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Energy saving through optimal fan and mine system matching

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ENERGY SAVING *THROUGH* OPTIMAL FAN AND MINE SYSTEM MATCHING

David Paul Barratt

A dissertation submitted to the Faculty of Engineering, University of the Witwatersrand, Johannesburg, in partial fulfilment of the *requirements* for the degree of Master of Science in Engineering.

Johannesburg, 1988

I declare that this dissertation is my own, unaided work. It is being submitted in partial fulfilment of the requirements for the Degree of Master of Science. It has not been submitted before for any degree or examination in any other university.

Signed: _____

this____day of_____1989

ABSTRACT

Maintaining an acceptable environment for underground workers is becoming increasingly expensive. A considerable part of the costs involved is attributable to the energy required to drive pumps, fans and reticulation compressors. This dissertation addresses some of the difficulties involved in the selection of mine ventilation fans.

A survey of interest to environmental engineers showed that the requirements for main surface fans changed significantly during the early years of a mine's life. This change has a significant effect on the relationship between a system and its fans. Traditional methods of fan selection do not take this into account.

A computer program has been developed to model fan performance requirements over the life of a mine. It is shown that considerable cost savings are achieved by the proper matching of fans to changing system resistances correctly and by operating the fans efficiently over the life of the mine.

ACKNOWLEDGEMENTS

I gratefully acknowledge help received in the preparation of this dissertation. Mr. R. M. Stroh originally brought this problem to the notice of the fan industry and shared his thoughts with us. The gold mining indurtry in general has been generous in providing the information which formed a basis for this work.

Thanks to Mr. D. Cipolat, my supervisor, for his patient guidance.

My employer, James Howden S.A. was generous in assisting with the use of computer equipment, design and costing information. Electric motor manufacturers also readily provided selection and costing information.

Finally thanks to my wife and family who encouraged and supported me during this work.

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CHAPTER 1

INTRODUCTION

In 1987 nearly 350 000 miners were completing main shifts daily in South African gold mines. Typical virgin rock temperatures they experienced were close to 40 degrees Celsius. The mean rock breaking depth was over 1 000 m below surface. To maintain working conditions in these mines at a standard acceptable for health, productivity and safety, large quantities of fresh ventilating air are required.

This air is used to convey heat, control dust and hazardous gas concentrations and provide oxygen. The driving force for the flow of ventilating air is provided by extraction fans. The resistance to air flow through the mine is considerable as each mine represents several kilometers of tunnel. Lloyd(1) notes that pressure differentials of up to 9kPa, between intake and exhaust, are required to maintain an adequate air supply rate. Energy consumption of ventilating equipment and consequently their running costs are high.

Since 1975 the cost of ESCOM power to gold mines has increased sharply from an average of 0,66 cents to 4.72 cents per kWh in 1986. The rate of increase as depicted in ESCOM's Statistical Yearbook(2) is illustrated in

figure 1.1. Ten percent tariff increases were imposed in January and November of 1985 and January and July of 1986. These rapid increases have been attributed to a falling Rand and concomitant high finance charges.

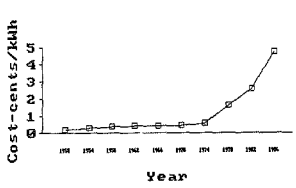


Figure 1.1 Average cost of power to the mining industry. ESCOM's 1986 Statistical Yearbook(2)

The mining industry currently consumes 27 percent of ESCOM's total power production. An estimated simultaneous peak demand of 4 000 MW was attributed to mines in 1985. During that year the national peak and average generating rates were 17 852 MW and 12 820 MW respec-

tively. The increase in power cost has had a marked effect on mining costs. For an average gold mine power represents ten percent of working costs. In the case of Western Deep Levels this figure is approaching 14 percent, with peak demands around 175 MW.

Hauptfleisch(3) recently reported that the ventilation plant on Vaal Reefs No. 2 Shaft had consumed 2 521 MWh during one month. The corresponding figure for a Vaal Reefs No. 8 Shaft was 3 022 MWh. The total energy consumption for these two centres was 16 134 and 36 758 MWh respectively. Main ventilation fans on this mine are responsible for more than 10 percent of the total energy consumption and probably more than one percent of the total mine running costs.

Large consumers of electricity in South Africa pay for power in two ways. In 1987 a charge of 2.787 cents was made for every kWh of electricity supplied. A further charge is made based on the maximum rate of energy consumption during each month. This was R15.65 per kW per month (1987). The make up of power costs is fully detailed in Appendix A. In order to minimize the heat load transferred from the rock to atmosphere underground, mine fans are run continuously. This aggravates the cost of running as each unit carries a full share of maximum demand charge.

A severe limitation regarding the minimizing of fan power consumption is the problem of matching mine system and fan characteristics. The environmental engineer is able to design his system reasonably accurately, but the system is dynamic and changes continuously. Typically a new fan will be faced with high pressures and a relatively low flow requirement. This is due to the shaft being sunk to its full depth with little further development having taken place. The volume requirement increases and pressures fall as more levels are opened up and booster fans are installed. Planned areas to be mined may alter from year to year, depending on their financial viability.

The fan manufacturer selects his equipment to match a planned series of duties. When the fan is installed and the system begins to deviate from design, the environmental engineer has to live with an increasingly inefficient plant.

Most surface fan duties on gold mines favour the use of centrifugal fans. This type of machine runs at a lower tip speed for the high pressures required, resulting in lower noise levels, erosion rates and impeller stresses. The configuration of the radial flow machine makes it easy to arrange a vertically upward discharge. This is desirable to minimize the nuisance of large quantities of water which are conveyed up from underground by the

air stream. Centrifugal fans however lack the flexibility of variable pitch axial flow fans which are able to cover a wide range of duties at high efficiency.

The scope of this dissertation is limited to identifying means by which centrifugal fan installations may be designed to provide efficient operation in spite of the practical difficulties involved. Literature reviewed showed that several avenues of investigation into power saving in mine ventilation systems had been followed. Fan control mechanisms and the flexibility of axial flow fans are documented in detail. The problem of a changing mine system resistance and the consequent deterioration of fan efficiencies has been recorded by Stroh(4).

Environmental engineers have been interviewed to establish the nature and extent of the problem. The change of mine system resistance with time was obtained for several mine shafts. Suppliers of ventilation equipment have been approached to obtain the cost of equipment involved. As capital costs are small relative to energy costs, consideration has been given to changing fan impellers part way through the life of the fan.

Aspects of centrifugal fan design theory are discussed briefly. A computer program, which can run on IBM compatible personal computers, has been written to

calculate minimized fan owning cost over the life of the installation. The basis of this software and results obtained using it are presented.

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

This literature survey reviewed work relating to energy saving in the entire mine ventilation system. Emphasis for this report was placed on fan and system interaction. Four main points were revealed.

1 The mining industry has been aware of the potential energy savings which may be achieved by paying attention to the design of details in the ventilation system. Much work has been done in this respect over the past thirty years.

2 The need for flexibility in fans has been addressed. Literature in this area has focussed on the use of axial flow fans with adjustable pitch blades. These machines are not favoured by South African gold mining engineers and in recent years have only been used as surface fans on isolated occasions.

3 Variable speed motors are often cited as a means of fan output regulation. Their effective use is limited to applications where the fan operates on a fixed system resistance.

4 The possibility of changing a centrifugal fan impeller's geometry, part way through the life of a mine, has been documented. This may be desirable to match fan performance to a changing system.

2.2 Ventilation system details

A gold mine ventilation system consists essentially of a downcast shaft through which air is introduced to the mine. This air circulates through the mine and is returned to an upcast shaft which channels it to atmosphere via a surface fan installation. A typical system is illustrated in figures 2.1 and 2.2. The upcast and downcast airways may be separate and some distance apart or, more commonly, they occupy the same circular concrete lined shaft and are separated by a brattice wall.

The downcast shaft is equipped to allow several skips and cages to operate. These convey men, materials and ore between surface and the underground workings. This section also contains pipes and cables for water, compressed air and electrical power. Structural members,

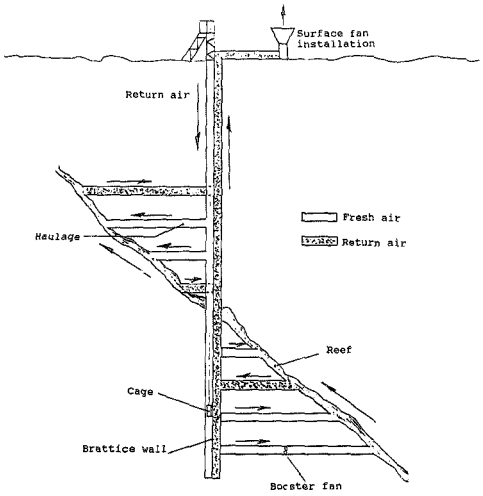


Figure 2.1 Section through a mine shaft centre line and reef.

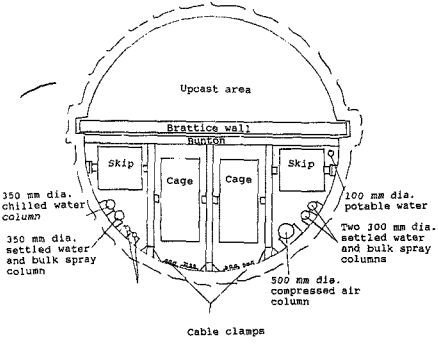


Figure 2.2 Cross section through a shaft as depicted by Lloyd(1)

which secure the skip and cage guides in position, are commonly referred to as buntons. These span the shaft at regular intervals and represent an appreciable

resistance to air flow. For this reason air velocities entering the mine are kept at moderate levels (between 10 and 12 m/s) and the buntons are usually streamlined.

A series of horizontal passages or haulages carry fresh air from the downcast shaft to the ore body at different depths. Velocity in the haulages is usually less than 5 m/s. Flow rate at different levels is balanced by regulators or the use of booster fans. At the reef the flow is distributed across the width being worked by a cross cut tunnel. From here the air follows the reef up two or three levels, picking up heat, dust and fumes. It is then rejected to the upcast airway.

The atmosphere in a return airway is highly corrosive. This passage is therefore unsuitable for housing pipes, cables and buntons. Large quantities of water vapour condense out as the air travels upward, expanding. Higher velocities are required to convey this water to surface and values between 15 and 20 m/s are common. At the top of the upcast airway the flow is turned through 90 degrees into the fan drift. This short horizontal airway usually splits into two or three branches serving different fans. Each branch contains a self closing door to avoid short circuiting when one or more of the surface fans is stopped. Velocities here are often greatly reduced to encourage entrained water to drop out and be drained away before entering the fan.

Creuer(5) described work carried out to reduce pressure losses in shafts. The investigation was carried out at The Mine Ventilation Research Centre in Essen, West Germany. Emphasis in this investigation was on reducing losses by streamlining buntons. His paper relates work done in Germany to results obtained in South Africa.

In 1965 Chasteau and Gillard(6) produced their work describing methods for predicting the resistance to air flow of equipped shafts. They concluded this work by claiming their analytical method could achieve results with an uncertainty of less than 15 percent. Downcast airways are usually equipped and are responsible for approximately thirty percent of the total pressure loss through a mine.

Much of the design data on losses in equipped airways has been summarized and correlated by Quilliam(7).

In more recent years the bend at the top of the upcast shaft, which connects the mine return airway to the exhaust fan, has come into focus. Model testing, to optimize the proportions of these bends for particular installations has been conducted by Eschenburg(8) and Wrigley(9).

Recirculating ventilating air underground is a way of limiting mass flow rate and pressure rise requirements. It is therefore a valuable means of saving main surface fan power. The evaluation of such a system at Loraine Gold Mine has been described by Burton et al(10). The implementation of recirculation increased productivity in the area concerned and confirmed that harmful gases do not accumulate.

2.3 Fan and system interaction

When a fan runs, pressure increases from inlet to discharge of the unit. An average total pressure on the fan discharge may be measured using a pitot tube and manometer. Similarly a pitot tube traverse across the fan inlet yields an average inlet total pressure. The difference between these two pressures is defined as the fan total pressure rise. Fan static pressure rise is defined in BS 848:Part 1:1980(11) as the total pressure rise, less a dynamic pressure on the fan discharge.

Fan static pressure may be measured as the difference between an average side tube reading at the fan discharge and a facing tube on the fan inlet. In the special case of a mine exhaust fan, where the discharge is open to atmosphere, a side tube reading becomes

negligibly small. A facing tube on the fan inlet therefore yields an accurate fan static pressure. A single side tube reading on the fan inlet side is often used as a measure of fan pressure rise. This technique gives a fan static pressure rise which is too high by one velocity pressure on the fan inlet.

In this report the term fan pressure rise implies fan static pressure rise. Static pressure is an appropriate parameter to use as it is this pressure which balances the losses in a mine system.

Figure 2.3 shows a typical centrifugal fan characteristic. Curve A-A depicts the unit's pressure rise capability against volume flow rate. Curve B-B represents a mine system characteristic. This is the pressure required to force a given volume of air through the mine system per unit time. Hall(12) specifies this curve as a square law line passing through the origin. Curve C-C shows the fan's efficiency plotted against volume flow rate. If the fan inlet and discharge were both unrestricted and open to atmosphere the unit would generate no static pressure rise. Flow rate would be a maximum and the unit operates at point 1 on its characteristic.

When the fan inlet is connected to a mine system both the fan and mine characteristics have to be satisfied

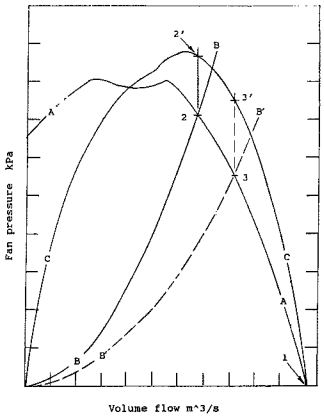


Figure 2.3 A typical main surface fan performance characteristic.

simultaneously. The unit now operates at point 2. Fan efficiency under these conditions can be read from the efficiency curve C-C and would correspond to point 2'.

The mine system characteristic may be changed in various ways. Closing a door underground would restrict the flow through the mine, increasing the system resistance. Conversely, installing a booster fan in a branch of the mine would reduce the system resistance, causing a higher air quantity to flow in a unit of time. Such a modified system is indicated in figure 2.3 by line B'-B'. In this case the fan would operate . point 3 and the operating efficiency would decrease to point 3'.

If this change in system resistance is large enough the drop in efficiency becomes significant and operating costs rise. This is the problem which environmental engineers frequently encounter.

In a recent paper centred around the flexibility of axial flow fans, Marples(13) makes the following points:

For equal pressure rise capabilities axial flow fans must run at substantially higher blade peripheral speeds than centrifugal fans. In the example cited an axial flow fan had to run at a tip speed 67 percent higher than the corresponding radial flow fan.

Methods of fan output control discussed by Marples include:

a. Damper control.

b. By pass control.

c. Adjustable inlet guide vane control.

d. Variable blade pitch control.

e. Speed control using variable speed motors, variable speed couplings and multi-speed motors.

Item d. can only be applied to axial flow fans. Items a. and b. are not energy efficient control devices, precluding their use on large mine ventilation fans.

Speed variation is a highly efficient means of fan control provided that the system on which the fan is operating has a constant square law characteristic. On varying systems, speed control can be used in conjunction with other control devices.

Marples describes the pronounced stall region which is evident in high efficiency axial flow fans. This unstable region of operation can be avoided by employing an impeller with blade pitch variable in motion.

This author does not mention the possibility of replacing fan components periodically to cope with a gradually changing system characteristic. He does discuss systems found in mining, tunneling and process plants where both resistance to air flow and flow rate requirements vary substantially. He points out the energy saving advantages of using variable pitch axial flow fans to meet these variations.

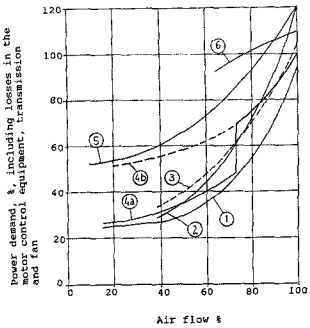
Lack[14] shown the relative efficiencies of various control devices on a square law system characteristic. Under these circumstances the variable speed control and variable pitch axial flow fan are shown to be at an advantage. This is illustrated in figure 2.4.

Wallis[15] addressed the problem of varying resistance seen by mine fans. He proposed that as wear due to abrasion and corrosion and general mechanical deterioration limit the life of a fan, duty points should be specified for the envisaged life of the fan rather than the life of the mine.

To give manufacturers a clear view of the range of duties which may be required, he suggested specifying the pressure and volume requirements as a block on the fan performance curve rather than a single point. This is shown in figure 2.5.

A list of possibilities for fan control was given. These are similar to those listed by Marples but include adjustable vane trailing edges for centrifugal fans.

In his section entitled "Flow Control" Wallis made reference to the fact that substantial loss in efficiency can be expected when the operating conditions vary significantly from the original design point. Again



1 Axial flow fan with variable pitch blades.

2 Speed control by frequency control.

3 Speed control by eddy-current coupling.

4a Inlet guide vane control with 2-speed fan.

4b Inlet guide vane control at constant speed fan.

5 Damper control; fan with forward curved blades.

6 Damper control; fan with backward curved blades.

Figure 2.4 A comparison of power demand and control ranges for various methods of control. Presented by Lack(14).

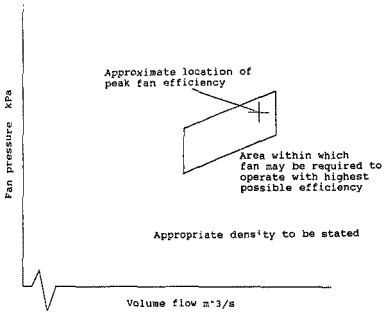


Figure 2.5 A proposal for the presentation of fan duties. (Wallis(12)).

this author was clearly in favour of the use of axial flow fans with adjustable blades and pointed out that high efficiencies were available over a wide range of duties.

His section entitled "Regulation" was ended with an example of the energy saving that can typically be achieved by using an underground booster in the mine network branch having the highest pressure loss.

2.4 Some problems related to mine fans in South Africa

2.4.1 Main fans at Elandsrand Gold Mine were operating at a pressure lower than the original design figure. This resulted in a fan efficiency of 71 %. Stroh(4) presented a case for rewinding the driving motors to reduce rotational speed from 600 to 500 rev/min. The design flow rate could then be achieved by operating three fans instead of two. Efficiencies would increase by 14 points to 85%. The cost of rewinding the motors was approximately R 100 000,00. The annual saving in power costs would exceed R250 000,00.

The possibilities of varying rotational speed, redesigning or modifying existing fan impellers, to improve efficiency, are mentioned.

2.4.2 The question of long term fan efficiency was addressed by Drummond(16) in 1972. Methods of measuring fan performance on site received attention. The results of seventeen tests on six different installations were presented. Only two of these tests revealed efficiencies

which were in line with the fan manufacturers' published figures. The range of efficiency measured was *from plus one* to minus 20,9 percentage points.

Several possible reasons for the shortfall in performance were put forward:

a) Fans had been overrated by suppliers.

b) Uncertainties involved in the measurement of performance were high.

c) Water and dirt in the airstream affected fan performance.

d) *Leakage.* The method of volume flow rate determination favoured was the measurement of a single velocity at the centre of the upcast shaft where the velocity profile was well developed. An *average* velocity was then estimated. This meant that any leakage between the measurement point and the fan was not taken into account.

e) Fan diffusers were ineffective in reducing the velocity of air ejected to atmosphere. Tests on one unit showed that *recirculation* was taking place with air flowing back into the diffuser effectively reducing its cross sectional area.

f) Dirt on internal components was shown to reduce fan efficiency by between 4,5 and 6,8 percent.

h) Tender adjudication procedures encouraged fan manufacturers to quote "enhanced" efficiencies.

The author did not address the problem of efficiency reduction due to system resistance variations.

2.5 System design on a new mine

Howse(17) documented the planning of ventilation and refrigeration requirements for Unisel Gold Mine. He optimized ventilation air quantity and shaft diameter against cost. Similar treatment was given to refrigeration capacity and air flow rate against cost. Several points in this paper are relevant to the current study:

The initial ventilation design was based on many assumptions. Some of these assumptions would not be realised once mining actually took place. It was important to plan as flexibly as possible.

To achieve the desired flexibility, Howse opted for the use of axial flow fans. These units were specified with blade pitch adjustable in motion. They were fitted with two speed driving motors. When the probable fan working area was plotted the axial flow machine could cover 74% of the area at an efficiency greater than 85% and 97% of the area at efficiencies above 80%. Comparable figures for centrifugal fans were 4.5 at efficiencies greater than 85% and 60% at efficiencies greater than 80%. Each fan was fitted with a 1400 kW motor.

The method used to calculate the main fan pressure requirement was to estimate the pressure loss due to the main upcast and down cast airways, subvertical airways and connecting passages. This must represent a worst case as resistance invariably drops with development, particularly if underground booster fans are used.

Over specifying pressure results in a more expensive brattice wall. If the specified pressure of 5 kPa was inadequate it could be supplemented by the use of underground booster fans.

2.6 Conclusions

The literature shows that the gold mining industry has expended considerable effort on reducing power required to provide ventilating air to the stopes. Difficulties

resulting from changing system pressure requirements have been recorded. At Elandsrand Gold Mine this problem was approached by changing the rotational speed and number of fans in operation.

The work that follows is an effort to produce a means by which flexibility may be designed into a system to cater for anticipated changes in a mine characteristic. To achieve this a computer program has been written to model the capital and running cost of main surface fan installations. An optimum combination of fan impeller configurations, inlet vane settings, motor speed variations and the number of units in operation is sought.

CHAPTER 3

EVALUATION OF SAMPLE DATA OBTAINED FROM MINES

3.1 Introduction

Several mines were asked to provide records of volume flow rate and in pressure rise over the life of their surface ventilation installations. In some cases comprehensive sets of data were available and in others only current performance and original design figures were given.

The focus in this survey was on variations over time, in resistance to air flow through the mine and air quantity demand. As fan pressure rise represents the sum of the losses in the air circuit, it has been used to determine resistance. The number or type of fans running at the time of any reading does not affect the mine characteristic and has not been recorded.

3.2 Processing and presentation of data

Wherever comprehensive sets of data were available they have been loaded onto a data base. For each flow rate and pressure rise recorded a specific resistance R was

calculated. When air density figures were available pressure readings have been corrected to a common density of 0.96 kg/m^3, to eliminate this variable. This was selected as it is representative for many mine fan installations.

Losses through the mine system have been assumed to vary as the square of the air flow rate giving the following relationship:

$$Pf = R Q^2$$

$$\text{Therefore } R = Pf / Q^2$$

When pressure is corrected to a common density this expression becomes:

$$R = (0.96\ Pf) / (Q^2 * w)$$

where R is a specific resistance.
Pf is the fan pressure rise.
Q is volume flow per unit time.
w is air density

Values of resistance and flow rate have been plotted against the period of operation in years, commissioning of the shaft being the usual datum time for these plots. Some results for individual shafts have been summarized

in table 3.1. Plots for individual shafts appear in figures 3.1 to 3.7. Tabulated results are shown in Appendix B.

Table 3.1 Initial and final ventilation requirements on different shafts.

Mine	Volume			Resistance		
	Initial	Final	%	Initia	Final	%
Lorsine 4	600	660	110	.0080	.0048	60
Lorsine 5	440	635	144	.0180	.0082	44
Harth'fntn 3	650	250	35	.0150	.0790	526
Harth'fntn 5	189	579	306	.1008	.0179	18
Vaal Reefs 2	472	644	136	.0269	.0071	26
Vaal Reefs 5	374	580	155	.0500	.0150	30
Elandsrand	990	850	86	.0092	.0096	109

3.3 Discussion of results

3.3.1 The following observations apply to relatively new shafts. The resistance in five of the seven shafts featured in table 3.1 dropped significantly with time. *Hartebeestfontein* No. 5 Shaft, Lorsine Ventilation Shaft No. 5, and Vaal Reefs No. 5 all showed a steep decline in the first five years of operation. After this period the curve is much flatter.

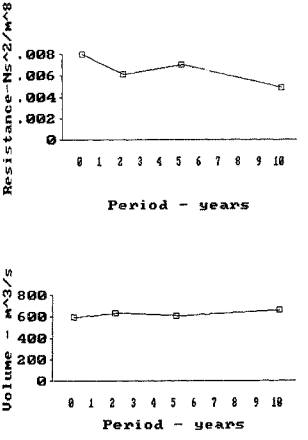


Figure 3.1 Lorsine Gold Mine. No. 4 Shaft

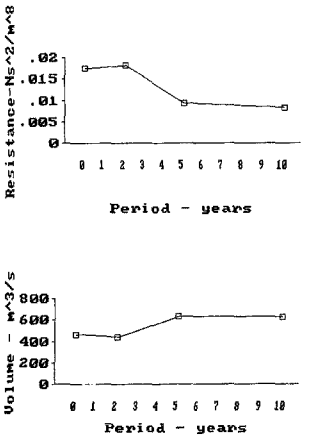


Figure 3.2 Loraine Gold Mine. No. 5 Shaft.

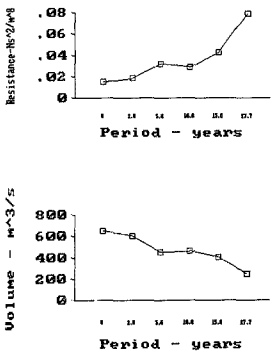


Figure 3.3 Hartebeestfontein No. 3 Shaft

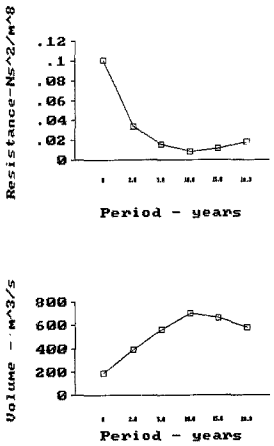


Figure 3.4 Hartebeestfontein No. 5 Shaft

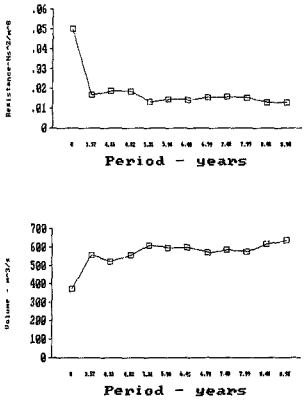


Figure 3.5 Vaal Reefs No. 5 Shaft

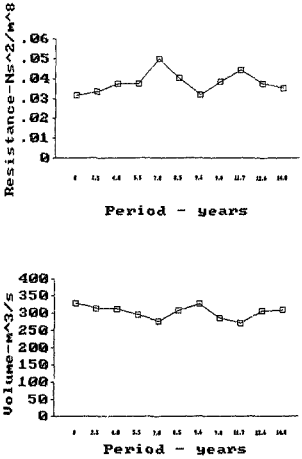


Figure 3.6 St. Helena No. 7 Shaft.

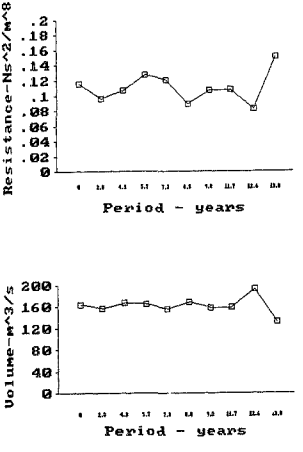


Figure 3.7 St. Helena No. 8 Shaft.

Environmental engineers at Vaal Reefs No. 2 Shaft had identified the fact that their fans were operating inefficiently. The installation of new, modified impellers into the existing casings improved the position considerably. Details of the rate of decrease in resistance at Vaal Reefs No. 2 Shaft are not available. Values shown in table 3.1 are an initial design figure and the current operating point. This installation has been in service for 15 years.

The operating resistance at Elandsrand is marginally up on design. Again intermediate values are not available. Elandsrand shaft was commissioned in 1977.

Hartebeestfontein No. 3 Shaft proved to be an exception with pressure requirement rising continually with time.

3.1.2 Characteristics of older mines appear in figures 3.6 and 3.7. Information from St. Helena Gold Mine showed relatively constant volume flow rate and pressure requirements over a fourteen year period.

3.3.3 Examining these results showed that considerable scatter is evident in the plots of resistance against time. Short term changes in the status of underground doors, booster fans and neighboring fans can contribute to this.

Resistance is inversely proportional to the square of flow rate and therefore sensitive to it. Volume flow rate is invariably measured by anemometer traverse. Surface fans may be checked by measuring flow at the fan drift or by using a combination of underground readings. Environmental engineers consider that uncertainties involved in this type of reading could be as high as ten percent.

Fan pressure rise can be measured accurately. Normal practice on mines is to measure pressure using a side tube on the fan inlet. This yields acceptable results provided that air velocity at the measuring station is not excessively high.

In the cases cited above the variations in resistance are large and the trends well defined enabling valid conclusions to be reached.

3.3.4 Numerous factors affect the way in which the system characteristic of a mine varies. These include:

a. Philosophy and assumptions made during planning.

b. The nature of the reef being mined.

c. The price of gold.

d. The timing and extent to which booster fans are used underground.

e. The quantity of water being conveyed in the upcast shaft.

f. Short circuit leakage through doors and walls.

g. The nature of mining; whether it is concentrated or scattered.

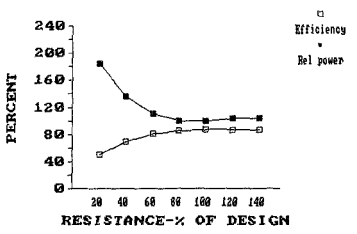


Figure 3.8 Fan performance relative to system resistance

Based on James Howden South Africa fan Type Z Design 98.

These variables make exact trends difficult to predict. Mine planners should anticipate that the mine characteristic is likely to vary considerably during the early life of the mine and that this variation is likely to lead to a drop in fan operating pressures.

3.3.5 Figure 3.8 shows the performance of a typical design of mine ventilation fan. Each point on a fan's characteristic will balance a particular system resistance. Resistance is plotted on the abscissa. Any geometric design of impeller can cover a wide range of duties (by selecting different diameters and speeds). R has therefore been plotted as a percentage, 100% corresponding to an ideal operating point. The ordinate is also a percentage scale showing relative power and actual isentropic efficiency for this design.

The term relative power has been adopted to compare actual power absorbed to the power which would be required for a fan doing the same duty but operating at a favourable reference efficiency (in this case 86.8%).

Operating resistances shown in table 3.1 can be plotted on figure 3.1 and the corresponding relative power obtained. The results are shown in table 3.2.

Table 3.2 The effect on efficiency of changes when a centrifugal fan is used.

MINE	RELATIVE POWER %	EFFICIENCY %
LORAINE #4	107.5	81.0
LORAINE #5	117.1	74.2
HARTEBEESTFONTEIN #3	This design fan would have stalled.	
HARTEBEESTFONTEIN #5	168.0	48.5
VAAL REEFS #2	140.0	59.0
VAAL REEFS #5	132.5	63.5
KLANDSRAND	100.0	87.2

The Vaal Reefs and Hartebeestfontein Fans are operating in a region where efficiency declines rapidly and relative power absorbed increases. For example, if Vaal Reefs No. 5 Shaft fans had the characteristic indicated in figure 3.1 they would be absorbing 35% more power than would be required if they were operating at a favourable point on the curve. The cost of this is shown below.

Pressure ratio across fan r = P / (P-Pf)
where P = atmospheric pressure (kPa).
and Pf =fan static pressure rise (kPa).
r = 88 / (88 - 5.2) = 1.063

Compressibility coefficient(Kp) as defined in
BS 848:pt 1:1980(11)

Kp = [r^((k - 1) / k) - 1] / ((r - 1)(e - 1))

Kp = [1.063^((1.4-1)/1.4)-1]/((0.063)(0.4))=0. 78

where K=ratio of specific heats for air.

Air power assuming isentropic compression.

Air power = Q * Pf * Kp

Air power = 600*5.2*0.978= 3 051 kW

where Q = air volume flow rate at the fan inlet (m^3/s).

Power absorbed at the fan shaft:

Power absorbed = Air power / Fan static efficiency

Power absorbed = 3051/0.635 = 4 804 kW

If the efficiency were restored to 86.8% :

Then power absorbed becomes = 3051/ 0.868 = 3 514 kW

Potential saving = 1 290 kW

Assuming that the average cost per unit of power is 6 cents / kWh.

Then cash saving per annum = 1 290*365*24*6/100

Cash saving per annum = R 678 024

These examples do not necessarily reflect the exact position on the mines involved. Each installation will have a different design of fan with a characteristic

somewhat different to that indicated in figure 3.1. They do however help to describe the problem and give an indication of its magnitude.

3.4 Conclusions

The system resistance of a mine varies considerably during the early life of that mine. The rate of change reduces considerably with time.

This variation results in reduced fan efficiencies.

The penalty in power cost is high.

The nature of the variation differs from mine to mine.

CHAPTER 4

CONTROL OF CENTRIFUGAL FANS

4.1 Introduction

The objective of this study is to seek means to maintain the efficiency of large centrifugal fans operating on gradually changing systems. The various means available for controlling the characteristics of centrifugal fans were discussed in 2.3. Most South African gold mining duties can be done using a single basic geometric design of fan. An appropriate design has been selected for this study and reference is made to it in the following section.

4.2 Controls considered

The output controls considered here are:

i Variations in rotational speed.

ii The use of inlet guide vanes.

iii Changing impeller geometry.

Changing rotational speed produces changes in performance which are readily predicted using well established similarity laws.

$$Q = x N$$

$$Pf = x' N^2$$

$$Pw = x'' N^3$$

Where Q = inlet volume flow rate

Pf = fan pressure rise

x = proportionality constant

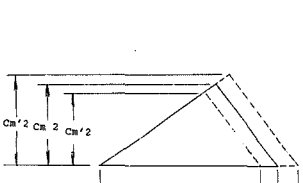
N = fan shaft rotational speed

Pw = shaft power absorbed

For a given position on the fan characteristic, efficiency is taken as constant. This assumption is valid over a wide range of Reynold's Number.

Adjustable inlet guide vanes are a commonly used form of output control. Efficiency drops as vane closure increases. This is confirmed in Figure 2.4 by comparing curves 4b and 2.

Changing impeller geometry in the context used here implies replacing an impeller with one of slightly differing dimensions. Small changes in geometry which are achieved by "cutting down" or extending blades on an existing rotor result in changes in performance which can be calculated with reasonable accuracy. These modifications affect the discharge velocity triangles as indicated in figure 4.1. As the diameter is changed the peripheral speed changes resulting in a different but



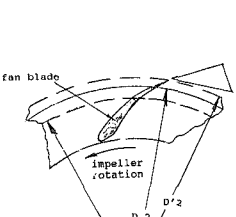


Figure 4.1 The effect of small changes in impeller diameter on velocity triangles

similar velocity triangle. If the subtractive term in Euler's Equation is ignored this results in a modified pressure rise capability which can be determined as follows. See Steppanoff(18):

$$Pf'/Pf = (U'/U)^2$$

where Pf' = fan pressure rise with modified impeller.
U' = corresponding fan impeller peripheral speed.

Similarly volume flow rate varies in direct proportion to the radial flow component Cm2.

$$Q'/Q = Cm2' / Cm2$$

$$Q'/Q = D' / D$$

where Cm2 = radial component of flow at impeller discharge.
Cm2' = radial component of flow with modified impeller.
D and D' are the respective impeller effective diameters.

If efficiency remains constant a revised power absorbed may be calculated using

$$Pw'/Pw = (D'/ D)^3$$

For reasons described by Stepanoff(18) these relationships can only be used safely for small variations in impeller diameter. The effect on efficiency and output should be checked by test work if changes are relatively large (say greater than five percent). All performance data used here is based on the James Howden design Z9B fan and has been confirmed by model testing.

This concept is used to provide flexibility in commercial ranges of fans. By minimizing the number of standard diameters the number of tools, patterns and drawings can be limited.

Impeller width may be varied substantially to alter the quantity of air handled. Changes from standard to +10 or -25% are common. Efficiency changes over this range are often negligible and should be confirmed test work. Actual values used in this exercise are based on test work and are shown in figure 4.2.

The casings on mine fans are substantial structures, often being cast in concrete. Any changes in impeller geometry during the life of an installation must be accommodated in the existing housing.

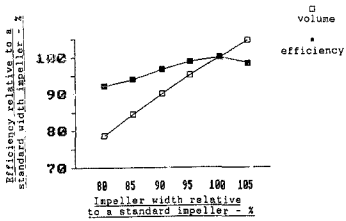


Figure 4.2 The effect of changing impeller width on volume flow rate and efficiency.

The number of combinations made possible by the variation of tip diameter and width, rotational speed and vane settings are enormous. This coupled with duties which change continually with time result in a range of possible selections which can only be optimized effectively by the use of a computer program.

CHAPTER 5

METHOD FOR EVALUATING OWNING COSTS

5.1 Introduction

In order to optimize equipment for ventilation, alternatives have to be selected and examined. The objective is to identify the fan configuration having the lowest owning cost. The scope of items considered and some assumptions made are given below.

5.2 Initial cost

The scope of items affecting initial cost included:

a. The fan comprising an impeller, casing, shaft, bearings, lubrication equipment, coupling, inlet vane control, diffuser, and bearing pedestals. These items were grouped together under "bare fan" for costing.

b. The driving motor.

c. Speed control equipment. This was been included in the motor cost when variable speed motors were considered.

The fan casing was assumed to have been fabricated from steel.

Minimum owning cost has been assessed by considering the differential cost between options. The following items were assumed to be common to all installations irrespective of the fan variant used. Their costs were therefore not considered:

a. Civil work.

b. Instrumentation.

c. The fan inlet drift.

d. Self closing doors.

e. Painting.

f. Erection and commissioning.

5.3 Running costs

Only power cost on the basis of the fan running 24 hours per day and 365 days per year were considered. Routine maintenance, including one impeller change in ten years was assumed to be common to all installations. An average power cost of 5 cents per kWh was assumed. This was based on a figure of 4.7218 cents reflected in Table 16 of ESCOM's 1986 Statistical Yearbook.

5.4 Present value

The concept of present value was used to gauge alternatives. The cost of power used in each year is discounted at a rate which may be selected by the

program user. When an impeller is changed to enhance efficiency, the cost of the impeller is discounted at a similar rate. An estimated inflation rate is also allowed as an input. The derivation of the present value calculation used appears in Appendix E.

5.5 The program

This software runs on IBM compatible personal computers with a minimum of 640 kbyte machine memory. The language used was Turbo Basic. The program basis is outlined in Appendix D. Time taken for a single run varies between 30 minutes and a few hours, depending on the length of life considered and the time at which an impeller change is planned to take place as well as the computer.

A program listing appears in Appendix F.

CHAPTER 6

DISCUSSION

6.1 Introduction

The actual fan duty requirements discussed in Chapter 3 have been used as input for the computer program. This was done to assess the potential benefits available if these projects were designed for minimum combined capital and running costs.

6.2 Vaal Reefs No. 5 Shaft

Several computer program runs were carried out based on actual duty requirements obtained from the Mine. The cost of various options and sensitivity to different parameters was investigated. Computer printouts for the various runs appears in Appendix G. All runs were based on an assumed 20 year life.

Three important results emerged from this exercise.

a. Being able to predict the duty requirement accurately over the life of the installation results in a most significant saving. The centrifugal fan considered here was flexible enough to cover the range of duties required at a reasonable efficiency.

b. A further relatively smaller saving could be achieved by changing the impeller after two years of operation. The replacement impeller would differ slightly in geometry compared to the original.

c. High initial cost of the variable speed option makes it unattractive at the time of writing.

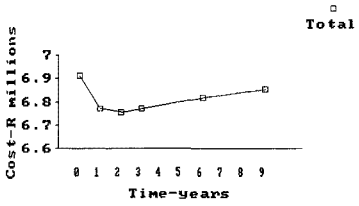


Figure 6.1 Optimum time for impeller change in years, from the date of commissioning.

6.2.1 *Time interval between commissioning and a change* in impeller geometry and speed was investigated. These runs were conducted using a constant 20 % hurdle rate. The system resistance on this mine fell rapidly over the

first few years of its life. The optimum time at which to change the impeller was two years after commissioning. See figure 6.1. This resulted in a present value owning cost of R6 755 578.00. Efficiency and power absorbed over the last ten years of life were 83.5% and 1 798 kW respectively. The working part of this fan's characteristic is shown in figure 6.2. The pressure rise and efficiency characteristics for four inlet guide vane angles are plotted against volume flow rate. Superimposed on this are the various duty points required. *Figure* 6.3 *is a similar* plot for the initial fan selected.

Comparing figures 6.2 and 6.3 shows the following points.

a. Both curves represent fans having the same standard impeller diameter (3.654 m). The impeller in fig. 6.2 is two percent over standard diameter and that in fig. 6.3 is six percent overdiameter.

b. The smaller impeller is not capable of the pressure rise requirement at the beginning of the fans life.

c. The smaller impeller means that the final operating point is relatively higher on the pressure volume characteristic which corresponds with a higher efficiency.

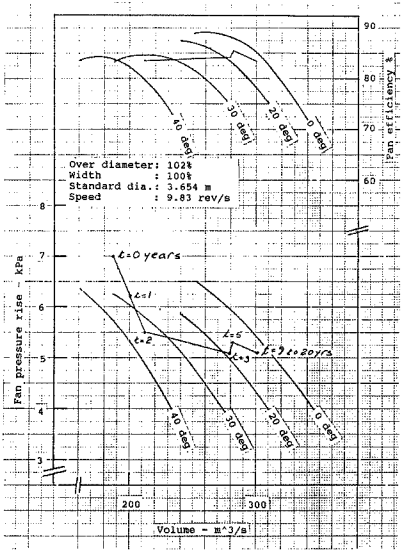


Figure 6.2 Vaal Reefs No. 5 Shaft. Fan performance after a proposed impeller change.

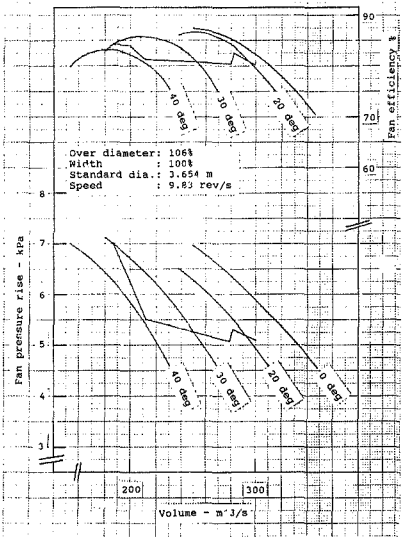


Figure 6.3 Vaal Reefs No. 5 Shaft. Fan performance with initial impeller fitted.

Not changing the impeller or speed results in the 6% over diameter impeller being an optimum. The present value of the owning cost is R 6 912 401. The present value of the saving resulting from changing the impeller is R 156 823 (or R313 646 for the two fan installation). The efficiency and power absorbed for the period from 9 to 20 years from commissioning is 80.6% and 1 857 kW respectively.

6.2.2 Sensitivity to hurdle rate was checked. Varying this parameter between ten and thirty percent resulted in the selection of the same equipment. A larger and slower running fan was selected in the extreme case of setting the hurdle rate equal to zero. This variation puts a heavy weighting on future operating cost and places less emphasis on capital and early operating costs. Figures 6.4 and 6.5 show performance curves of the unit concerned. Poor efficiency in the installation's early life is apparent. Over the period 9 to 20 years, efficiency was 86.5% and power absorbed was 1 730 kW per fan.

6.2.3 General

a. In this exercise no cost advantage could be shown by using variable speed drives.

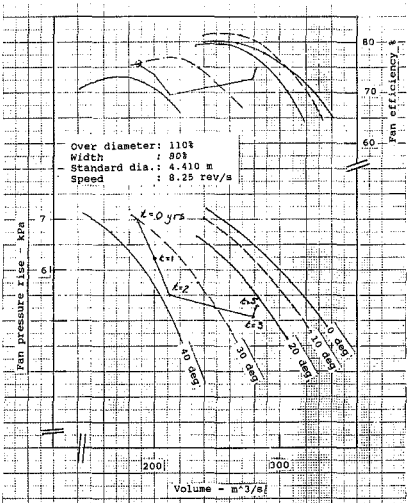


Figure 6.4 Vaal Reefs No. 5 Shaft. Performance of a fan selected with hurdle rate zero. The first nine years.

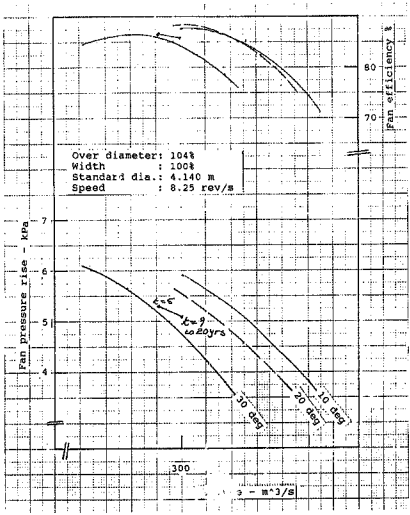


Figure 6.5 Vaal Reefs No. 5 Shaft. Performance of a fan selected with hurdle rate zero. Years 6 to 20.

b. A selection based the initial duty only, gave a small high speed fan. This selection, depicted in fig. 6.6 shows a final efficiency of 56%. The fan is unable to meet the final duties, the shortfall in volume flow rate being 13.5% on a square law system characteristic.

6.3 Loraine No 4 Shaft

The range of duties reported for this shaft were small enough for a single speed fan without an impeller change to be an optimum. The variable speed option was again more expensive.

6.4 Loraine No 5 Shaft

The change in duty over the life of this installation was too great to be coped with even with a change in impeller. A variable speed selection was the only option returned by the program. In practice this wide range of duties is met using an adjustable pitch axial flow fan.

6.5 Hartebeestfontein No. 3 Shaft

Volume flow rate reported for this shaft varied from an initial 649 m^3/s down to 247 m^3/s. Only a variable speed drive showed the flexibility to cope with this

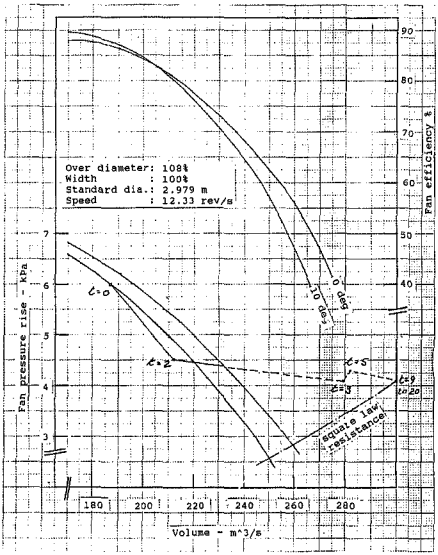


Figure 6.6 Vaal Reefs No. 5 Shaft. Performance curve of a fan selected considering the initial duty only.

fluctuation. A possible solution here would be to start with a three fan installation and gradually decrease this to a single fan in operation for the final duty.

6.6 Hartebeestfontein No. 5 Shaft

The change in duties was too great to be covered efficiently by even the variable speed option of the fan considered in this project. Again the number of fans in service could be varied to cope with this.

CHAPTER 7

CONCLUSIONS

7.1 Introduction

Software for the optimizing fan selection has been developed. The program minimizes capital and running costs of fans installed on a gradually changing system. Several mines with known histories have been modelled. This investigation has lead to the following conclusions.

1 The resistance to ventilating air flow through a mine varies considerably with time.

2 Optimization of fan selection using the computer program developed results in large cost savings and performance benefits.

3 In the examples studied, changing the impeller, part way through an installations life can result in a further saving.

4 The selection of equipment was insensitive to the hurdle rate used in the evaluation.

5 Variable speed motors cannot be justified in terms of the cost and performance parameters discussed here. Exceptions are the cases where the spread of duties can only be coped with by using a range of speeds.

7.2 Recommendations for future work

a. This program can be used as a tool to assist in the planning of actual projects.

b. Its application can be expanded by including performance parameters for different fans.

c. Cost data must be updated on a continual basis.

Appendix A

COST OF POWER TO LARGE CONSUMERS (1987)

Many mines are selecting to be charged for power under ESCOM's recently introduced Tariff E. Rates quoted below are applicable to supply voltages between 380V and 6 600V. The charge is made up as follows:

Unit Charge

Each kWh of electrical energy supplied to the customer is paid for at a rate of 2.787 cents.

Maximum Demand

This will be charged in one of two ways Consumers are currently able to choose the option they prefer.

Option 1: Energy consumed over each consecutive hour is measured. The highest consumption in any one hour period determines the maximum demand charge for that month. Under this option the cost is R15,65 per kW per month.

Option 2: This is similar to option 1 but the measurement period is 30 minutes and the energy is measured as kVA. In this case the cost is R16,26 per kVA per month.

Under Tariff E the maximum demand is only measured during the period from 7h00 to 23h00 on weekdays, subject to a maximum load factor of 127,5%. Load factor is the ratio of total energy consumed in a given period

to the energy which would have been consumed if demand was steady at maximum demand. For gold mines the load factor is typically between 80% and 90%.

Load factor = kWh/(kW max. demand * hours in period)

Monthly charge per supply point

There is a modest charge of R59.89 per supply point.

Transmission surcharge

A transmission surcharge of 1% per 300 km radial distance from Johannesburg is levied. Starting at 301 km it extends up to a maximum of 3%.

Appendix B

Tabulation of data received from Loraine Gold Mine for No. 4 Shaft.

OLUME-m^3/s	PRESSURE-Pa	DENSITY-kg/m^3	PERIOD YRS	RESISTANCE-Ns^2/m^8
596	2840	.96	0	.0080
633	2460	.96	2.00	.0061
608	2600	.96	5.00	.0070
658	2120	.96	10.00	.0049

Appendix B

Tabulation of data received from Loraine Gold Mine for No. 2 Shaft.

\ LUME-m^3/s	PRESSURE-Pa	DENSITY-kg/m^3	PERIOD YRS	RESISTANCE-Ns^2/m^8
462	3700	.96	0	.0173
440	3500	.96	2.00	.0181
630	3700	.96	5.00	.0093
622	3200	.96	10.00	.0083

Appendix B

Tabulation of data received from Hartebeestfontein for No. 3 Shaft.

LUME-m^3/s	PRESSURE-Pa	DENSITY-kg/m^3	PERIOD-YRS	RESISTANCE-Ns^2/m^8
649	6500	.96	0	.0154
600	6800	.96	2.00	.0189
453	6500	.96	5.00	.0317
465	6300	.96	10.00	.0291
401	6900	.96	15.00	.0429
247	4800	.96	17.67	.0787

Appendix B

Tabulation of data received from Hartebeestfontein Gold Mine for No. 5 Shaft.

LUME-m^3/s	PRESSURE-Pa	DENSITY-kg/m^3	PERIOD-YRS	RESISTANCE-Ns^2/m^8
189	3600	.96	0	.1008
391	5200	.96	2.00	.0340
563	5000	.96	5.00	.0158
698	4200	.96	10.00	.0086
660	5100	.96	15.00	.0117
579	6000	.96	18.33	.0179

Appendix B

Tabulation of [illegible] received from Vaal Reefs Gold Mine for No. 5 Shaft.

VOLUME-m^3/s	PRESSURE-Pa	DENSITY-kg/m^3	PERIOD YRS	RESISTANCE-Ns^2/m^8
[illegible]4	7000	.96	0	.0500
440	4980	.96	2.65	.0257
440	5200	.96	2.74	.0269
474	4980	.96	2.82	.0222
558.80	5080	.96	3.06	.0163
589.80	5100	.96	3.32	.0147
559.50	[illegible]240	.96	3.57	.0167
[illegible]9.60	5220	.96	3.90	.0186
[illegible]40.40	5000	.96	3.99	.0144
584.10	5200	.96	4.06	.0152
513	4900	.96	4.15	.0130
[illegible]97.20	5200	.96	4.23	.0146
[illegible]22.90	5180	.96	4.31	.0189
[illegible]07.60	5200	.96	4.40	.0141
[illegible]41.60	5060	.96	4.48	.0150
[illegible]70	5500	.96	4.57	.0166
572.[illegible]	5600	.96	4.65	.0171
565.[illegible]	5480	.96	4.73	.0171
557.80	5720	.96	4.82	.0184
574.70	5200	.96	4.90	.0157
565.80	5300	.96	4.99	.0166

[illegible]	5500	.96	5.06	.0175
551.50	5500	.96	5.15	.0181
581.20	5380	.96	5.23	.0159
610.50	4920	.96	5.31	.0132
534.30	5100	.96	5.57	.0179
537.70	4980	.96	5.65	.0172
543.30	4980	.96	5.73	.0169
521.80	5120	.96	5.82	.0188
512	4940	.96	5.90	.0188
496	5180	.96	5.98	.0146
596.30	5000	.96	6.06	.0141
536.90	5000	.96	6.15	.0173
601.10	5000	.96	6.23	.0138
621.70	4850	.96	6.32	.0125
587	5130	.96	6.40	.0149
601.60	5100	.96	6.48	.0141
595.40	5200	.96	6.57	.0147
573.80	5600	.96	6.65	.0170
586.20	5200	.96	6.74	.0151
573.10	5300	.96	6.82	.0161
602	5260	.96	6.90	.0145
572.80	5140	.96	6.99	.0157
580	5150	.96	7.06	.0153
549.30	5180	.96	7.15	.0172
560.30	5180	.96	7.23	.0165
604.90	5170	.96	7.32	.0141
556.70	5000	.96	7.40	.0161

585	5380	.96	7.48	.0157
585	5200	.96	7.57	.0152
553.50	4500	.96	7.65	.0147
564.60	4900	.96	7.73	.0154
560.10	5220	.96	7.82	.0166
564.80	4900	.96	7.90	.0154
577.10	5050	.96	7.99	.0152
577.10	5050	.96	8.07	.0152
601.60	5000	.96	8.15	.0138
600.80	5100	.96	8.23	.0141
600.80	5100	.96	8.31	.0141
593.60	5100	.96	8.40	.0145
618	5000	.96	8.48	.0131
586	5175	.96	8.57	.0151
594	5100	.96	8.65	.0145
580	5200	.96	8.73	.0155
589.60	5290	.96	8.82	.0152
638.20	5300	.96	8.90	.0130

Appendix B

Tabulation of data received from St Helena Gold Mine for No. 7 Shaft.

LUME-m^3/s	PRESSURE-Pa	DENSITY-kg/m^3	DATE	RESISTANCE Ns^2/m^8
327.70	3400	.97	Mar 31, 73	.0314
316.25	3060	.99	Oct 4, 73	.0298
327.02	3330	.96	Mar 1, 74	.0312
323.70	3200	.96	Sep 28, 74	.0306
323.45	3110	.96	Mar 14, 75	.0298
321.52	3210	.92	May 30, 75	.0323
312.67	3290	.96	Sep 23, 75	.0335
321	3060	.99	Dec 31, 75	.0288
308.04	3350	.98	Mar 17, 76	.0346
324.02	3160	.97	Jun 19, 76	.0298
299.50	3250	1	Aug 6, 76	.0348
298.34	3520	.98	Dec 13, 76	.0389
312.41	3680	.97	Mar 25, 77	.0373
293.65	3660	.99	Jul 8, 77	.0412
279.53	3270	.98	Sep 23, 77	.0409
294.77	3580	.97	Jan 20, 78	.0406
304.01	3670	.97	Jan 23, 78	.0393
324.66	3460	.98	Jun 30, 78	.0322
294.84	3350	.99	Sep 25, 78	.0374
293.86	3440	.98	Dec 26, 78	.0390
301.57	3700	.97	Mar 20, 79	.0403

312.10	3300	.99	Jun 15, 79	.0327
314.10	3360	.95	Sep 7, 79	.0343
307.15	3460	.97	Dec 12, 79	.0362
275.10	3840	.98	Apr 2, 80	.0499
302.83	3240	1.00	Jul 1, 80	.0339
297.27	3200	.98	Sep ?, 80	.0354
262.06	3760	.95	Dec 26, 80	.0555
290.60	3940	.98	Mar 6, 81	.0459
289	3760	.99	Jul 2, 81	.0438
307	3750	.95	Sep 29, 81	.0402
277.10	3500	.96	Feb 4, 82	.0455
286.84	3700	.98	May 22, 82	.0440
290.75	3900	.98	Aug 31, 82	.0414
315.22	3560	.97	Sep 28, 82	.0354
323.66	3520	.98	Nov 15, 82	.0331
325.68	3420	.97	Nov 17, 82	.0318
286	3230	.99	Jan 28, 83	.0383
283.50	3440	1	Jul 13, 83	.0411
294.90	3460	1.00	Oct 26, 83	.0381
282.50	3300	.99	Mar 20, 84	.0402
275.30	3220	.99	Apr 26, 84	.0410
279.40	3550	1.01	Oct 9, 84	.0432
269.70	3470	1.04	Nov 27, 84	.0442
281.20	3230	.98	Mar 7, 85	.0400
288	3500	.99	Apr 29, 85	.0408
297.50	3010	1.01	Jul 4, 85	.0322
288.05	3160	.99	Aug 27, 85	.0368

291.90	3340	.98	Sep 27, 85	.0382
305.90	3460	.95	Oct 22, 85	.0374
296.40	3660	.98	Nov 11, 85	.0407
366.14	3700	.99	Dec 30, 85	.0268
201.16	1500	.98	Mar 27, 86	.0362
183.06	1470	1.02	May 9, 86	.0414
333.40	3470	.96	Sep 30, 86	.0313
309.30	3480	1.00	Jan 7, 87	.0350

Appendix B

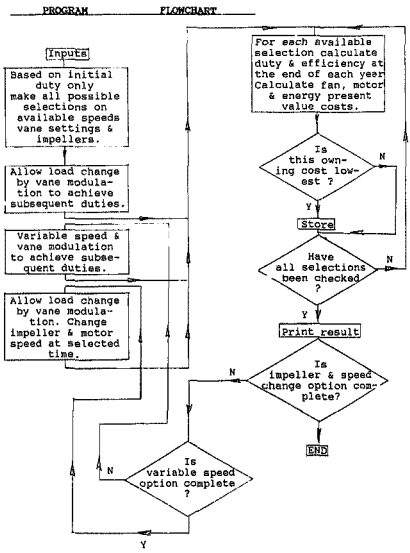
Tabulation of data received from St Helena Gold Mine for No. 8 Shaft.

VOLUME-m^3/s	PRESSURE-Pa	DENSITY-kg/m^3	DATE	RESISTANCE Ns^2/m^8
164.19	3160	.972	Mar 31, 73	.1158
163.90	3020	.974	Oct 4, 73	.1108
170.60	3230	.960	Mar 1, 74	.1110
168.20	3760	.954	Sep 28, 74	.1337
172.93	2940	.947	Mar 14, 75	.0997
123.94	2920	.935	May 30, 75	.1952
162.16	3180	.961	Sep 23, 75	.1208
156.89	2420	.980	Dec 31, 75	.0963
163.30	3250	960	Mar 17, 76	.1219
166.18	2900	.970	Jun 19, 76	.1039
169.42	3320	.990	Aug 6, 76	.1122
158.48	2920	.966	Dec 13, 76	.1155
169.75	2970	.970	Mar 25, 77	.1020
168.26	3120	.990	Jul 8, 77	.1069
157.96	3080	.972	Sep 23, 77	.1219
161.37	3000	.969	Jan 20, 78	.1141
152.40	3020	.963	Jan 23, 78	.1296
174.18	3440	.980	Jun 30, 78	.1111
162.69	2820	.990	Sep 25, 78	.1033
165.82	3500	.960	Dec 26, 78	.1273
157.23	3520	.950	Mar 20, 79	.1439

Appendix B

171.79	3260	.980	Jun 15, 79	.1082
167.60	3320	.977	Sep 7, 79	.1161
163.20	3360	.969	Dec 12, 79	.1250
155.40	3280	.973	Apr 2, 80	.1340
155.53	3060	1.003	Jul 1, 80	.1211
161.94	3300	.977	Sep 4, 80	.1236
143.27	3180	.947	Dec 26, 80	.1570
157.10	3060	.983	Mar 6, 81	.1211
168.40	3160	1.000	Jul 2, 81	.1070
170	3200	.969	Sep 29, 81	.1097
169.12	2930	.950	Feb 4, 82	.0894
171.19	2730	.984	May 22, 82	.0909
166.82	2900	.963	Aug 31, 82	.1039
172	2850	.966	Sep 28, 82	.0957
172	2850	.966	Nov 15, 82	.0957
158.60	2780	.990	Jan 28, 83	.1072
162.50	3030	1.002	Jul 13, 83	.1099
169.60	2900	1.012	Oct 26, 83	.0956
162.40	2850	.994	Mar 20, 84	.1044
170.70	2720	1.000	Apr 26, 84	.0897
161.10	2860	1.010	Oct 9, 84	.1047
159.40	2940	1.031	Nov 27, 84	.1077
167.70	3240	.980	Mar 7, 85	.1128
161	2570	1.020	Apr 29, 85	.0910
162.40	2300	1.030	Jul 4, 85	.0813
170.80	3020	1.052	Aug 27, 85	.1039
168.30	3020	1.001	Sep 27, 85	.1060

193.50	3180	.984	Oct 22, 85	.0828
125.90	1640	1.010	Nov 26, 85	.0983
183.50	3280	1.002	Dec 30, 85	.0933
171.15	2810	.994	Mar 27, 86	.0926
173.55	2740	1.060	May 9, 86	.0824
156.50	2720	.991	Sep 30, 86	.1076
132	2750	1.003	Jan 7, 87	.1511


PROGRAM FLOWCHART
Inputs
Based on initial duty only make all possible selections on available speeds vane settings & impellers.
Allow load change by vane modulation to achieve subsequent duties.
Variable speed & vane modulation to achieve subsequent duties.
Allow load change by vane modulation. Change impeller & motor speed at selected time.
Is variable speed option complete ?
N
Y
Is impeller & speed change option complete?
N
END
For each available selection calculate duty & efficiency at the end of each year Calculate fan, motor & energy present value costs.
Is this owning cost lowest ?
N
Y
Store
Have all selections been checked ?
N
Y
Print result

PROGRAM BASIS

1 **Input required:**

a. The number of duties to be considered. This was limited to a maximum of ten. The time in years at which each flow rate and pressure rise will be required must be specified. Time must be entered as an integer, fractions are not accepted. The volume flow rate required is that for each fan on the installation.

b. Site atmospheric pressure and inlet temperature are assumed to be constant over the life of the installation and are only entered once. For simplicity only dry bulb temperature is considered.

c. The life of the installation in years is required. Again only integer values are accepted.

d. The average current cost for electrical power is next. This must be based on unit cost and maximum demand charge, bearing in mind that these fans will run 24 hours per day.

e. An assumed annual cost escalation must be entered. A separate figure for power and fan capital cost is called for. The latter only affects the cost of replacement impellers and is of minor importance.

f. The hurdle rate required. This is usually a matter of company policy.

g. Finally the time interval until an impeller and motor speed change would take place. This must be entered as a whole number of years starting from the fan commissioning date.

2 Fan sizing procedure.

As many selections as possible are made using the original duty specified. For each of these selections the following procedure is used.

a. An induction motor speed is assumed from 16,33; 12,33; 9.83 and 8,25 rev/s.

b. Reference charts for the Howden Design Z9B are stored in the computer. These are based on the performance of a 1m diameter fan rotating at a speed of 31,83 rev/s and handling air at a density of 1 kg/m^3. Each pressure volume characteristic is split into two parts. These halves are stored as quadratic functions obtained using least squares curve fits. Fan efficiency characteristics are represented in the same fashion. The program allows operating points up to 95% of the fans peak pressure capability.

Coefficients for curves representing vane closure of 0; 10; 20; 30; and 40 degrees were included. Over diameters range from 110% down to 96% in eight equal steps.

c. The initial duty is corrected to chart conditions for speed and density using standard fan laws. 1 is represents the performance of the required fan if it were sped up from the assumed speed to 31.83 rev/s. A volume correction factor is applied if the impeller width considered is not standard.

d. The specific speed required to meet this duty is then calculated. If this lies within the considered fan's capability the procedure continues (see figure D1.).

e. The diameter of the fan is now reduced until its performance coincides with that of the reference fan. This enables the required diameter to be calculated again using fan laws.

f. This process is repeated and an impeller diameter for all practical vane setting, impeller width, rotational speed and over diameter combinations is stored. 80%; 100% and 106% are the three impeller widths considered.

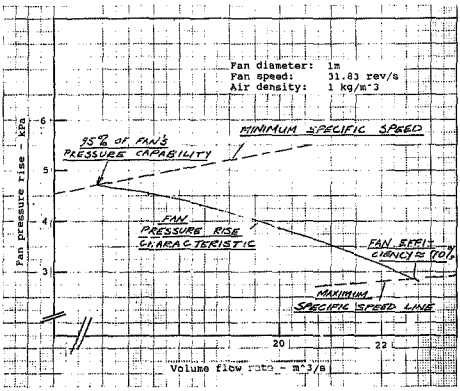


Figure D1 The operating portion of a fan pressure characteristic bounded by limiting specific speed lines.

h. The program rejects any selection requiring an impeller peripheral speed of over 140 m/s. This is a wheel stress consideration.

2.1 The fixed impeller constant speed option.
For each available impeller diameter the following procedure is used:

a. The duty at the end of each year of operation is established by linear interpolation between duties which have been fed in. This duty is corrected to reference chart conditions and an efficiency is calculated by interpolation between the two adjacent vane setting curves. (Inlet guide vane modulation is the only means of control considered in this section.)

b. An average power consumption for each year is then determined.

c. The cost of power is calculated on a 24h per day, 365 day per year basis. The average unit price escalated to the year concerned is multiplied by units consumed. This cost is then discounted using the hurdle rate specified, to give a present value. See Appendix E.

d. Bare fan cost is expressed as a function of impeller standard diameter. Two different curves are used depending on whether the pressure rise required is above or below 6 kPa. Fan costs are based on information obtained from James Howden South Africa.

e. Motor cost is a function of capacity required and rotational speed. The curves used were drawn up from data furnished by Siemens Limited, Johannesburg.

f. The total ownership cost was taken as the sum of the fan, motor and discounted energy cost.

g. Each option cost is compared to the previous lowest figure, the lower of the two figures is retained.

2.2 The fixed impeller diameter, variable speed option.

a. A duty for each year of operation is obtained in the manner described above.

b. The fan speed is adjusted to allow the duty to be met using each available inlet guide vane angle. The best efficiency and corresponding speed are retained.

c. The power cost calculation is carried out exactly as indicated above, as is the bare fan cost.

d. The cost of the motor and its controller are based on information which was supplied by GEC SA. The assumption that price is a function of motor torque gave a good correlation and has been used.

2.3 The impeller change, 2-speed motor option.

a. All calculations in this section are similar to those described in Section 2.1.

b. For each selection made as described in 2.1 the procedure is identical until the time which is specified as the change time is reached. The bare fan cost and power cost up to this point are calculated and stored.

c. A marginal cost is then calculated for each impeller width, vane setting, over diameter and motor speed which can be used in conjunction with the original casing.

d. The marginal cost includes an impeller replacement, a 15% premium on the motor cost if a two speed unit is used, an additional cost if the speed of the motor is decreased, meaning a heaver frame and the discounted power cost after the change.

e. The lowest marginal cost is retained and added to the initial cost obtained in b. to give a total owning cost.

f. The lowest total owning cost is returned at the end of the run.

g. The impeller cost was expressed as a function of pressure rise and volume handled. This again was based on information obtained from James Howden South Africa.

Appendix E

PRESENT VALUE CALCULATION

Let the present cost of power be A cents/kWh and the assumed inflation rate per annum per unit be e.
The cost of power n years from now becomes

$$Cn = A(1+e)^{(n-1)}$$

If the required hurdle rate is h per unit, then the present value of a unit of electricity is

$$pv = Cn/((1+h)^n)$$

This term multiplied by the number of units consumed during year n gives the present value of energy used during that year.

```
'last update: 88/04/08

 PTION BASE 1
CLS

'Assume fan curve can be represented by Pref = AQ^2 + BQ + C
'Assume fan efficiency can be represented by Z = DQ^2 + EQ + F
DIM A(5,8):'8 * overdiameters, 5 * vane settings. (m,n)
DIM B(5,8):' i. e. 2 quadratics per curve.
DIM C(5,8),D(5,8)
DIM E(5,8)
DIM F(5,8)
DIM G(5,8)
DIM H(5,8)
DIM I(5,8)
DIM J(5,8)
DIM K(5,8)
DIM L(5,8)
DIM Q70(5,8)
DIM Qmin(5,8):'Lower volumes are too close to the fan stall
DIM Q(10): 'Duties which can be entered. (j)
DIM P(10)
DIM Prd(10)
DIM N(4):'4-speeds (i)
```

```
DIM De(8,5,4,3):'selection identification :m,n,i,w
DIM Ie(8,5,4,3)
DIM EfficiencyCorrection(3)
DIM VolumeCorrection(3)
DIM ad(8)
DIM Width(3)

DATA  1e.33,12.33,9.83,8.25
 'N

DATA  -0.02022e,-0.01741,-0.01271,-0.01617,-0.01891,-0.02127,-0.0227e,-0.02437
 'A 0

DATA  -0.02652,-0.02057,-0.01618,-0.02054,-0.0288e,-0.01231,-0.02262,-0.02896
 'A 10

DATA  -0.02633,-0.029,-0.02531,-0.01719,-0.02331,-0.02096,-0.02905,-0.03399
 'A 20

DATA  -0.02481,-0.03730,-0.02047,-0.02219,-0.02292,-0.02998,-0.03163,-0.03865
 'A 30

DATA  -0.05199,-0.02920,-0.03479,-0.03902,-0.03708,-0.02073,-0.04264,-0.04248
 'A 40

DATA  0.4811,0.3573,0.1955,0.5267,0.4085,0.5365,0.5972,0.6447
 'B 0

DATA  0.6799,0.4273,0.3992,0.4311,0.7807,0.1414,0.5112,0.6413
 'B 10

DATA  0.6188,0.7234,0.52a7,0.2754,0.5267,0.4291,0.6838,0.8698
 'B 20

DATA  0.3741,0.7741,0.2221,0.3168,0.375,0.3331,0.6568,0.9621
 'B 30

DATA  0.8764,0.3533,0.4949,0.6149,0.5e25,0.2297,0.9120,0.8387
 'B 40

DATA  4.06e,4.94e,3.077,4.400,3.702,1.647,0.9075,0.1769
 'C 0

DATA  2.291,4.4e4,4.922,3.68e,-0.05635,5.5,1.9e,0.3701
 'C 10

DATA  2.826,1.4098,2.778,4.983,2.278,2.877,0.5196,-1.518
 'C 20

DATA  5.374,2.063,5.673,4.903,3.914,3.900,1.105,-0.6708
 'C 30

DATA  2.922,3.394,4.221,3.231,3.354,4.371,0.3984,-0.09834
 'C 40

DATA  -0.4331,-0.4399,-0.3369,-0.4431,-0.6249,-0.4930,-0.6152,-0.6299
 'D 0

DATA  -0.6079,-0.5046,-0.4706,-0.4831,-0.5689,-0.5461,-0.6576,-0.9001
 'D 10

DATA  -0.6823,-0.6847,-0.6384,-0.5405,-0.4935,-0.5929,-0.9472,-1.096
 'D 20

DATA  -0.5675,-0.9054,-0.7033,-0.5068,-0.5153,-0.3334,-0.8335,-1.059
 'D 30
```

```
DATA  -0.6782,-0.7080,-0.8029,-0.8229,-0.7679,-0.3077,-1.001,-1.201
 'D 40

DATA  15.19,14.71,11.49,14.99,21.68,14.39,21.21,23.26
 'E 0

DATA  21.43,16.45,15.41,15.03,18.93,17.05,21.03,29.62
 'E 10

DATA  23.39,23.22,21.25,19.49,15.43,18.45,30.11,35.17
 'E 20

DATA  18.23,26.42,19.71,14.51,14.59,9.245,23.22,30.39
 'E 30

DATA  18.13,17.38,19.58,20.20,17.88,7.602,25.24,30.65
 'E 40



DATA  -46.15,-35.10,-5.026,-39.61,-98.81,-49.38,-97.96,-94.10
 'F 0

DATA  -100.1,-44.29,-37.56,-45.27,-68.24,-51.76,-82.86,-158.3
 'F 10

DATA  -117.1,-110.1,-90.12,-64.01,-32.97,-53.29,-134.8,-197.7
 'F 20

DATA  -32.61,-107.1,-32.27,-17.31,-19.51,22.99,-76.73,-134.3
 'F 30

DATA  -16.62,-23.22,-36.12,-40.93,-19.42,34.49,-76.70,-110.4
 'F 40

DATA  -0.02467,-0.03385,-0.02457,-0.01361,-0.01314,-0.01015,-0.00678,-0.01118
 'G 0

DATA  -0.01213,-0.03948,-0.02041,-0.007143,-0.001392,-0.03899,-0.01347,-0.02841
 'G 10

DATA  -0.03019,-0.03782,-0.04427,-0.05306,-0.00648,-0.03135,-0.03458,-0.1087
 'G 20

DATA  -0.01017,-0.04862,-0.01318,-0.04269,-0.02473,-0.01052,-0.03101,-0.07644
 'G 30

DATA  -0.04988,-0.0279,-0.07738,-0.04153,-0.02513,-0.03365,-0.1506,-0.1562
 'G 40

DATA  0.7286,1.1502,0.7316,0.1905,0.1650,0.2621,2.147,0.03572
 'H 0

DATA  0.07364,1.333,0.437,-0.1843,-0.4624,1.346,0.07912,0.7358
 'H 10

DATA  0.7645,1.084,1.388,1.803,-0.2767,0.0229,0.8991,3.813
 'H 20

DATA  -0.2537,2.042,0.002443,1.081,0.3941,-0.1711,0.7527,2.705
 'H 30

DATA  0.9835,0.2342,1.908,0.7437,0.1899,0.5279,4.138,4.344
 'H 40

DATA  0.6835,-5.206,-0.8428,6.191,6.263,4.723,-16.65,7.175
 'I 0

DATA  9.724,-6.177,5.875,10.31,13.99,-7.988,6.983,-.5375
 'I 10

DATA  1.463,-2.325,-6.186,-11.29,11.60,-.8810,.0279,-30.37
 'I 20

DATA  12.72,-10.21,8.443,-9.383,4.220,9.329,-0.8238,-17.05
```

```
DATA  0.7855,6.592,-7.479,1.7911,6.211,2.8019,-25.05,-26.97
DATA  -.8306,-.9917,-.7425,-.7088,-.7907,-.9506,-2.099,-1.125
DATA  -.6590,-1.005,-.9367,-.8639,-.5789,-1.669,-1.020,-1.507
DATA  -1.156,-1.427,-1.643,-2.238,-0.9954,-1.908,-2.048,-4.196
 ATA  -0.8764,-2.169,-0.9051,-2.621,-1.685,-1.431,-2.113,-4.522
DATA  -1.719,-1.542,-2.556,-2.908,-1.725,-2.651,-5.119,-6.796
DATA  34.91,41.85,29.33,26.68,30.442,37.04,87.99,41.90
DATA  23.82,39.50,35.52,31.72,17.63,68.63,34.31,54.61
DATA  43.44,54.02,62.93,89.07,33.51,72.05,71.34,156.4
DATA  25.41,74.33,25.23,92.14,56.38,44.26,66.37,152.5
DATA  48.86,42.00,74.39,87.87,47.16,78.26,151.2,205.6
DATA  -290.6,-367.5,-211.5,-166.7,-212.5,-282.2,-849.1,-708.9
DATA  -129.1,-308.39,-255.3,-206.2,-34.67,-632.4,-201.6,-415.7
DATA  -325.1,-430.5,-522.6,-806.1,-192.5,-602.3,-540.19,-1383
DATA  -95.86,-559,-86.19,-729.9,-390.8,-258.8,-443.2,-1210.0
DATA  -273.04,-207,-465.2,-588.8,-243.8,-503.6,-1039,-1475
DATA  16.7,16.6,16.6,16.4,16.8,16.4,16.4,16.4
DATA  16.6,16.6,16.4,16.4,16.5,15.6,15.9,15.9
DATA  16.2,15.8,15.8,16,16,15.1,15.2,15.2
DATA  12.6,12.0,12.0,12.4,12.5,13,12.9,13.6
DATA  9.98,9.9,10.2,10.3,10.7,9.80,11.3,11
DATA  23.8,23.1,23,23.1,22.9,22.6,22.2,21.6
DATA  22.6,22,21.9,21.8,22,20.9,20.7,20.4
DATA  21.2,20.8,20.6,20.6,20.6,19.5,19.4,19.1
DATA  18.2,18,17.85,18.2,18.3,17.5,17.5,17.35
DATA  15.4,15.4,15.3,15.6,15.5,15.5,15.5,15.8
```

```
DATA  .976,1,.922                                          'Efficienc
DATA  1.055,1.0,0.785                                      'VolumeCor
DATA  1.1,1.08,1.06,1.04,1.02,1,.98,.96                    'Over diam
DATA  106,100,80                                           'Over widt


LPRINT "    FAN OWNING COST ESTIMATE"
LPRINT
Input"Enter site name: ",Site$
Input"Enter job reference: ",Job$
Input"Enter your initials: ",Initials$
LPRINT"Site name: ";Site$
LPRINT"Job reference: ";Job$
LPRINT"Initials: ";Initials$
LPRINT
LPRINT "INPUT"
Input "Date: ",Dte$
LPRINT"Date: ";Dte$
LPRINT


FOR I = 1 to 4:READ N(I):NEXT I
FOR I = 1 TO 5:FOR J= 1 TO 8:READ A(I,J): NEXT J,I
FOR I = 1 TO 5:FOR J= 1 TO 8:READ B(I,J): NEXT J,I
FOR I = 1 TO 5:FOR J= 1 TO 8:READ C(I,J): NEXT J,I
FOR I = 1 TO 5:FOR J= 1 TO 8:READ D(I,J): NEXT J,I
FOR I = 1 TO 5:FOR J= 1 TO 8:READ E(I,J): NEXT J,I
FOR I = 1 TO 5:FOR J= 1 TO 8:READ F(I,J): NEXT J,I
```

```
FOR i=1 TO 5:FOR j= 1 TO 8:READ G(i,j): NEXT J,I
FOR i=1 TO 5:FOR j= 1 TO 8:READ H(i,j): NEXT J,I
FOR i=1 TO 5:FOR j= 1 TO 8:READ I(i,j): NEXT J,I
FOR i=1 TO 5:FOR j= 1 TO 8:READ J(i,j): NEXT J,I
FOR i=1 TO 5:FOR j= 1 TO 8:READ K(i,j): NEXT J,I
FOR i=1 TO 5:FOR j= 1 TO 8:READ L(i,j): NEXT J,I
FOR i=1 TO 5:FOR j= 1 TO 8:READ Qmin(i,j): NEXT J,I
FOR i=1 TO 5:FOR j= 1 TO 8:READ Q70(i,j): NEXT J,I
FOR i=1 TO 3: READ EfficiencyCorrection(i): NEXT i
FOR i=1 TO 3: READ VolumeCorrection(i): NEXT i
FOR i=1 TO 8: READ od(i): NEXT i
FOR i=1 TO 3: READ Wdth(i): NEXT i

'Function for calculating air density at fan inlet and equivalent head.
DEF FNDensity = (Barometer - P)/(0.2861 * (AirTemperature + 273))
DEF FNr = Barometer/(Barometer -P)
DEF FNKp = (FNr^(.4/1.4) -1) * 1.4/(.4*(FNr-1))
DEF FNHe=P/FNDensity*FNKp

Input "How many duty points must be considered   ";DutyNo%
Input "Initial volume flowrate per fan (m^3/s) = ",Q(1)
Input "Initial fan pressure rise (kPa) = ", P(1)
LET Psmax=P(1)
LET Prd (1)=0
For j   2 to DutyNo%:'10 maximum
PRINT
PRINT "Duty No "USING "#";j
```

```
Input "Volume flowrate (m^3/s) = ", Q(j)
Input "Fan pressure rise (kPa) = ", P(j)
IF P(j)>Psmax THEN Psmax=P(j)
Input "Enter period in years when this duty will be required  ",Prd(j)
Next j
LPRINT "Number of duty points considered:  "Using"##";DutyNo%
LPRINT "Initial volume flowrate per fan (m^3/s):   "Using"####.#";Q(1)
LPRINT "Initial fan pressure rise (kPa):   "Using"##.##";P(1)
For j = 2 to DutyNo%:'10 maximum
LPRINT
LPRINT "Duty No "USING "#";j
LPRINT "Volume flowrate (m^3/s) =   "Using"####.#";Q(j)
LPRINT "Fan pressure rise (kPa) =   "Using"##.##"; P(j)
LPRINT "Prd in years when this duty will be required: "Using"##";Prd(j)
Next j
'Assume temperature and atmospheric pressure remain constant over the life
'the installation.
PRINT
LPRINT
Input "Site barometric pressure (kPa) =  ",Barometer
Input "Inlet air temperature (degree C) =  ", AirTemperature
LPRINT"Site barometric pressure (kPa) =  "using"###.#";Barometer
LPRINT"Inlet air temperature (degree C) =  "using"##.#";AirTemperature
Input "Enter life of the installation (years) ",Life
Input "Average initial power cost (cents/KWh) =  ",PowerCost
Input "Assumed annual power cost escalation (%) =  ",PowerEscalation
Input "Assumed escalation in fan capital cost (%) = ",FanCostEscalation
```

```
Input "Required hurdle rate (%) = ",HurdleRate
Input "Time (years) at which to consider impeller and speed change = ",_
ChangeTim
LPRINT "Life of the installation (years)  "Using"##.##";Life
LPRINT "Average initial power cost (cents/kWh):   "Using"##.##";PowerCost
PowerCost=PowerCost/100: 'cost of power in Rands/kWh
LPRINT "Assumed annual power cost escalation (%):  "_
Using"##.##";PowerEscalation
PowerEscalation=PowerEscalation/100
LPRINT "Assumed escalation in fan capital cost (%):  "_
Using"##.##";FanCostEscalation
FanCostEscalation=FanCostEscalation/100
LPRINT "Required hurdle rate (%):  "Using"##.##";HurdleRate
HurdleRate=HurdleRate/100
LPRINT "Time (years) to impeller and speed change:  "Using"##";_
ChangeTim
LPRINT
LPRINT
LPRINT"OUTPUT"
LET Prd(DutyNo%+1)=0.1



'MAIN ROUTINE
LET Sizing$="Free"
'Impeller geometry and fan speed is fixed for first routine
LET Selection$="FixedFan"
Sizing$="free"
```

```
j=1:'j is suffix for duty
P=P(j)
FOR i=1 TO 4 :'Speed selection
FOR w=1 TO 3 :'For w=1 impeller width is 106% of standard
'for w=2 impeller width is standard, for w=3 width is 80% of standard
GOSUB ChartSpeedCorrection:                                    'a
GOSUB Selection:                                               'b
NEXT w,i

'Evaluation over life of the installation
LET LastCost=20^20
FOR i=1 TO 4
LET n=0
CLS
PRINT "This program takes between 30 and 90 minutes to run."
GOSUB AvailableSelections:                                     'e
NEXT i
BEEP 1
IF LastCost>19^20 THEN GOTO Kim1

LPRINT "FIXED GEOMETRY CONSTANT SPEED FAN"
LPRINT "Total cost"USING"  R########";LastCost
LPRINT "Motor capacity"USING" #### kW";MotorCapacity
LPRINT "Impeller standard diameter ="USING"##.### m";Dselected
LPRINT "Rotational speed"USING" ##.## rev/s";Speed
LPRINT "Impeller overdiameter="USING"###.## %";Overdiameter
LPRINT "Impeller overwidth ="USING"###.## %";ImpellerWidth
```

```
GOTO Kim2
Kim1:
LPRINT "No practicle fixed speed selection"
Kim2:
LPRINT

Selection$="VariableSpeed"
LET LastCost=20*20
FOR i = 1 TO 4
LET b =
'Go to Available selections:                                    'e
NEXT i
BEEP 2
IF LastCost<19*20 THEN GOTO Kim3



LPRINT "FIXED GEOMETRY VARIABLE SPEED FAN"
LPRINT "Total cost"USING"  R########";LastCost
LPRINT "Motor capacity"USING" #### kW";MotorCapacity
LPRINT "Impeller standard diameter "USING"##.### m";Dselected
LPRINT "Rotational speed (maximum)"USING" ##.## rev/s";MaxSpeed
LPRINT "Rotational speed (minimum)"USING" ##.## rev/s";MinSpeed
LPRINT "Impeller overdiameter="USING" ###.## %";Overdiameter
LPRINT "Impeller overwidth ="USING" ###.## %":ImpellerWidth
GOTO Kim4
Kim3:
LPRINT "No practicle variable speed selection"
```

```
Kim4:
LPRINT

Sizing$="ChangeImp"
LPRINT
LPRINT
LPRINT
PRINT "Still busy - relax!"
LET LastTotalCost=20^20
FOR i=1 TO 4' (should be 1 to 4)
LET n=0
GOSUB AvailableSelections:                                    'dd
NEXT i
KEEP 3
IF LastTotalCost>19 20 THEN GOTO Kim5

LPRINT "CHANGE IN IMPELLER SIZE AND SPEED
LPRINT "Total cost"USING"  ########";LastTotalCost
LPRINT "Motor capacity"USING" #### kW";MotorSize
LPRINT "Impeller standard diameter ="USING" #.### m";Dselected
LPRINT "      Initial selection:"
LPRINT "Rotational speed "USING" ##.## rev/s";N(OriginalSpeed)
LPRINT "Impeller overdiameter="USING" ###.## %";OriginalOverdia
LPRINT "Impeller overwidth  "USING" ###.## %";OriginalWidth
LPRINT "      Final selection"
LPRINT "Rotational speed "USING" ##.## rev/s";Speed
LPRINT "Impeller overdiameter="USING" ###.## %";FinalDiameter
```

```
LPRINT "Impeller overwidth ="USING" ###.# ";FinalWidth
GOTO Kim6
Kim5:
LPRINT "No practicle variable speed selection"
Kim6:
LPRINT
'End main routine
CLS

END

ChartSpeedCorrection:'                                    from a
Qj1.83=Q(j)*31.83/N(i)/VolumeCorrection(W)
Hej1.83=FNHe#(j1.83/N(i))^2
Ns=31.83*Qj1.83^.5/Hej1.83^.75
RETURN:'                                                  to a



Selection:'                                               from b
FOR m=1 TO 8' m=1 for 10% overdiameter
FOR n=1 TO 4:' n=1 for vanes full Open
Pmax=A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
P70=A(n,m)*Q70(n,m)^2+B(n,m)*Q70(n,m)+C(n,m)
Nsmax=31.83*Q70(n,m)^.5/P70^.75
Nsmin=31.83*Qmin(n,m)^.5/Pmax^.75
IF Ns>Nsmax THEN Ds(m,n,i,w)=0:Zs(m,n,i,w)=0:GOTO Cats
```

```
IF Ns<Nsmin THEN Ds(m,n,i,w)=0:Zs(m,n,i,w)=0:GOTO Cats
GOSUB ConstantSpeedSelection: '                                    d
Cats:
NEXT n,m
RETURN: '                                                          to b


ConstantSpeedSelection:'                                           from d
LET Qc=(Qmin(n,m)+Q70(n,m))/2
NewVol:
Hes=(31.8)/Ns*(Qc)^.5)^(4/3):'Pressure calculated from specific speed.
Hep=A(n,m)*Qc^2+B(n,m)*Qc+C(n,m):'Pressure calculated from characteristic
IF ABS(Hes-Hep)<.02 THEN GOTO SelectionOK
Qc=Qc+1.85*(Hep-Hes)
GOTO NewVol
SelectionOK:
Ds (m,n,i,w)=(Q31.83/Qc)^(1/3)
TipSpeed=3.14*Dr(m,n,i,w)*N(i)*od(m)
IF TipSpeed>140 THEN Ds(m,n,i,w)=0
Zs(m,n,i,w)=(D(n,m)*Qc^2+E(n,m)*Qc+F(n,m))*EfficiencyCorrection(w)/100
RETURN: '                                                          to d


AvailableSelections:'                                              from e,q,qtc
FOR w=1 TO 3:FOR m=1 TO 8
Method$="Free"
Repeat:
LET LastMarginalCost=20^20
```

```
LET Energy=0
LET Pwmax=0
LET LastMax=N(i):LastMin=N(i)
Ttt=0
LET Sss=0
LET Z=1
LET j=1
LET Rr=Prd(j)+1
n n+1
'PRINT n,m,i,w
LET Tqmax=0
LET Squibb=0
LET nn=n:' as n will be varied to accomadate later duties
IF Ds(m,n,i,w)=0 THEN GOTO NextVane
LET Zlast=Zs(m,n,i,w)
LET Z=Zs(m,n,i,w)
LET Qlast=Q(i)
LET Plast=P(i)
GOSUB BareFanCost:'                                    f
GOSUB DutyWithTime:'                                   g
IF Z=0 THEN GOTO Dogs
IF Sizing$="ChangeImp" THEN GOTO Dogs
GOSUB MotorCost:'                                      n
GOSUB TotalCostCalculation:'
GOSUB CompareCosts:'                                   p
Dogs:
LET Energy=0
```

```
LET Energy=0
LET Pwmax=0
LET LastMax=N(i):LastMin=N(i)
Ttt=0
LET Sss=0
LET Z=1
LET j=1
LET Rr=Prd(j)+1
n=n-1
'PRINT n,m,i,W
LET Tqmax=0
LET Squibb=0
LET nn=n;' as n will be varied to accomadate later duties
IF Ds(m,n,i,w)=0 THEN GOTO NextVane
LET Zlast=Zs(m,n,i,W)
LET Z=Zs(m,n,i,W)
LET Qlast=Q(1)
LET Plast=P(1)
GOSUB BarePanCost:'                                          f
GOSUB DutyWithTime:'                                         g
IF Z 0 THEN GOTO Dogs
IF LizingS="ChangeImp" THEN GOTO Dogs
GOSUB MotorCost:'                                            n
GOSUB TotalCost'alculation:'
GOSUB CompareCosts:'                                         p
Dogs:
LET Energy=0
```

```
IF n<5 THEN GOTO Xxxx
GOTO Repeat
NextVane:
IF n<5 THEN GOTO Repeat
Xxxx:
LET n=0
NEXT m,W
RETURN: '                                          to e, q, etc

DutyWithTime:'                                     from g
LET Ant=0
FOR Tim=Rr TO Life
LET j=1
IF Z=0 THEN GOTO Star
CheckLater:
IF Tim>Prd(j+1) THEN Interpolate
j=j+1
IF j=DutyNo% THEN Qt=Q(DutyNo%):Ant=1
IF j=DutyNo% THEN Pt=P(DutyNo%)
IF j=DutyNo% THEN GOTO Proceed
GOTO CheckLater
Interpolate:
Qt=Q(j)+(Q(j+1)-Q(j))*(Tim-Prd(j))/(Prd(j+1)-Prd(j))
Pt=P(j)+(P(j+1)-P(j))*(Tim-Prd(j))/(Prd(j+1)-Prd(j))
Proceed:
IF Sizing$="ChangeImp" THEN GOSUB TimCheck:'                    S
LET I=1
```

```
IF Selection$="FixedFan" THEN GOSUB EfficiencyCalculation:'          h
IF Z=0 GOTO moon
IF Selection$="FixedFan" THEN GOSUB PowerCostCalculation:'           j
IF Selection$="VariableSpeed" THEN GOSUB EfficiencyAndSpeed:'        r
IF Z=0 THEN GOTO moon
LET n=nn
star:
NEXT Tim
moon:
IF Method$="ChangeImp" THEN Rr=ChangeTim+1:Plast=Pip:Qlast=Qip
n=nn
IF Selection$="FixedFan" THEN GOTO blesbok
IF Sizing$="ChangeImp" THEN GOSUB bushbuck:'                         A
Art   0
IF Ttt=1 THEN GOTO DutyWithTime
blesbok:
RETURN:'                                                          to g


EfficiencyCalculation:'                                           from h
P=Pt
Qtc=Qt*(1/Ds(m,n,i,w))^3*(11.8)/N(i)))/VolumeCorrection(w)
Ptc=PNHe*(11.8)/Ds(m,n,i,w)/N(i))^2
Rt=Ptc/Qtc^2
LET n=1
Pmax=A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
```

```
IF Rt<Rmax THEN GOTO Proceed2
LET n=2
Pmax=A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
IF Rt<Rmax THEN GOTO Proceed2
LET n=3
Pmax=A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
IF Rt<Rmax THEN GOTO Proceed2
LET n=4
Pmax=A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
IF Rt>Rmax THEN GOTO Uitgang
Proceed2:
GOSUB SquareLawIntercept: '                                    k
IF Qtc>Qci THEN GOTO Uitgang
Recheck:
LET Qci1=Qci:Z1=Z
LET n=n+1
GOSUB SquareLawIntercept
IF Qtc<Qci THEN GOTO CloseVane
Z=Z+(Z1-Z)*(Qtc-Qci)/(Qci1-Qci)
RETURN: '                                                      to h
Uitgang:
Z=0
RETURN: '                                                      to h
CloseVane:
IF n=5 THEN GOTO Uitgang:' Vanes too far closed
```

```
GOTO Recheck


PowerCostCalculation:'                                    from j,
Zj=Zlast
GOSUB MaxPower: '                                           1
Zave=(Zlast+Z)/2
Zlast=Z
Qave=(Qt+Qlast)/2
Qlast=Qt
Qip=Qt
Pave=(Pt+Plast)/2
Plast=Pt
Pip=Pt
Zj=Z
GOSUB MaxPower:'This routine called up twice to get power at _
'1st & last duty                                             m
P=Pave
Pw=Qave*Pave*FNKp/Zave
EnergyConsumption = Pw*24*365
EnergyCost=EnergyConsumption*PowerCost_
*(1+PowerEscalation)^(Tim-1)/(1+HurdleRate)^(Tim)
Energy=Energy+EnergyCost
RETURN:'                                                    to j


SquareLawIntercept:'                                      from k
```

```
LET aa=0
A=A(n,m): B=B(n,m): C=C(n,m). D=D(n,m): E=E(n,m): F=F(n,m)
NewRefVol:
Her=Rt*Qci^2
Hep=A*Qci^2+B*Qci+C
IF ABS(Hep-Her)<0.02 THEN GOTO CheckSelection
Qci=Qci+1.1*(Hep-Her)
GOTO NewRefVol
CheckSelection:
IF aa=1 THEN GOTO CalculateEfficiency
IF Qci<Q70(n,m) THEN GOTO CalculateEfficiency
LET A=G(n,m):B=H(n,m):C=I(n,m):D=J(n,m):E=K(n,m):F=L(n,m)
LET aa=1
GOTO NewRefVol
CalculateEfficiency:
Z=(D*Qci^2+E*Qci+F)*EfficiencyCorrection(w)/100
RETURN'                                                    to k


CompareCosts:'                                             from p,bb,kk
IF TotalCost>LastCost THEN RETURN
MotorCapacity=Mc
Dselected=Ds(m,n,i,w)
IF w=1 THEN ImpellerWidth=1.06*100
IF w=2 THEN ImpellerWidth=1.0 *100
IF w=3 THEN ImpellerWidth=0.80*100
IF m=1 THEN Overdiameter=1.10*100
```

```
IF m=2 THEN Overdiameter=1.08*100
IF m=3 THEN Overdiameter=1.06*100
IF m=4 THEN Overdiameter=1.04*100:'          Fan identIFication
IF m=5 THEN Overdiameter=1.02*100
IF m=6 THEN Overdiameter=1.00*100
IF m=7 THEN Overdiameter=0.98*100
IF m=8 THEN Overdiameter=0.96*100
LastCost=TotalCost
IF i=1 THEN Speed=16.33
IF i=2 THEN Speed=12.33
IF i=3 THEN Speed=9.83
IF i=4 THEN Speed=8.25
IF Selection$="FixedFan  THEN RETURN
LET MaxSpeed=LastMax
LET MinSpeed=LastMin
RETURN:'                                                    to p


EfficiencyAndSpeed:'                                        from r
Zmax=0
Qtc=Qt*(1/Ds(m,n,i,w))^3/VolumeCorrection(w)
P=Pt
Ptc=Pt*(1/Ds(m,n,i,w))^2*FNKp/FNDensity
Rt=Ptc/Qtc^2
LET n=1
Pmax= A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
```

```
IF Rt>Rmax THEN GOTO Leaf1  'Fan would stall
GOSUB SpeedCheck
Zmax=Z
Nlast=Nf
TipSpeed=3.14*Ds(m,nn,i,w)*Nf*od(m)
IF TipSpeed>140 THEN Z=0
IF TipSpeed>140 THEN GOTO sun
Leaf1:
LET n=2
Pmax= A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
IF Rt>Rmax THEN GOTO Leaf2
GOSUB SpeedCheck
TipSpeed=3.14*Ds(m,nn,i,w)*Nf*od(m)
IF TipSpeed>140 THEN GOTO Bud
IF Z>Zmax THEN Nlast=Nf
IF Z>Zmax THEN Zmax=Z
Leaf2:
LET n=3
Pmax= A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
IF Rt>Rmax THEN GOTO Leaf3
GOSUB SpeedCheck
TipSpeed=3.14*Ds(m,nn,i,w)*Nf*od(m)
IF TipSpeed>140 THEN GOTO Bud
IF Z>Zmax THEN Nlast=Nf
IF Z>Zmax THEN Zmax=Z
```

```
Leaf3:
LET n=4
Pmax= A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
IF Rt>Rmax THEN GOTO Leaf4
GOSUB SpeedCheck
TipSpeed=3.14*Ds(m,nn,i,w)*Nf*od(m)
IF TipSpeed>140 THEN GOTO Bud
IF Z>Zmax THEN Nlast=Nf
IF Z>Zmax THEN Zmax=Z
Leaf4:
LET n=5
Pmax= A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
IF Rt>Rmax THEN Z=0
IF Rt>Rmax THEN GOTO sun
GOSUB SpeedCheck
TipSpeed=3.14*Ds(m,nn,i,w)*Nf*od(m)
IF TipSpeed>140 THEN GOTO Bud
IF Z>Zmax THEN Nlast=Nf
IF Z>Zmax THEN Zmax=Z
GOTO Bud
SpeedCheck:
GOSUB SquareLawIntercept
Nf=31.83*Qtc/Qci
RETURN
Bud:
```

```
IF Zmax=0 THEN GOTO Sun
Nf=Nlast
Z=
G          xSpeed:'                                          11
    LB PowerCostCalculation:'                                ff
S n:
RETURN :'to r


MinMaxSpeed:'                                                from 11
IF Nf>LastMax THEN LastMax=Nf
IF Nf<LastMin THEN LastMin=Nf
RETURN:'                                                     to 11


MaxPower:'                                                   from 1,m
P=Plast
Pwnow=Qlast*P*FNKp/Zj
IF Selection$="VariableSpeed" THEN GOSUB Torque
IF Pwmax<Pwnow THEN LET Pwmax=Pwnow
Mc= Pwmax*1.1:'                          Mc = Motor capacity
RETURN:'to                                                   1,m
Torque:
IF Squibb=0 THEN Nnn=N(i)
IF Squibb=1 THEN Nnn=Nf
Tqnow=Pwnow/(2*3.14*Nnn)
IF Tqmax<Tqnow THEN LET Tqmax=Tqnow
```

```
Tqc=1.1*Tqmax
LET Squibb=1
Return

B reFanCost:'                                                    from f
IF Psmax>5.9999996 THEN BareFan=(-21.78*Ds(m,n,i,w)^2+337.8*_
Ds(m,n,i,w)-539.9)*1000
IF Psmax<5.9999996 THEN BareFan=(-18.00*Ds(m,n,i,w)^2+305.7*_
Ds(m,n,i,w)-514.3)*1000
RETURN: '                                                      to f


TimCheck:'                                                       from s
IF Tim<(ChangeTim+1) THEN LET Selection$="FixedFan":RETURN '      to s
Selection$="Free"
Method$="ChangeImp"
IF Art=1 THEN GOTO Arty
IF Tim=(ChangeTim+1) THEN LET Tim=ChangeTim:Art=1:Qt=Qlast:Pt=Plast
Arty:
GOSUB ChangeImp: '                                                t
RETURN: '                                                        to s


ChangeImp:  '                                                    from t
IF Sss=1 THEN GOTO jupiter
LET ww=w:ii=i:mm=m:Dss=Ds(m,n,i,w)
FOR m=1 TO 8'SHOULD BE 1 TO 8
```

```
FOR w=1 TO 3
FOR i=1 TO 4 'SHOULD BE 1 TO 4
Pwmax=0
MarginalCost=0
IF Ttt=1 THEN RETURN:'                                    to A
T pSpeed= 3.14*Dss*N(i)*od(m)
:F TipSpeed>140 THEN GOTO neptune
jupiter:
GOSUB EstimateEfficiency:'                                  u
LET Sss=1
IF Z=0 THEN LET Ttt=1:GOTO ape
IF Tim=ChangeTim THEN RETURN:'                            to t
GOSUB MarginalPowerCost:'                                   v
ape:
RETURN: '                                                 to t


bushbuck:'                                                from A
IF Z=0 THEN GOTO neptune
j=1
Q=Q(j)
P=P(j)
LET Zf=.15  'assume initial & final speeds differ
IF i=ii THEN Zf=0  'In case they don't
GOSUB ImpellerReplacementCost:'                             mm
LET Mmc=Mc  'Mc is original motor capacity, value must be retained
IF Mci>Mc THEN Mc=Mci 'Mci is motor capacity after impeller/speed change
```

```
LET Ij=i 'motor cost will be based on this speed option
GOSUB MotorCost
Motor2=Motor
Ij=ii   'motor cost will be based on original speed option
GOSUB MotorCost
Delta=Motor2-Motor
IF Delta<0 THEN LET Delta=0  'Delta is cost penalty if 2nd speed is lowe
IF Delta>0 THEN LET Motor = Motor2
Mc=Mmc
TotMargCost=MarginalCost+Impeller+2f*Motor+Delta
GOSUB CompareTheseCosts      '                                          nn
neptune:
LET Z=1
NEXT i,w,m
Ttt=0
IF Z=0 THEN GOTO bleabok
IF MotorCapacity>Mc THEN Mc=MotorCapacity
IF MotorCapacity<Mc THEN MotorCapacity=Mc
Ij=ii
GOSUB MotorCost
TotalCost=BareFan+Motor+Energy+LastMarginalCost

IF TotalCost<LastTotalCost THEN LastTotalCost=TotalCost
'F TotalCost>LastTotalCost THEN GOTO Beaver
GOSUB ChangedID'                                                       P
GOSUB FanIdentificatio.'                                               J
Beaver:
```

```
LET w=ww
LET i=ii
LET m=mm
LET Ds(m,n,i,w)=Dss
GOTO blesbok                                        ' to t

EstimateEfficiency:'                                 from u
P=Pt
Qtc=Qt*(1/Dss)^3*(31.83/N(i))/VolumeCorrection(w)
Ptc=FNHe*(31.83/Dss/N(i))^2
Rt=Ptc/Qtc^2
LET n=1
Pmax=A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
IF Rt<Rmax THEN GOTO Proceed3
LET n=2
Pmax=A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
IF Rt<Rmax THEN GOTO Proceed3
LET n=3
Pmax=A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
IF Rt<Rmax THEN GOTO Proceed3
LET n=4
Pmax=A(n,m)*Qmin(n,m)^2+B(n,m)*Qmin(n,m)+C(n,m)
Rmax=Pmax/Qmin(n,m)^2
IF Rt>Rmax THEN GOTO Outlet
```

```
Proceed3:
GOSUB SquareLawIntercept
IF Qtc>Qci THEN GOTO Outlet
Recheck2:
LET Qci1=Qci:Z1=Z
L! : n=n+1
GOSUB SquareLawIntercept
IF Qtc<Qci THEN GOTO CloseVane2
Z=Z+(Z1-Z)*(Qtc-Qci)/(Qci1-Qci)
IF Tim=ChangeTim THEN Zlast = Z
RETURN'                                          to u
Outlet:
Z=0
RETURN                                           'to u
CloseVane2:
IF n=5 THEN GOTO Outlet
GOTO Recheck2

MarginalPowerCost:                               'from v
GOSUB MaxiPower'                                      G
Zave=(Zlast+Z)/2
Zlast=Z
Qave=(Qlast+Qt)/2
Qlast=Qt
Pave=(Plast+Pt)/2
Plast=Pt
GOSUB MaxiPower'                                      H
```

```
P=Pave
Pw=Qave*Pave*FNKp/Zave
EnergyConsumption = Pw*24*365
EnergyRands=EnergyConsumption*PowerCost_
^(1+PowerEscalation)^(Tim-1)/(1+HurdleRate)^(Tim)
MarginalCost=MarginalCost+EnergyRands
RETURN'                                                    to v


FanIdentification:                                         'from J
Dselected=Dss
OriginalWidth=Wdth(ww)
OriginalSpeed=ii
OriginalOverDia=od(mm)*100
MotorSize=Mc
RETURN                                                     'to J


MotorCost:
IF Selection$= "VariableSpeed" THEN GOTO VariSpeedCost
IF Ij=1 THEN Xy=1
IF Ij=2 THEN Xy=1.15:'Factor for correcting cost f:. speed
IF Ij=3 THEN Xy=1.4
IF Ij=4 THEN Xy=1.54
IF Mc> 1999 THEN Motor=Xy*(-.0000075*Mc^2+.1125*Mc-13);*1000:RETURN
IF Mc< 1800 THEN Motor=Xy*(-7.918*10^(-6)*Mc^2+.1001*Mc ^5.47)*1000:RETU
Motor=Xy*180000:RETURN
```

```
VariSpeedCost:
Motor=25700*Tqc
RETURN

TotalCostCalculation:
 F Selection$="FixedFan" THEN TotalCost=BareFan+Motor+Energy
IF Selection$="VariableSpeed" THEN TotalCost=BareFan+Motor+Energy
RETURN

ImpellerReplacementCost:                                    from mm
IF w<ww THEN GOTO SWOP
IF w>ww THEN GOTO SWOP
IF m<mm THEN GOTO SWOP
IF m>mm THEN GOTO SWOP
Impeller=0
RETURN                                                      'to mm
SWOP:
IF P>7.998 THEN Impeller=(.283*Q^2+124.2*Q+15069)_
*(1+FanCostEscalation)^(ChangeTim-1)/(1+HurdleRate)^(ChangeTim):RETURN


IF P>5.996 THEN Impeller=(.459*Q^2+50.90*Q+13000)_
*(1+FanCostEscalation)^(ChangeTim-1)/(1+HurdleRate)^(ChangeTim):RETURN
IF P>3.994 THEN Impeller=(.972*Q^2+105.0*Q+28200)_
*(1+FanCostEscalation)^(ChangeTim-1)/(1+HurdleRate)^(ChangeTim):RETURN
Impeller=(.171*Q^2+141.0*Q+12186)_
*(1+FanCostEscalation)^(ChangeTim-1)/(1+HurdleRate)^(ChangeTim)
```

```
RETURN'                                                    to mm

CompareTheseCosts:                                         'from nn
LET Ttt=1
IF TotMargCost<LastMarginalCost THEN LastMarginalCost=TotMargCost
IF TotMargCost=LastMarginalCost THEN GOTO Pawpaw
RETURN
Pawpaw:
IF w=1 THEN SFinalWidth=1.06*100
IF w=2 THEN SFinalWidth=1.0 *100
IF w=3 THEN SFinalWidth=0.80*100
IF m=1 THEN SFinalDiameter=1.10*100
IF m=2 THEN SFinalDiameter=1.08*100
IF m=3 THEN SFinalDiameter=1.06*100
IF m=4 THEN SFinalDiameter=1.04*100:'          Fan identification
IF m=5 THEN SFinalDiameter=1.02*100
IF m=6 THEN SFinalDiameter=1.00*100
IF m=7 THEN SFinalDiameter=0.98*100
IF m=8 THEN SFinalDiameter=0.96*100
IF i=1 THEN SSpeed=16.33
IF i=2 THEN SSpeed=12.33
IF i=3 THEN SSpeed=9.83
IF i=4 THEN SSpeed=8.25
MotorCapacity=Mci
RETURN'                                                    to nn

ChangedID:
```

```
FinalWidth=SFinalWidth
FinalDiameter=SFinalDiameter
Speed=SSpeed
RETURN'                                                    to F

'axiPower:'                                                from G,H
P=Plast
Pwnow=Qlast*P*FNKp/Z
IF Pwmax<Pwnow THEN LET Pwmax=Pwnow
Mci= Pwmax*1.1:'                    Mci = Motor capacity after chang
RETURN:'to                                                 G,
```

Site name: Vaal Reefs #5

Job reference: Change time sensitivity. Run #6

Initials: DPB

INPUT

Date: 88/04/10

Number of duty points considered: 6

Initial volume flowrate per fan (m^3/s): 187.0

Initial fan pressure rise (kPa): 7.00

Duty No 2

Volume flowrate (m^3/s) = 200.0

Fan pressure rise (kPa) = 6.24

Prd in years when this duty will be required: 1

Duty No 3

Volume flowrate (m^3/s) = 212.0

Fan pressure rise (kPa) = 5.50

Prd in years when this duty will be required: 2

Duty No 4

Volume flowrate (m^3/s) = 279.0

Fan pressure rise (kPa) = 5.08

Prd in years when this duty will be required: 3

Duty No 5

Volume flowrate (m^3/s) = 282.0

Fan pressure rise (kPa) = 5.30
Prd in years when this duty will be required: 5

Duty No 6
Volume flowrate (m^3/s) = 300.0
Fan pressure rise (kPa) = 5.10
Prd in years when this duty will be required: 9

Site barometric pressure (kPa) = 88.0
Inlet air temperature (degree C) = 25.0
Life of the installation (years) = 20.00
Average initial power cost (cents/kWh) = 5.00
Assumed annual power cost escalation (%) = 10.00
Assumed escalation in fan capital cost (%) = 10.00
Required hurdle rate (%) = 20
Time (years) to impeller and speed change = 1

OUTPUT
FIXED GEOMETRY CONSTANT SPEED FAN
Total cost R 6912401
Motor capacity 2045 kW
Impeller standard diameter = 3.654 m
Rotational speed 9.83 rev/s
Impeller overdiameter = 106.00%
Impeller overwidth = 100.00%

FIXED GEOMETRY VARIABLE SPEED FAN

Total cost R 7422690

Motor capacity 2036 kW

Impeller standard diameter = 3.654 m

Rotational speed (maximum) 9.83 rev/s

Rotational speed (minimum) 9.27 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

CHANGE IN IMPELLER SIZE AND SPEED

Total cost R 6770113

Motor capacity 2000 kW

Impeller standard diameter = 3.654 m

Initial selection:

Rotationalspeed 9.83 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

Final selection:

Rotationalspeed 9.83 rev/s

Impeller overdiameter = 104.00%

Impeller overwidth = 100.00%

Appendix G

Site name: Vaal Reefs #[illegible]

Job reference: Change time sensitivity. Run #1

Initials: DPB

INPUT

Date: 88/04/08

Number of duty points considered: 6

Initial volume flowrate per fan (m^3/s): 187.0

Initial fan pressure rise (kPa): 7.00

Duty No 2

Volume flowrate (m^3/s) = 200.0

Fan pressure rise (kPa) = 6.24

Prd in years when this duty will be required: 1

Duty No 3

Volume flowrate (m^3/s) = 212.0

Fan pressure rise (kPa) = 5.50

Prd in years when this duty will be required: 2

Duty No 4

Volume flowrate (m^3/s) = 279.0

Fan pressure rise (kPa) = 5.08

Prd in years when this duty will be required: 3

Duty No 5

Volume flowrate (m^3/s) = 282.0

Fan pressure rise (kPa) = 5.30

Prd in years when this duty will be required: 5

Duty No 6

Volume flowrate (m^3/s) = 300.0

Fan pressure rise (kPa) = 5.10

Prd in years when this duty will be required: 9

Site barometric pressure (kPa) = 88.0

Inlet air temperature (degree C) = 25.0

Life of the installation (years) = 20.00

Average initial power cost (cents/kWh) = 5.00

Assumed annual power cost escalation (%) = 10.00

Assumed escalation in fan capital cost (%) = 10.00

Required hurdle rate (%) = 20

Time (years) to impeller and speed change = 3

OUTPUT

FIXED GEOMETRY CONSTANT SPEED FAN

Total cost R 6912401

Motor capacity 2045 kW

Impeller standard diameter = 3.654 m

Rotational speed 9.83 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

FIXED GEOMETRY VARIABLE SPEED FAN

Total cost R 7422690

Motor capacity 2036 kW

Impeller standard diameter = 3.654 m

Rotational speed (maximum) 9.83 rev/s

Rotational speed (minimum) 9.27 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

CHANGE IN IMPELLER SIZE AND SPEED

Total cost R 6770504

Motor capacity 1979 kW

Impeller standard diameter = 3.654 m

Initial selection:

Rotationalspeed 9.83 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

Final selection:

Rotationalspeed 9.83 rev/s

Impeller overdiameter = 102.00%

Impeller overwidth = 100.00%

Site name: Vaal Reefs #5
Job reference: Change time sensitivity. Run #2
Initials: DPB

INPUT
Date: 88/04/08

Number of duty points considered: 6
Initial volume flowrate per fan (m^3/s): 187.0
Initial fan pressure rise (kPa): 7.00

Duty No 2
Volume flowrate (m^3/s) = 200.0
Fan pressure rise (kPa) = 6.24
Prd in years when this duty will be required: 1

Duty No 3
Volume flowrate (m^3/s) = 212.0
Fan pressure rise (kPa) = 5.50
Prd in years when this duty will be required: 2

Duty No 4
Volume flowrate (m^3/s) = 279.0
Fan pressure rise (kPa) = 5.08
Prd in years when this duty will be required: 3

Duty No 5
Volume flowrate (m^3/s) = 282.0

Fan pressure rise (kPa) = 5.30
Prd in years when this duty will be required: 5

Duty No 6
Volume flowrate (m^3/s) = 300.0
Fan pressure rise (kPa) = 5.10
Prd in years when this duty will be required: 9

Site barometric pressure (kPa) = 88.0
Inlet air temperature (degree C) = 25.0
Life of the installation (years) = 20.00
Average initial power cost (cents/kWh) = 5.00
Assumed annual power cost escalation (%) = 10.00
Assumed escalation in fan capital cost (%) = 10.00
Required hurdle rate (%) = 20
Time (years) to impeller and speed change = 6

OUTPUT
FIXED GEOMETRY CONSTANT SPEED FAN
Total cost R 6912401
Motor capacity 7045 kW
Impeller standard diameter = 3.654 m
Rotational speed 9.83 rev/s
Impeller overdiameter = 106.00%
Impeller overwidth = 100.00%

FIXED GEOMETRY VARIABLE SPEED FAN

Total cost R 7422[illegible]

Motor capacity 2036 [illegible]

Impeller standard diameter 3.654 m

Rotational speed (maximum) 9.83 rev/s

Rotational speed (minimum) 9.27 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

CHANGE IN IMPELLER SIZE AND SPEED

Total cost R 6816928

Motor capacity 1979 kW

Impeller standard diameter = 3.654 m

Initial selection:

Rotationalspeed 9.83 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

Final selection:

Rotational speed 9.83 rev/s

Impeller overdiameter = 102.00%

Impeller overwidth = 100.00%

Appendix G

Site name: Vaal Reefs #5

Job reference: Change time sensitivity. Run #3

Initials: DPB

INPUT

Date: 88/04/08

Number of duty points considered: 6

Initial volume flowrate per fan (m^3/s): 187.0

Initial fan pressure rise (kPa): 7.00

Duty No 2

Volume flowrate (m^3/s) = 200.0

Fan pressure rise (kPa) = 6.24

Prd in years when this duty will be required: 1

Duty No 3

Volume flowrate (m^3/s) = 212.0

Fan pressure rise (kPa) = 5.50

Prd in years when this duty will be required: 2

Duty No 4

Volume flowrate (m^3/s) = 279.0

Fan pressure rise (kPa) = 5.08

Prd in years when this duty will be required: 3

Duty No 5

Volume flowrate (m^3/s) = 282.0

Fan pressure rise (kPa) = 5.30
Prd in years when this duty will be required: 5

Duty No 6
Volume flowrate (m^3/s) = 300.0
Fan pressure rise (kPa) = 5.10
Prd in years when this duty will be required: 9

Site barometric pressure (kPa) = 88.0
Inlet air temperature (degree C) = 25.0
Life of the installation (years) = 20.00
Average initial power cost (cents/kWh) = 5.00
Assumed annual power cost escalation (%) = 10.00
Assumed escalation in fan capital cost (%) = 10.00
Required hurdle rate (%) = 20
Time (years) to impeller and speed change = 9

OUTPUT
FIXED GEOMETRY CONSTANT SPEED FAN
Total cost R 6912401
Motor capacity 2045 kW
Impeller standard diameter = 3.654 m
..otational speed 9.83 rev/s
Impeller overdiameter = 106.00%
Impeller overwidth = 100.00%

FIXED GEOMETRY VARIABLE SPEED FAN

Total cost R 7422690

Motor capacity 2036 kW

Impeller standard diameter = 3.654 m

Rotational speed (maximum) 9.83 rev/s

Rotational speed (minimum) 9.27 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

CHANGE IN IMPELLER SIZE AND SPEED

Total cost R 6854219

Motor capacity 2045 kW

Impeller standard diameter = 3.654 m

Initial selection:

Rotationalspeed 9.83 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

Final selection:

Rotationalspeed 9.83 rev/s

Impeller overdiameter = 102.00%

Impeller overwidth = 100.00%

Appendix G

Site name: Vaal Reefs #5

Job reference: Change time sensitivity. Run #4

Initials: DPB

INPUT

Date: *88/04/08*

Number of duty points considered: 6

Initial volume flowrate per fan (m^3/s): 187.0

Initial fan pressure rise (kPa): 7.00

Duty No 2

Volume flowrate (m^3/s) = 200.0

Fan pressure rise (kPa) = 6.24

Prd in years when this duty will be required: 1

Duty No 3

Volume flowrate (m^3/s) = 212.0

Fan pressure rise (kPa) = 5.50

Prd in years when this duty will be required: 2

Duty No 4

Volume flowrate (m^3/s) = 279.0

Fan pressure rise (kPa) = 5.08

Prd in years when this duty will be required: 3

Duty No 5

Volume flowrate (m^3/s) = 282.0

Fan pressure rise (kPa) = 5.30

Prd in years when this duty will be required: 5

Duty No 6

Volume flowrate (m^3/s) = 300.0

Fan pressure rise (kPa) = 5.10

Prd in years when this duty will be required: 9

Site barometric pressure (kPa) = 88.0

Inlet air temperature (degree C) = 25.0

Life of the installation (years) = 20.00

Average initial power cost (cents/kWh) = 5.00

Assumed annual power cost escalation (%) = 10.00

Assumed escalation in fan capital cost (%) = 10.00

Required hurdle rate (%) = 20

Time (years) to impeller and speed change = 12

OUTPUT

FIXED GEOMETRY CONSTANT SPEED FAN

Total cost R 6912401

Motor capacity 2045 kW

Impeller standard diameter = 3.654 m

Rotational speed 9.83 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

FIXED GEOMETRY VARIABLE SPEED FAN

Total cost R 7422690

Motor capacity 2036 kW

Impeller standard diameter = 3.654 m

Rotational speed (maximum) 9.83 rev/s

Rotational speed (minimum) 9.27 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

CHANGE IN IMPELLER SIZE AND SPEED

Total cost R 6878124

Motor capacity 2045 kW

Impeller standard diameter = 3.654 m

Initial selection:

Rotationalspeed 9.83 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

Final selection:

Rotationalspeed 9.83 rev/s

Impeller overdiameter = 102.00%

Impeller overwidth = 100.00%

Site name: Vaal Reefs #5

Job reference: Change time sensitivity. Run #5

Initials: DPB

INPUT

Date: 88/04/08

Number of duty points considered: 6

Initial volume flowrate per fan (m^3/s): 187.0

Initial fan pressure rise (kPa): 7.00

Duty No 2

Volume flowrate (m^3/s) = 200.0

Fan pressure rise (kPa) = 6.24

Prd in years when this duty will be required: 1

Duty No 3

Volume flowrate (m^3/s) = 212.0

Fan pressure rise (kPa) = 5.50

Prd in years when this duty will be required: 2

Duty No 4

Volume flowrate (m^3/s) = 279.0

Fan pressure rise (kPa) = 5.08

Prd in years when this duty will be required: 3

Duty No 5

Volume flowrate (m^3/s) = 282.0

Fan pressure rise (kPa) = 5.30
Prd in years when this duty will be required: 5

Duty No 6
Volume flowrate (m^3/s) = 300.0
Fan pressure rise (kPa) = 5.10
Prd in years when this duty will be required: 9

Site barometric pressure (kPa) = 88.0
Inlet air temperature (degree C) = 25.0
Life of the installation (years) = 20.00
Average initial power cost (cents/kWh) = 5.00
Assumed annual power cost escalation (%) = 10.00
Assumed escalation in fan capital cost (%) = 10.00
Required hurdle rate (%) = 20
Time (years) to impeller and speed change = 2

OUTPUT
FIXED GEOMETRY CONSTANT SPEED FAN
Total cost R 6912401
Motor capacity 2045 kW
Impeller standard diameter = 3.654 m
Rotational speed 9.83 rev/s
Impeller overdiameter = 106.00%
Impeller overwidth = 100.00%

FIXED GEOMETRY VARIABLE SPEED FAN

Total cost R 7422690

Motor capacity 2036 kW

Impeller standard diameter = 3.654 m

Rotational speed (maximum) 9.83 rev/s

Rotational speed (minimum) 9.27 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

CHANGE IN IMPELLER SIZE AND SPEED

Total cost R 6755578

Motor capacity 1979 kW

Impeller standard diameter = 3.654 m

Initial selection:

Rotationalspeed 9.83 rev/s

Impeller overdiameter = 106.00%

Impeller overwidth = 100.00%

Final selection:

Rotationalspeed 9.83 rev/s

Impeller overdiameter = 102.00%

Impeller overwidth = 100.00%

Appendix G

Site name: Loraine #4

Job reference: Assuming 3 fans are used to meet duties

Initials: DPB

INPUT

Date: 88/05/06

Number of duty points considered: 4

Initial volume flowrate per fan (m^3/s): 198.6

Initial fan pressure rise (kPa): 2.84

Duty No 2

Volume flowrate (m^3/s) = 211.0

Fan pressure rise (kPa) = 2.46

Prd in years when this duty will be required: 2

Duty No 3

Volume flowrate (m^3/s) = 202.7

Fan pressure rise (kPa) = 2.60

Prd in years when this duty will be required: 5

Duty No 4

Volume flowrate (m^3/s) = 219.3

Fan pressure rise (kPa) = 2.12

Prd in years when this duty will be required: 10

Site barometric pressure (kPa) = 88.0

Inlet air temperature (degree C) = 25.0

Life of the installation (years) = 20.00
Average initial power cost (cents/kWh) = 5.00
Assumed annual power cost escalation (%) = 10.00
Assumed escalation in fan capital cost (%) = 10.00
Required hurdle rate (%) = 20
Time (years) to impeller and speed change = 5

OUTPUT

FIXED GEOMETRY CONSTANT SPEED FAN
Total cost R 2835282
Motor capacity 745 kW
Impeller standard diameter = 3.381 m
Rotational speed 8.25 rev/s
Impeller overdiameter = 104.00%
Impeller overwidth = 100.00%

FIXED GEOMETRY VARIABLE SPEED FAN
Total cost R 2987799
Motor capacity 761 kW
Impeller standard diameter = 3.627 m
Rotational speed (maximum) 8.25 rev/s
Rotational speed (minimum) 7.16 rev/s
Impeller overdiameter = 96.00%
Impeller overwidth = 100.00%

CHANGE IN IMPELLER SIZE AND SPEED
Total cost R 2835282

Appendix G

Motor capacity 745 kW

Impeller standard diameter = 3.381 m

Initial selection:

Rotationalspeed 8.25 rev/s

Impeller overdiameter = 104.00%

Impeller overwidth = 100.00%

Final selection:

Rotationalspeed 8.25 rev/s

Impeller overdiameter = 104.00%

Impeller overwidth = 100.00%

Appendix G

Site name: Loraine #5

Job reference: Assuming 2 fans are used to meet duties

Initials: DPB

INPUT

Date: 88/05/07

Number of duty points considered: 4

Initial volume flowrate per fan (m^3/s): 261.0

Initial fan pressure rise (kPa): 3.70

Duty No 2

Volume flowrate (m^3/s) = 220.0

Fan pressure rise (kPa) = 3.90

Prd in years when this duty will be required: 2

Duty No 3

Volume flowrate (m^3/s) = 315.0

Fan pressure rise (kPa) = 3.70

Prd in years when this duty will be required: 5

Duty No 4

Volume flowrate (m^3/s) = 311.0

Fan pressure rise (kPa) = 3.20

Prd in years when this duty will be required: 10

Site barometric pressure (kPa) = 98.0

Inlet air temperature (degree C) = 25.0

Life of the installation (years) = 20.00
Average initial power cost (cents/kWh) = 5.00
Assumed annual power cost escalation (%) = 10.00
Assumed escalation in fan capital cost (%) = 10.00
Required hurdle rate (%) = 20.00
Time (years) to impeller and speed change = 5

OUTPUT
No practicle fixed speed se.ection

FIXED GEOMETRY VARIABLE SPEED FAN
Total cost R 5496083
Motor capacity 1577 kW
Impeller standard diameter = 3.868 m
Rotational speed (maximum) 8.51 rev/s
Rotational speed (minimum) 7.11 rev/s
Impeller overdiameter = 104.00%
Impeller overwidth = 100.00%

No practicle fixed speed selection

Site name: Hartebeestfontein #3
Job reference: Assuming 2 fans are used to meet duties
Initials: DPB

INPUT
Date: 88/06/07

Number of duty points considered: 6
Initial volume flowrate r fan (m^3/s): 324.5
Initial fan pressure rise (kPa): 6.50

Duty No 2
Volume flowrate (m^3/s) = 300.0
Fan pressure rise (kPa) = 6.80
Prd in years when this duty will be required: 2

Duty No 3
Volume flowrate (m^3/s) = 226.5
Fan pressure rise (kPa) = 6.50
Prd in years when this duty will be required: 5

Duty No 4
Volume flowrate (m^3/s) = 232.5
Fan pressure rise (kPa) = 6.30
Prd in years when this duty will be required: 10

Duty No 5
Volume flowrate (m^3/s) = 200.5

Fan pressure rise (kPa) = 6.90
Prd in years when this duty will be required: 15

Duty No 6
Volume flowrate (m^3/s) = 123.5
Fan pressure rise (kPa) = 4.80
Prd in years when this duty will be required: 18

Site barometric pressure (kPa) = 88.0
Inlet air temperature (degree C) = 25.0
Life of the installation (years) = 20.00
Average initial power cost (cents/kWh) = 5.00
Assumed annual power cost escalation (%) = 10.00
Assumed escalation in fan capital cost (%) = 10.00
Required hurdle rate (%) = 20.00
Time (years) to impeller and speed change = 5

OUTPUT
No practicle fixed speed selection

FIXED GEOMETRY VARIABLE SPEED FAN
Total cost R 7717959
Motor capacity 2816 kW
Impeller standard diameter = 3.436 m
Rotational speed (maximum) 12.33 rev/s
Rotational speed (minimum) 9.02 rev/s
Impeller overdiameter = 102.00%

Impeller overwidth = 100.00%

No practicle variable speed selection

Appendix G

Site name: Hartebeestfontein #5

Job reference: Assuming 2 fans are used to meet duties

Initials: DPB

INPUT

Date: 88/05/07

Number of duty points considered: 6

Initial volume flowrate per fan (m^3/s): 94.5

Initial fan pressure rise (kPa): 3.60

Duty No 2

Volume flowrate (m^3/s) = 195.5

Fan pressure rise (kPa) = 5.20

Prd in years when this duty will be required: 2

Duty No 3

Volume flowrate (m^3/s) = 281.5

Fan pressure rise (kPa) = 5.00

Prd in years when this duty will be required: 5

Duty No 4

Volume flowrate (m^3/s) = 349.0

Fan pressure rise (kPa) = 4.20

Prd in years when this duty will be required: 10

Duty No 5

Volume flowrate (m^3/s) = 330.0

Fan pressure rise (kPa) = 5.10
Prd in years when this duty will be required: 15

Duty No 6
Volume flowrate (m'3/s) = 289.5
Fan pressure rise (kPa) = 6.00
Prd in years when this duty will be required: 18

Site barometric pressure (kPa) = 88.0
Inlet air temperature (degree C) = 25.0
Life of the installation (years) = 20.00
Average initial power cost (cents/kWh) = 5.00
Assumed annual power cost escalation (%) = 10.00
Assumed escalation in fan capital cost (%) = 10.00
Required hurdle rate (%) = 20.00
Time (years) to impeller and speed change = 5

OUTPUT
No practicle fixed speed selection

No practicle variable speed selection

No practicle variable speed selection

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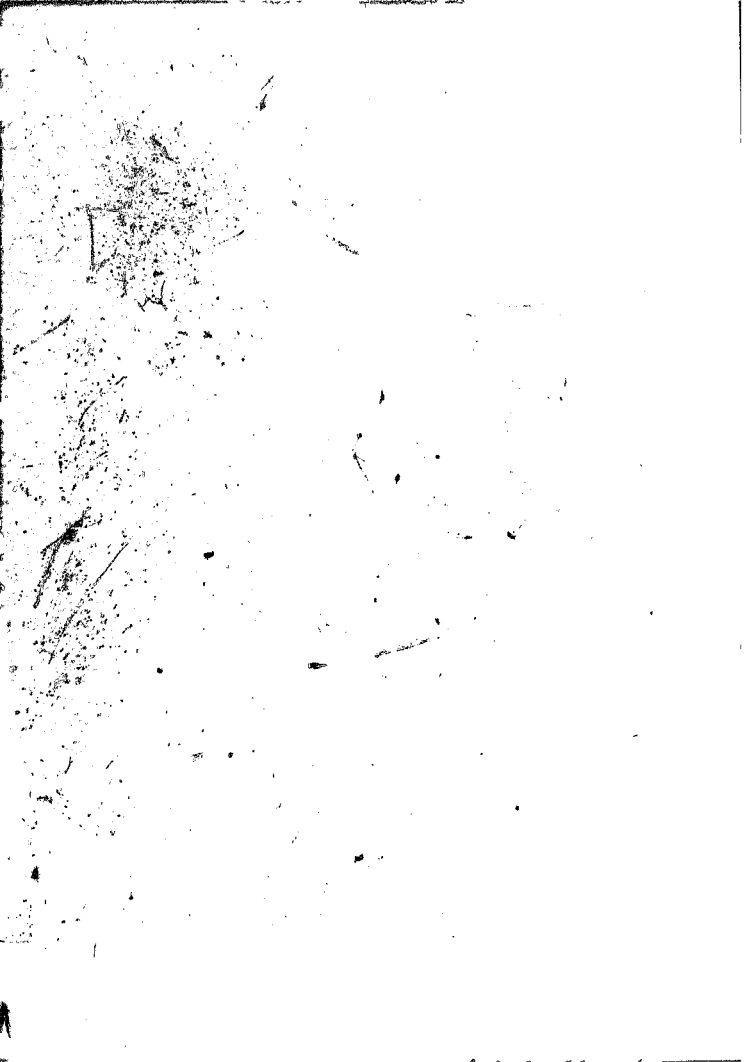
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Author Barratt David Paul
Name of thesis Energy Saving Through Optimal Fan And Mine System Matching. 1988

PUBLISHER:
University of the Witwatersrand, Johannesburg
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