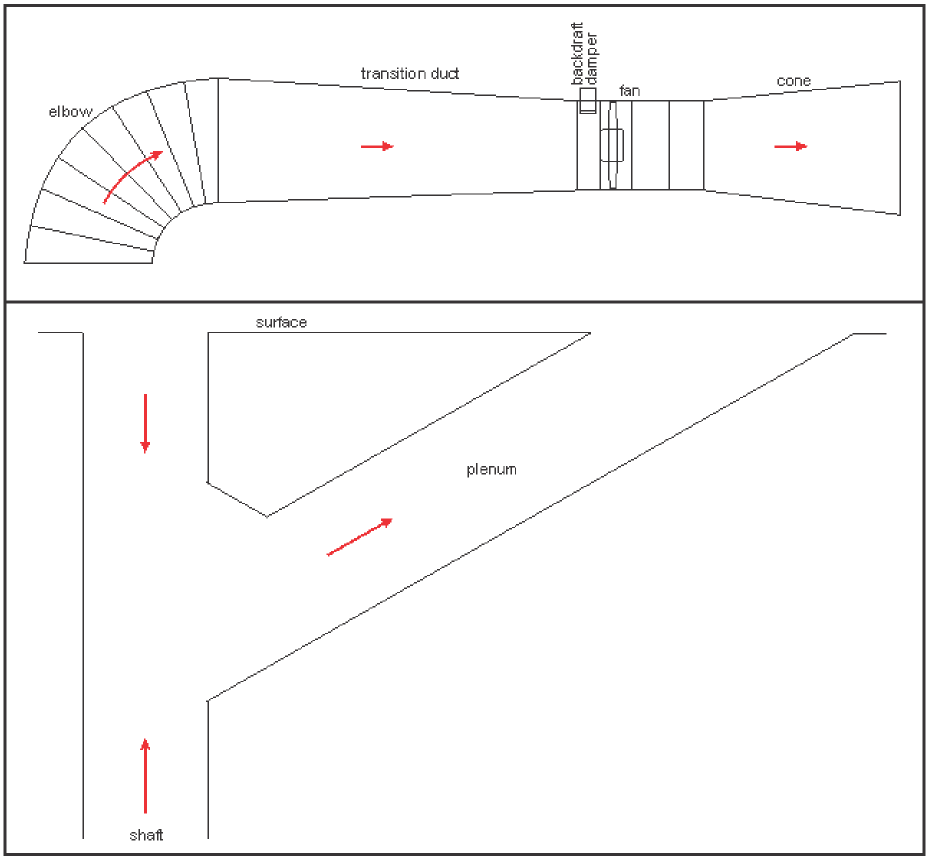

Figure 1 – Main exhaust fan system layout

PLENUM DESIGN

A number of inexact plenum designs have been encountered by the author when analysing fan operation issues during consulting activities. Conditions at the shaft-plenum intersection and the plenum layout are analysed.

Shaft-Plenum Intersection

The effects of geometry and of static to velocity pressure conversion are analysed in this case. Consider six design conditions, illustrated in Figure 2. Cases 1A–1C consider the smaller plenum and cases 1D–1F consider the larger plenum.

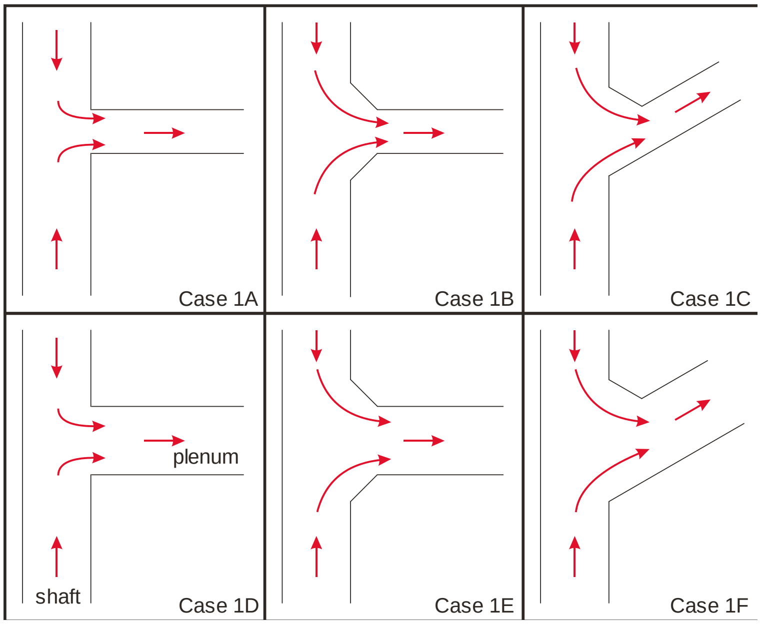

Figure 2 – Shaft-plenum intersection designs

For Case 1A, the head losses are estimated at 396 Pa and the annual power cost of transferring the air from the shaft to the plenum is $69,001/year. If the plenum is installed with bevelled corners (Case 1B), then the head losses are reduced to 198 Pa and the annual power cost of transferring the air from the shaft to the plenum is reduced to $41,511/year. If the plenum is installed at an angle, as shown in Case 1C, then the head losses are further reduced to 99 Pa and the annual power cost to $27,766/year. It is noted that, for cases 1A-1C, the head losses pertain to the geometry and to the increase in velocity as the air enters the plenum.

For Case 1D, the shock loss is estimated at 194 Pa and the annual power cost of transferring the air from the shaft to the plenum is $26,941/year. If the plenum is installed with bevelled corners (Case 1E), then the shock loss is reduced to 97 Pa and the annual power cost of transferring the air from the shaft to the plenum is reduced to $13,470/year. If the plenum is installed at an angle (Case 1F), then the head loss is further reduced to 48 Pa and the annual power cost to $6,735/year.

Table 1 presents a summary of results. The percent reduction in costs for each case was estimated relative to Case 1A. The percent reduction in operating costs clearly shows that, when properly designed, substantial energy and cost savings, approximating 90%, can be achieved.

Table 1 – Head losses, power and operating costs for shaft-plenum intersections

Case	Hl (Pa)	Power (kW)	$/year	% reduction
1A	395.8	93.8	69,001	-
1B	197.9	56.4	41,511	39.8
1C	99.0	37.7	27,766	59.8
1D	193.9	36.6	26,941	61.0
1E	97.0	18.3	13,470	80.5
1F	48.5	9.2	6,735	90.2

It is noted that for Cases 1D-1F, the plenum and shaft areas are the same and so the velocity pressures. Since there is no change in velocity pressure as the air enters the plenum, no equivalent increases in static pressure at the fan would be required. In general, the plenum should be sized such that the velocity pressure in the plenum should be similar to the velocity pressure in the shaft or raise. This is to minimize the static pressured required by the fan.

Plenum Layout

The plenum layout considers two design conditions, illustrated in Figure 3. Case 2A represents a plenum with a 90 degree bend and Case 2B represents a plenum with a 135 degree bend.

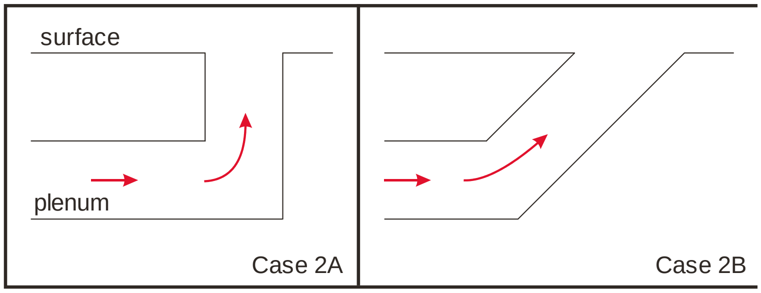

Figure 3 – Plenum designs

For Cases 2A and 2B, friction and shock losses are considered to estimate the power and cost of transferring air through the plenum.

For the case of the plenum with a 90 degree bend (Case 2A), the head losses are estimated at 70.9 Pa and the annual power cost of transferring air through the plenum is $9,849/year. If the plenum is installed with a 135 degree bend (Case 2B), then the head losses are reduced to 43.2 Pa and the annual power cost of transferring air through the plenum is reduced to $6,003/year.

Table 2 presents a summary of results. The percent reduction in operating costs clearly shows that, when the plenum section is properly designed, energy and cost savings, approximating 39%, can be achieved.

In general, in order to minimize shock losses, the plenum should not be constructed with sharp turns.

Table 2 – Head losses, power and operating costs for plenum section

Case	H_l (Pa)	Power (kW)	$/year	% reduction
2A	70.9	13.4	9,849	-
2B	43.2	8.2	6,003	39.1

ELBOW

The elbow layout considers two design conditions, illustrated in Figure 4. Case 3A represents a square elbow and Case 3B represents a normal bend.

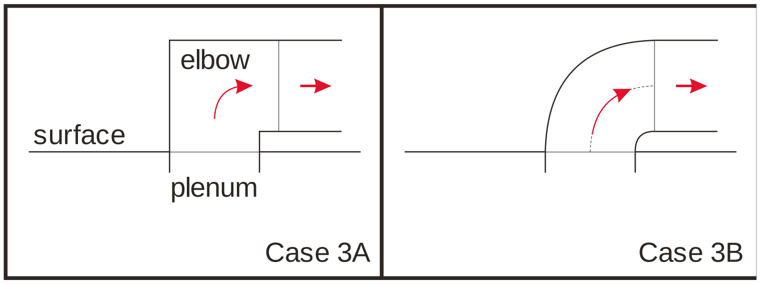

Figure 4 – Elbow designs

For Cases 3A and 3B, shock losses are considered to estimate the power and cost of transferring air through the elbow to the fan stacks.

For the case of a square elbow (Case 3A), the shock losses are estimated at 44.6 Pa and the annual power cost of transferring air through the elbow is $9,195/year. For the case of a normal bend (Case 3B), then the head losses are reduced to 18.6 Pa and the annual power cost of transferring air through the elbow is reduced to $2,581/year.

Table 3 presents a summary of results. The percent reduction in operating costs clearly shows that, when the elbow section is properly designed, energy and cost savings, approximating 58%, can be achieved. Square, crowded or segmented bends should be avoided since they result in larger shock losses. Further reductions in energy and costs could be achieved with the inclusion of features such as splitter vanes. The use of vanes would also provide structural support to the elbow.

Table 3 – Head losses, power and operating costs for elbow section

Case	H_l (Pa)	Power (kW)	$/year	% reduction
3A	44.6	8.4	6,195	-
3B	18.6	3.5	2,581	58.3

SPLIT LOSSES (DUCTING BRANCHING)

The split represents the branching of the two stacks. The split layout considers two design conditions, illustrated in Figure 5. Case 4A represents a split with a large angle (60 degrees) and Case 4B represents a split with a smaller angle (20 degrees).

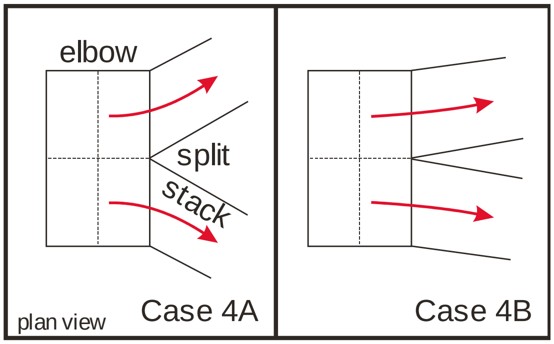

Figure 5 – Split designs

For Cases 4A and 4B, shock losses are considered to estimate the power and cost of transferring air through the elbow to the fan stacks.

For the case of a split with large angles (Case 4A), the shock losses are estimated at 57.2 Pa and the annual power cost of transferring air through the elbow is $7,948/year. For the case of a split with low angles (Case 4B), then the head losses are reduced to 29.1 Pa and the annual power cost of transferring air through the elbow is reduced to $4,041/year.

Table 4 presents a summary of results. The percent reduction in operating costs clearly shows that, when the stacks are installed at lower angles, energy and cost savings, approximating 49%, can be achieved.

Table 4 – Head losses, power and operating costs for split section

Case	H_l (Pa)	Power (kW)	$/year	% reduction
4A	57.2	10.8	7,948	-
4B	29.1	5.5	4,041	49.2

TRANSITION DUCT

The transition duct serves to transfer air from the split to fan, and is tapered such that its shape is changed from a rectangular at the elbow to a circular section at the fan. The transition duct layout considers two design conditions, illustrated in Figure 6. Case 5A represents a straight duct and Case 3B represents tapered duct.

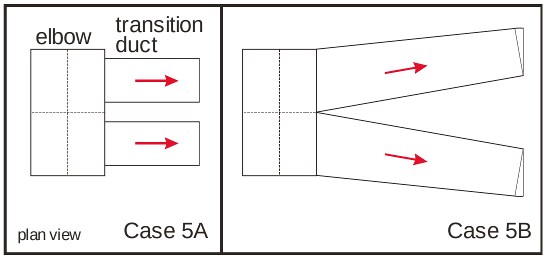

Figure 6 – Transition duct designs

For Cases 5A and 5B, friction, shock losses and the effect of static to velocity pressure conversion are considered to estimate the power and cost of transferring air through the transition duct.

For the case of the duct with a sudden contraction (Case 5A), the head losses are estimated at 474.3 Pa and the annual power cost of transferring air through the duct is $32,945/year per fan. For the case of the duct with a low taper angle (Case 5B), then the head losses are reduced to 368.3 Pa and the annual power cost of transferring air through the duct is reduced to $25,578/year.

Table 5 presents a summary of results. The percent reduction in operating costs clearly shows that, when a proper transition duct is designed, energy and cost savings, approximating 22.4%, can be achieved.

Table 5 – Head losses, power and operating costs for transition duct

Case	H_l (Pa)	Power (kW)	$/year	% reduction
5A	474.3	44.8	32,945	-
5B	368.3	34.8	25,578	22.4

FAN OUTLET CONE

The outlet cone serves minimize system exit losses. The fan outlet included two cone design conditions, illustrated in Figure 7. Also, the case including the fan without a cone is included. Case 6A represents the fan with no cone installed in it, Case 6B represents the fan fitted with a short cone, and Case 6C represents the fan fitted with a longer, more efficient cone.

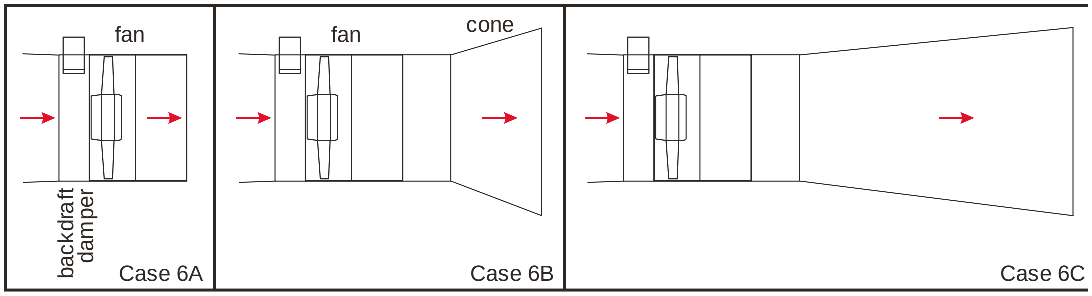

Figure 7 – Fan outlet cone designs

For Cases 6A-6C, shock losses and fan velocity pressure, including losses, is also determined in the cone analysis.

For the case of the fan with no cone (Case 6A), the head losses are estimated at 566.9 Pa and the annual power cost of exhausting the air is $39,374/year per fan. For the case of a short cone (Case 6B), then the head losses are reduced to 313 Pa and the annual power cost of exhausting the air is reduced to $27,669/year. For the case of a more efficient cone (Case 6C), the head losses are reduced to 163.7 Pa and the annual power cost of exhausting the air is reduced to $17,301/year.

Table 6 presents a summary of results. The percent reduction in operating costs clearly shows that, when a proper fan cone is designed and installed, energy and cost savings, approximating 56%, can be achieved.

Table 6 – Head losses, power and operating costs for fan cone

Case	$Hv_{\text{(incl. losses)}}$ (Pa)	H_l (Pa)	Power (kW)	$/year
6A (no cone)	566.9	566.9	53.5	39,374
6B	398.4	313.0	37.6	27,669
6C	249.1	163.7	23.5	17,301

ANALYSIS

A comparison between the following installations is presented to assess overall system power and cost savings:

Installation	Description
1	smaller plenum (Case 1A) and fan with no cone (Case 6A)
2	larger plenum (Case 1F) and fan with a proper cone (Case 6C)
3	larger plenum (Case 1D) and fans with a shorter cone (Case 6B)

The overall system comprises of all fan assemblage components and the plenum section (Figure 1).

A comparison between the first and second installations is presented. The first installation has a smaller plenum (Case 1A) and the fans operate without a cone (Case 6A). The second installation has a larger plenum (Case 1F) and the fans fitted with a proper cone (Case 6C). All other components of the system are the same.

For the first installation, a total pressure of 2,855.3 Pa is required per fan, for a flow of 94.4 m^3/s. The proposed fans (8400-VAX-3150) would not be able to operate under such conditions, since the required total pressure falls outside the fans operating pressure range (Figure 8). For the second installation, a total pressure of 2002.2 Pa is required per fan, for the design flow of 94.4 m^3/s. The fan efficiency would be 79% and the brake power would be 239 kW. The fan operating point is shown in Figure 8.

For the first case the overall power is 558.1 kW and the overall annual operating cost is $410,632/year. For the second case the overall power is 378.1 kW and the overall annual operating cost is $278,119. Power and annual cost savings in the order of 180 kW and $132,513/year would be realized. A reduction in overall power and operating cost of more than 32% would thus be achieved.

A comparison between the third and second installations is presented. The third installation with a larger plenum (Case 1D) and the fans with a shorter cone (Case 6B). The second installation has a larger plenum (Case 1F) and the fans fitted with a proper cone (Case 6C). All other components of the system are the same.

For the third installation, a total pressure of 2,484.7 Pa is required per fan, for a flow of 94.4 m^3/s. A total pressure of 2484.7 Pa is required per fan, for the design flow of 94.4 m^3/s (Figure 8). The fan efficiency would be 70% and the brake power would be 335 kW. As presented earlier, for the second installation, a total pressure of 2002.2 Pa is required per fan, for a flow of 94.4 m^3/s. The fan efficiency would be 79% and the brake power would be 239 kW. Savings in capital costs would also be realized because of the smaller motor required.

For the third case the overall power is 469.1 kW and the overall annual operating cost is \$345,162/year. For the second case the overall power is 378.1 kW and the overall annual operating cost is \$278,119. Power and annual cost savings in the order of 91 kW and \$67,043/year would be realized. A reduction in power and operating cost of more than 17% would be achieved.

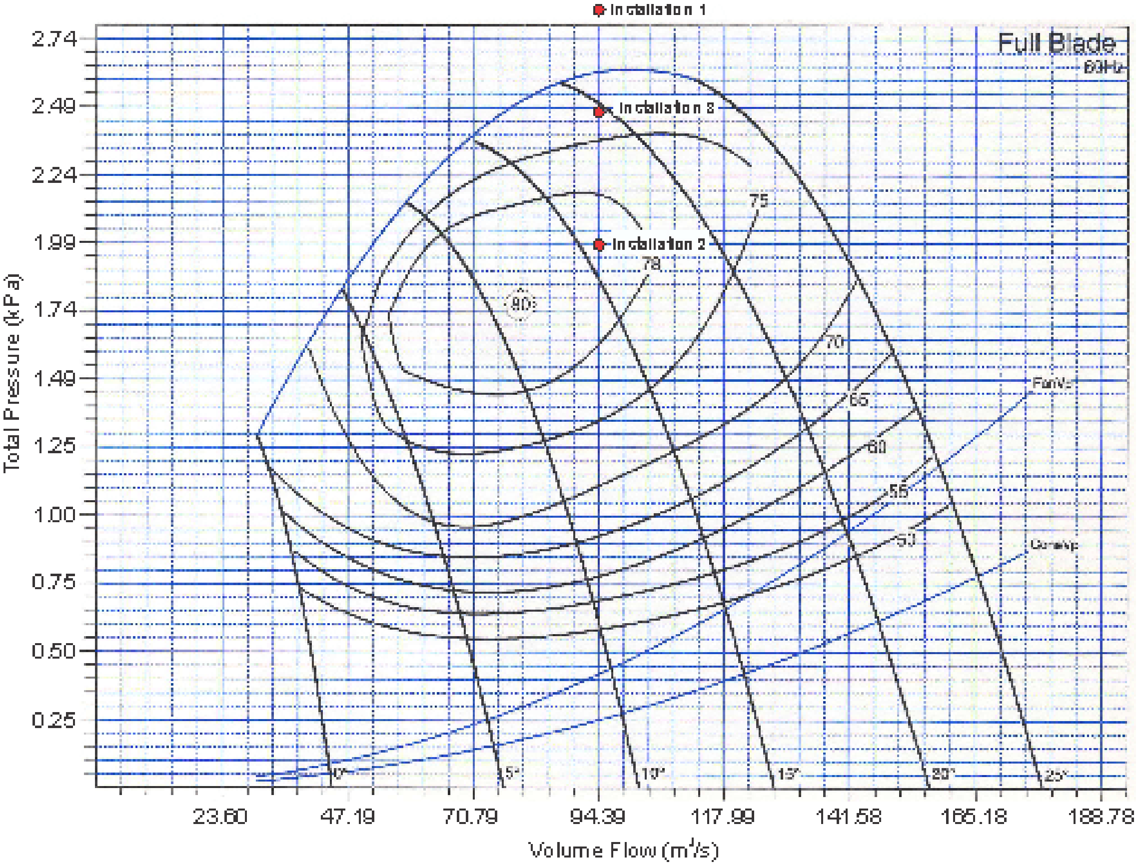

Figure 8 – Fan operating points

CONCLUSIONS

This paper has demonstrated how the use of proper engineering design for optimal main fan installation designs would dramatically result in reduced energy consumption and in reduced operating costs. When properly designed, using engineering principles of fluid flow, a fan system can operate efficiently with substantial power and operating cost savings.

In a case study presented, it has been illustrated that savings in energy exceeding 30% can be achieved by commissioning a properly designed fan assemblage.

This paper has shown how engineering designs can be applied to improve main fan system assemblage efficiencies with minimum capital investment. By improving the performance and efficiency of fan installations, substantial reductions in power consumption, cost and greenhouse gas emissions can be achieved.