

Enhancing Industrial Fan Performance: A Data-driven Framework for Energy Savings and Cost Reduction

P.K. Ngongo^{1*}, A.M.A. Almaktoof¹ & M.T.E. Kahn¹

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Contact details

* Corresponding author
prospn34@gmail.com

Author affiliations

1 Department of Electrical,
Electronic and Computer
Engineering, Cape Peninsula
University of Technology, Cape
Town, South Africa

ORCID® identifiers

P. K. Ngongo
<https://orcid.org/0000-0001-8542-3907>

A.M.A. Almaktoof
<https://orcid.org/0000-0002-1134-5587>

M.T.E. Kahn
<https://orcid.org/0000-0002-3999-6322>

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ABSTRACT

South Africa faces the challenge of balancing energy demand with sustainable development goals. Heating, ventilation, and air conditioning (HVAC) systems consume about 40.6 billion kWh of energy annually, which accounts for 20% of the country's overall energy consumption, according to the Eskom Energy Management Information Pack from July 2015. Many fans used in these systems operate inefficiently, leading to increased energy and maintenance costs. Often, these fans are selected on the basis of standard sizes rather than being custom designed, resulting in oversizing and higher operational expenses. Optimising the entire system could lead to greater energy savings than simply optimising individual components. To assist in this effort, the US Department of Energy's Office of Energy Efficiency and Renewable Energy has developed a free online fan system assessment tool (FSAT). This tool helps manufacturers, end-users, and engineers of industrial fan systems to identify and capitalise on energy optimisation opportunities. This paper outlines the basic features and functions of the FSAT, emphasising its role in promoting the sustainable development of facilities and addressing energy-efficiency gaps. The FSAT evaluates the efficiency, potential energy savings, and cost-effectiveness of a fan system by examining the energy consumption framework of a sample facility. It analyses operational parameters and energy usage patterns, providing detailed options for improving energy consumption. According to the findings, using an energy-efficient motor along with an optimised fan could lead to an estimated annual energy savings of 24.84% compared with the selected fans, and savings of 1.49% when compared with the overall facility energy usage.

OPSOMMING

Suid-Afrika staan voor die uitdaging om energievraag met volhoubare-ontwikkelingsdoelwitte in balans te bring. Verhitting-, ventilasie- en lugversorgingstelsels (HVAC-stelsels) verbruik jaarliks ongeveer 40.6 miljard kWh energie, wat volgens Eskom se Inligtingspakket oor Energiebestuur van Julie 2015, 20% van die land se algehele energieverbruik uitmaak. Baie waaiers wat in hierdie stelsels gebruik word, werk ondoeltreffend, wat tot verhoogde energie- en instandhoudingskoste lei. Hierdie waaiers word dikwels op grond van standaardgroottes gekies, eerder as om pasgemaak ontwerp te word, wat tot oorbemeting en hoër bedryfskoste lei. Die optimalisering van die hele stelsel kan tot groter energiebesparings lei as die blote optimalisering van individuele komponente. Om hierdie poging te ondersteun, het die Amerikaanse Departement van Energie se Kantoor vir Energiedoeltreffendheid en Hernubare Energie 'n gratis aanlyn hulpmiddel vir die assessering van waaierstelsels, die Fan System Assessment Tool (FSAT), ontwikkel. Hierdie hulpmiddel help vervaardigers, eindgebruikers en ingenieurs van industriële waaierstelsels om geleenthede vir energieoptimalisering te identifiseer en te benut.

Hierdie artikel beskryf die basiese kenmerke en funksies van die FSAT, met klem op die rol daarvan in die bevordering van die volhoubare ontwikkeling van fasiliteite en die aanspreek van leemtes in energiedoeltreffendheid. Die FSAT evalueer die doeltreffendheid, potensiele energiebesparings en kostedoeltreffendheid van 'n waaierstelsel deur die energieverbruiksraamwerk van 'n voorbeeldfasiliteit te ondersoek. Dit ontleed bedryfsparameters en energieverbruikspatrone, en verskaf omvattende opsies om energieverbruik te verbeter. Volgens die bevindinge kan die gebruik van 'n energiedoeltreffende motor saam met 'n geoptimaliseerde waaier tot 'n geraamde jaarlikse energiebesparing van 24.84% lei in vergelyking met die geselekteerde waaiers, en tot 'n besparing van 1.49% in vergelyking met die algehele energieverbruik van die fasiliteit.

1. INTRODUCTION

South Africa currently faces an energy crisis, with the country struggling with power shortages that leave millions without access to reliable electricity [1], [2], [3]. The depletion of energy resources has led to frequent load-shedding, what has a significant impact on industries and on the economy [4], [5]. According to the South Africa Energy Sector Report, the industrial sector is the largest consumer of energy, followed by transportation at 26%, commerce and public services at 11%, residential at 7%, agriculture at 2%, and non-specified sectors at 3%. It accounts for around 51% of Eskom's total energy production [4], [5], [6]. This means that the industrial sector alone has a substantial potential for energy savings that could be recouped through correct energy management [7], [8], [9]. Massive efforts to reduce power demand; consequently, global greenhouse gas (GHG) emissions are required to prevent blackouts and total grid collapse situations while reaching the goals set in the Paris Agreement [10], [11], [12].

In manufacturing, fan systems are the backbone of a vast range of industries that provide solutions to various industrial processes [13], [14], [15]. They are mostly used to supply air for combustion processes, cooling, extracting waste gases or heat from a process, dust collection, material handling, air conditioning, and chemical processing. No matter the industry or the process, fan system operation has a significant impact on plant production [16], [17]. Because of the support to production processes, many fans operate continuously. These long run times translate into significant energy consumption and substantial annual operating costs [13], [14].

Generally, most industrial fans or blowers could be categorised into one of four fundamental types, which are named in relation to the direction of flow through the impeller: axial flow fans, centrifugal fans, mixed flow fans, and crossflow fans [18], [19], [20]. These fan types differ from one another in the design and functionality related to the intended process conditions, and ultimately they are selected on the basis of the amount of airflow, pressure, and efficiency required for the process [19], [21], [22].

Fan systems are often selected from a variety of models and sizes rather than being custom-designed for a specific purpose [23], [24]. The importance of fan reliability and of protection against being held responsible for inadequate system performance often causes system designers to compensate for uncertainties in the design process by oversizing the fan system [7], [25]. Fan systems that are oversized for their service requirements do not operate with optimal efficiency. This creates performance problems that can increase purchasing costs and system operating costs, and decrease system reliability [13], [14].

The study uses the free online US Department of Energy (DoE) FSAT. A fan system optimisation assessment (FSOA) is conducted to assess the efficiency of systems and to identify any potential energy-saving opportunities [13], [14]. The FSOA is a multifaceted process that uses the fundamentals of system operating needs such as airflow rates, velocity, temperatures, pressures, airstream characteristics, and system structure. The approach involves establishing and analysing current operating parameters, determining the present process needs and load duty cycles, and assessing energy consumption with respect to performance [7], [16], [26]. The evaluation explores the running costs and the possible energy-saving potential of an adopted fan system.

Even though the efficient use of electrical energy is considered one of the unsung heroes in the fight to alleviate the global energy crisis and to create a resilient low-carbon footprint in any economic environment, there are still difficulties in getting facilities to act to achieve effective energy-efficiency strategies and techniques [27], [28]. Often, they tend to consent to the existing inefficient facility status. The resistance to acting to improve energy efficiency is mainly driven, among other things, by the lack of knowledge and adequate technical skills needed to implement effective energy efficiency measures [29], [30], [31]. The knowledge and skill gaps are also coupled with a lack of information about and understanding of the financial and qualitative benefits that energy efficiency could provide.

The objective of this research is thus to present a practical case of energy savings that promotes energy-efficiency initiatives. The study investigates a practical technique that is aimed at analysing the energy performance of a process fans system, characterising its consumption patterns, and demonstrating ways to quantify energy-efficiency savings. This practical case aims to produce a roadmap that any facility could adopt to help to accelerate energy sustainability.

2. FAN SYSTEM'S MAIN COMPONENTS

From the four types of fans or blowers mentioned in the introduction, the centrifugal type is most often used in commercial and industrial HVAC applications. Centrifugal blowers produce airflow by accelerating the airstream radially and transforming its kinetic energy into pressure [18], [24]. They intend to displace a consistent air volume at high speeds to provide tailored industrial applications. The impeller increases the speed of the airstream entering the fan, causing it to gain kinetic energy and to accelerate radially. Centrifugal fans' blade forms include forward-curved, radial-blade, radial-tip, backward-inclined, backward-curved, and airfoiled forms. "Backward-curved centrifugal fans" are used in this paper's application. They are best suited to applications that require larger flow rates. A backward-curved impeller fan's power requirement often peaks in the middle of its performance characteristic [18], [20], [23]. This feature reduces the possibility of the motor becoming overloaded at lower pressures and higher flow rates. They are efficient, although faster operation is required to achieve higher airflow rates.

Fans and blowers have some basic components that are critical to the operation and functionality of the system. A typical fan system has a fan, an electric motor, a drive system, ductwork or pipe, flow control devices, and air conditioning equipment. The impeller, fan blades, fan housing, drive shaft, air intake duct, air outlet duct, and electric motor are the essential components of a fan. Figure 1 shows the various fan components [32].

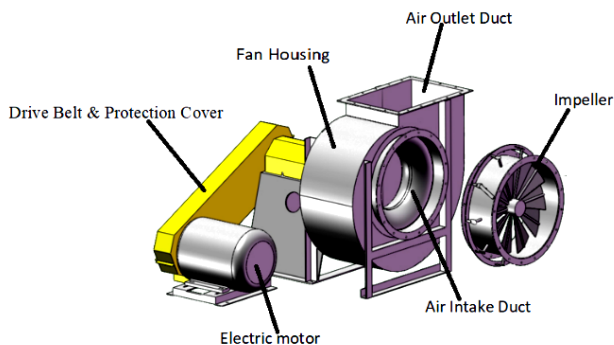


Figure 1: Main fan components [32]

3. ASPECTS OF ASSESSMENT OF FAN SYSTEM OPTIMISATION

Fan performance is typically defined by a plot of the developed pressure and power required over a range of fan-generated airflow. Understanding this relationship is key to optimum fan system design, selection, and operation. Fan system efficiency is the ratio of the power imparted to the airstream to the power delivered by the motor [13]. The ideal power of the airflow is the product of the pressure and the flow, corrected for units' consistency. The general equation for calculating the total efficiency can be expressed as:

$$P_i = \Delta p \times Q \tag{1}$$

where P_i is the ideal or airflow power consumption (W), Δp is the total pressure increase in the fan (P_a , N/m^2), and Q is the air volume flow delivered by the fan (m^3/s).

The fan efficiency, on the other hand, is the ratio between power transferred to airflow and the power used by the fan. In general, the fan efficiency is independent of the air density, and can be expressed as:

$$\eta_f = \left(\frac{\Delta p \times Q}{P} \right) \times 100 \quad (2)$$

where η_f is the fan efficiency, including motor and belt (%), Δp is the total pressure increase in the fan (P_a , N/m^2), Q is the air volume delivered by the fan (m^3/s), and P is the true or active power used by the fan (W , Nm/s).

Figure 2 describes an important aspect of the fan performance curve: the best efficiency point (BEP). This point represents the operational state at which a fan achieves optimal cost-effectiveness, ensuring both energy efficiency and reduced maintenance requirements. Recognising and targeting the BEP is essential for enhancing performance and achieving significant operational savings. Operating a fan system near its BEP improves its performance and reduces wear, allowing longer intervals between repairs. Moving a fan system's operating point away from its BEP increases bearing loads and noise [23], [24].

In any fan system, the resistance to airflow (pressure) increases when the flow of air is increased. The pressure required by a system over a range of flows can be determined and a system performance curve (system curve as shown in Figure 2) can be developed. This system curve is plotted on the fan curve to show the fan's actual operating point. This is the point where the fan curve and system curve intersect. This operating point is at a specific air flow (x-coordinate) delivered against a specific pressure (y-coordinate) at a predetermined speed. A fan operates along a performance given by the manufacturer for a particular fan speed. The fan's actual performance point on this curve will depend on the system resistance. Two methods can be used to reduce air flow. The first method is to restrict the airflow by partially closing a damper in the system. This action causes a new system performance curve in which the required pressure is greater for any given airflow. The second method is to reduce airflow by reducing the speed while keeping the damper fully open. In practice, the reduction of the fan speed is a much more efficient method to decrease airflow, since less power is required and less energy is consumed [13], [14].

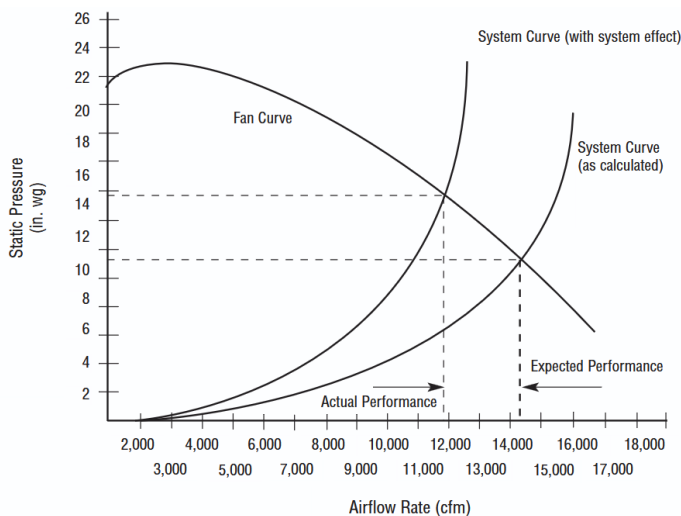


Figure 2: Typical fan characteristic curve [13].
Cfm = cubic feet per minute, in. wg = inches of water

The FSOA focuses on various fan systems situated in a manufacturing facility. Their performances are investigated by establishing measurements such as the operating pressures, flow rate, and velocity to allow the fan systems' static efficiency to be determined. The FSOA process enables any facility to obtain a clear idea of the fan system's performance and energy consumption [14]. It also enables the facility to identify more accurately whether a fan system has significant potential for energy savings, and whether any anomalies in the fan's performance would need to be rectified.

The industrial energy-efficiency assessment that undertakes the optimisation of the fan systems in a facility is crucial. The FSOA has a specific emphasis on optimising the fan system by highlighting energy savings opportunities [33], [34], [35]. The assessment entails reviewing the current processes and usage patterns of energy consumed by fan systems in a facility, and running a detailed analysis of the available options to improve energy consumption [13], [14], [36].

The assessment focuses on the following activities and outcomes: walk through the facility to understand the layout and operation; quantify the energy consumption related to the fan system and associated motor systems; establish the baseline energy consumption; determine the control mechanisms used in the fan systems; collect data on energy consumption and production data for the facility; quantify the energy consumed by the fan system and associated motor system in relation to the overall facility consumption; understand the role that fans play in the process; physical measurement of the fan systems using specialised fan systems optimisation equipment; determine energy-saving opportunities, including possible technology changes to the system and retrofits; and run financial feasibility studies on identified energy-saving opportunities. Energy savings opportunities can be categorised into two kinds [13], [14], [37]: first, quantitative opportunities (optimal use of VSDs already on site, installation of VSDs on other fans, V-belt maintenance, etc.), in which savings are clearly calculated and corroborated; and second, qualitative opportunities, which are more maintenance-based and are less easily quantified.

4. FUNDAMENTALS OF FAN SYSTEM ECONOMIC EVALUATION

4.1. Assumptions

All estimates and calculations are based on the following assumptions. The facility operates 24/7, 365 days a year, translating to $24 \times 365 = 8,760$ hours per year, and $(365/12) \times 24 = 730$ hours a month. This factor is conservatively used to account for anomalies and different motor loading values. The diversity factor also takes into consideration the effect of the drive belts, variable speed drives (VSDs), and soft start (SS) systems on the overall consumption of the fan system. These drive systems have the advantage of slowing down the speed of the fan system. This results in decreased energy consumption, since fans are subject to the affinity laws, which state that a 10% decrease in speed results in a 27% decrease in energy consumption. The only energy resource consumed by the fan systems is electricity. There is power factor correction over the entire facility at each of the substations. The power factor correction is observed to be 0.98. Electricity is the main source of energy that is used in the facility. The energy-saving costs are based on the chosen facility's 2024/25 electricity tariff structure and average cost deduced from the consumption behaviour (R1.4377/kWh or $R1.4377 \times (1\$/R18.16) = \0.0792 , excluding all network charges) [38], [39]. The facility consumes around 21,753 MWh each year. All savings estimations are based on the current energy price.

4.2. Fan system configuration

The fan systems at the facility serve two main purposes, namely for use in HVAC and in process-related requirements. The fan system used for HVAC is essentially fresh air fans, which transport air from the outside atmosphere into the building. The air from the plant is transported to a filtration system to remove excess dust from the stale air, which is then discarded into the atmosphere. The fans used in the manufacturing process feed air into process equipment to maintain a certain temperature that is critical to the product. The oldest fan systems on site were installed ten years earlier. They are highly inefficient in their design. They use standard efficiency motors and technology supplied by New York Blower [40].

Figure 3 shows the basic manufacturing process flow diagram from raw material to distribution, which shows the pathway from raw materials through the various lines: manufacturing, bagging, or packaging, sealing of the packaged goods, palletising, and warehousing and eventual distribution.

Some of the fan systems are fitted with VSDs and soft starters, and others are connected direct-on-line (DoL). Fan systems fitted with VSDs on the process side are run at a constant wavelength rather than being continuously adjusted. This constancy in speed is because the process requires a set volumetric flow rate of air rather than an adjustable load. The HVAC fans use VSD control, and are pressure controlled. Dampers are used and situated at various points on the systems. These are plate dampers: they are rarely adjusted, and their positions remain the same for long periods of time. To ascertain that adequate flow is delivered to various pieces of machinery, physical pressure and flow measurements are obtained over the systems.

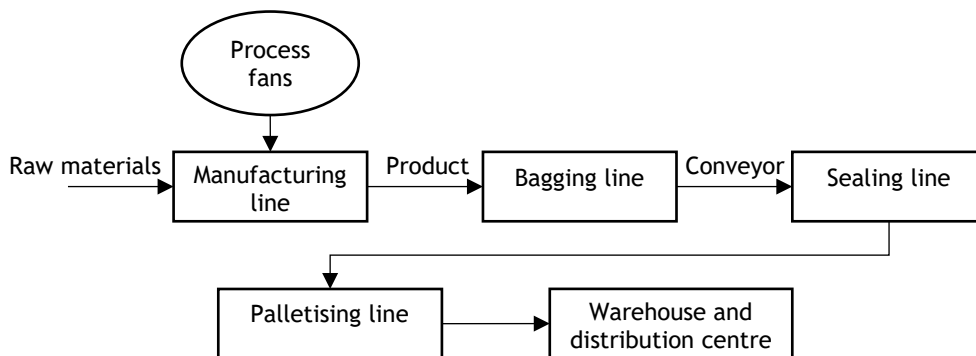


Figure 3: Simplified process flow

The fan systems used in the whole facility account for 33% of the total annual energy consumption. Based on the observations of all the fan systems, the five fan systems that needed to be assessed further were identified with respect to their size, potential for optimisation and energy savings, longer operational hours, and loads. Table 1 lists the fan systems deemed to be the best candidates for offering the most energy savings opportunities. The table also records the measured process parameters of the corresponding fan systems. The selected fan systems undergo further analysis and measurements during this assessment.

Table 1: Key process parameters of selected fan systems

Fan system	Fan type	Rated kW (hp)	Measured fan speed (rpm)	Measured power in kW	Measured static pressure Pa (in H ₂ O)	Measured flowrate m ³ /sec (cfm)	% loading	VSD/soft start/DoL
Fan 1	NYB - HP pressure blower E11304-140	45 (60)	2 566	22.34	12 678 (51)	0.77 (1 632)	50	Soft start
Fan 2	NYB - Series 60 fan E11304-110	75 (100)	2 477	32.1	9 693 (39)	3.58 (7 586)	43	Soft start
Fan 3	NYB - pressure blower ARR-102013-07145-01	15 (20)	2 477	6.52	5 355 (21)	1.52 (3 221)	43	DoL
Fan 4	NYB - Series 60 fan 275132-6	90 (125)	2 377	39.82	9 435 (38)	2.75 (5 827)	44	DoL
Fan 5	NYB - pressure blower 275132-4	75 (100)	2 577	48.01	14 716 (59)	1.25 (2 649)	64	DoL

The criteria used to select these five fan systems considered in the FSOA were the following: fan systems that offer the most potential for energy saving based on physical observations such as vibration, heat losses, dirt ingress present on fan blades and ducting; the most energy-intensive fan systems; and fan systems that are representative of other systems present at the facility. This step enables the observation of a larger number of fan systems and of the fan systems that are of major importance to the overall processes.

4.3. Potential fan system efficiency using fan system assessment tool

The data in Table 1 are input into the US DoE FSAT to rate the fan's potential for optimisation [14]. This is given as a percentage; and the lower the percentage efficiency, the greater the opportunity optimisation of that particular fan system. Figures 4, 5, 6, 7, and 8 illustrate the online tool assessment for Fans 1 to 5 respectively.

The interface of the fan optimisation assessment tool is illustrated in Figure 4, providing a comprehensive summary for Fan 1, a 45 kW NYB - HP pressure blower with the model number E11304-140. Similarly, Figure 5 presents an optimisation summary for Fan 2, a 75 kW NYB - Series 60 fan with the model number E11304-110. Figure 6 shows a summary for Fan 3, which is a 15 kW NYB - pressure blower (model ARR-102013-07145-01). Figure 7 details the optimisation summary for Fan 4, a 90 kW NYB - Series 60 fan (model 275132-

6). Lastly, Figure 8 provides an optimisation summary for Fan 5, a 75 kW NYB - pressure blower (model 275132-4).

The interface is organised into sections for inputs, which include field measurements and design data points, as well as outputs for analysing the current performance of the fan systems. It evaluates energy consumption, and identifies potential savings that could be achieved through optimisation when operating at the BEP. Key output metrics are fan and motor efficiency, annual energy consumption, annual operating costs, potential annual energy savings, and the expected energy reduction from optimisation.



Figure 4: Fan 1 system assessment



Figure 5: Fan 2 system assessment



Figure 6: Fan 3 system assessment



Figure 7: Fan 4 system assessment



Figure 8: Fan 5 system assessment

5. RESULTS AND DISCUSSION

Built into FSAT are three efficiency estimates for each fan type [14]. One is an estimate of the existing fan efficiency, based on using a standard efficiency motor. The annual energy consumption of the existing fan while using a standard motor, based on the time the fan is operated, is given. The second is an estimate of the existing fan efficiency, based on the use of an energy-efficient (EE) motor. The annual energy consumption of the existing fan while using an EE motor, based on the time the fan is operated, is given. Third is an estimate of the optimal fan efficiency for the specified fan style and gas conditions while using an EE motor. These estimates are calculated by dividing the fluid power by the estimated shaft power. The fluid power is calculated from the product of the flow rate, fan static pressure, and compressibility. The shaft power is estimated to be using the motor performance characteristics model. An annual energy consumption of the optimised fan using an EE motor, based on the estimated power required and on the fraction of time the fan is operated, is given. The estimated annual energy cost savings accrued from using an energy-efficient motor on the optimised fan is also offered [13], [14].

The colour pattern behind the dial indicator changes at 10% increments in the ‘Optimisation rating’ according to the following pattern: red for below 60%, orange for between 60 and 70%, yellow for between 70 and 80%, olive for between 80 and 90%, green for between 90 and 100%, and blue for above 100%. This approach forms the basis for estimating motor efficiency, shaft power, and other parameters in the FSAT [14].

The calculated data from the FSAT yields the results shown in Table 2. As may be seen in this table, the fans highlighted in green are operating efficiently and optimally. The fans in red in the FSAT rating (%) column (Fan 1, Fan 4, and Fan 5) are not displaying optimum efficient operation, and are currently operating too far left of the fan characteristic curve. EE opportunities are thus to be developed, taking the above considerations into account.

Table 3 shows the costs associated with running the group of selected fans and the potential savings. The annual energy consumption is calculated using three efficiency estimates: an estimate of existing fan efficiency with a standard efficiency motor (column D), an estimate of existing fan efficiency with an energy-efficient motor (column F), and an estimate of optimal fan efficiency with an energy-efficient motor (column H). The values in Table 3 columns D, F, and H are retrieved from Figures 4, 5, 6, 7, and 8, illustrating the FSAT for each fan after the relevant information from Table 1 has been entered. The estimated annual energy cost savings accrued from using an energy-efficient motor on the optimised fan are determined in columns G and I respectively [28], [39], [41].

Table 2: Fan performance characteristics

Fan system	FSAT existing static efficiency (%)	FSAT rating (%)	Comments
Fan 1	49.3	60.3	The FSAT rating indicates that the fan is optimisable. The fan is operating far to the left of the fan curve, indicating a region where mechanical disturbances are experienced.
Fan 2	120.0	143.1	The FSAT rating indicates that the fan is operating in an efficient and optimal zone.
Fan 3	144.0	168.7	The FSAT rating indicates that the fan is operating in an efficient and optimal zone.
Fan 4	72.5	87.5	The FSAT rating indicates that the fan is optimisable.
Fan 5	42.1	51.9	The FSAT rating indicates that the fan is optimisable. The fan is operating far to the left of the fan curve, indicating a region where mechanical disturbances are experienced.

Table 2 summarises the findings of fan system field data entered into the FSAT. The table distinguishes between fans that operate optimally and those that do not operate efficiently. kW = kilowatt, hp = horsepower, rpm = revolutions per minute, Pa = pressure in Pascal, in H₂O = inches of water, m³/sec = cubic metres per second, cfm = cubic feet per minute.

Table 3: Energy-efficiency consumption data

A Fan system	B Measured kW	C Annual operating hours	D Annual consumption MWh	E % of total facility consumption	F Annual consumption MWh	G Annual savings from existing fan system (MWh)	H Annual consumption MWh	I Annual savings from existing fan system (MWh)
			Existing fan + standard motor		Existing fan + EE motor	Optimal fan + EE motor		
Fan 1	22,3	8 760	195,35	0,90%	190,50	4,85	117,70	77,65
Fan 2	32,1	8 760	281,20	1,29%	281,20	0,00	281,20	0,00
Fan 3	6,5	8 760	56,94	0,26%	56,94	0,00	56,94	0,00
Fan 4	39,8	8 760	348,65	1,60%	340,00	8,65	305,00	43,65
Fan 5	48,0	8 760	420,48	1,93%	413,40	7,08	218,20	202,28
Total fan system energy consumption (MWh)			1 302,61	6%	1 282,04	20,58	979,04	323,58
Fan system energy cost (R1.4377 per kWh)			R1 872 757		R1 843 175	R29 582	R1 407 554	R465 203
Annual facility consumption (MWh)			21 752,89					
Annual facility energy cost (R1.4377 per kWh)			R31 274 130					

Savings from existing fan system	1,58%	Savings from existing fan system	24,84%
Savings from annual facility consumption	0,09%	Savings from annual facility consumption	1,49%

Table 3 illustrates the operating costs of the chosen group of fans. The potential savings are deduced using the existing fan with standard motor, the existing fan with EE motor, and the optimal fan with EE motor. R = South African Rand, MWh = Megawatt-hour, kWh = Kilowatt-hour.

The annual energy savings determined in column G (existing fan + EE motor) are obtained by subtracting the values in column D (annual consumption of the existing fan with standard motor) from the value in column F (annual consumption of the existing fan with an energy-efficient motor):

$$E_{\text{Savings - FAN1}} = 195.35 - 190.50 = 4.85\text{MWh}$$

$$E_{\text{Savings - FAN2}} = 281.20 - 281.20 = 0.00\text{MWh}$$

$$E_{\text{Savings - FAN3}} = 56.94 - 56.94 = 0.00\text{MWh}$$

$$E_{\text{Savings - FAN4}} = 348.65 - 340.00 = 8.65\text{MWh}$$

$$E_{\text{Savings - FAN5}} = 420.48 - 413.40 = 7.08\text{MWh}$$

The total annual energy savings of the existing fan with an EE motor compared with the existing fan with a standard motor are thus $4.85 + 8.65 + 7.08 = 20.58\text{MWh}$. The associated cost savings are estimated using a rate based on the facility's consumption behaviour of $\text{R}1.4377/\text{kWh}$: $20.58\text{MWh} \times 1,000 \times \text{R}1.4377/\text{kWh} = \text{R}29,582$. These savings represent 1.58% of the existing fan system and 0.09% of the annual facility consumption.

Similarly, the annual energy savings determined in column I (optimal fan + EE motor) are obtained by subtracting the values in column D (annual consumption of the existing fan with standard motor) from the value in column H (annual consumption of the optimal fan with an EE motor):

$$E_{\text{Savings - FAN1}} = 195.35 - 117.70 = 77.65\text{MWh}$$

$$E_{\text{Savings - FAN2}} = 281.20 - 281.20 = 0.00\text{MWh}$$

$$E_{\text{Savings - FAN3}} = 56.94 - 56.94 = 0.00\text{MWh}$$

$$E_{\text{Savings - FAN4}} = 348.65 - 305.00 = 43.65\text{MWh}$$

$$E_{\text{Savings - FAN5}} = 420.48 - 218.20 = 202.28\text{MWh}$$

The total annual energy savings of the optimal fan with an EE motor compared with the existing fan with a standard motor is, therefore, $77.65 + 43.65 + 202.28 = 323.58\text{MWh}$. The associated cost savings are estimated using a rate based on the facility's consumption behaviour of $\text{R}1.4377/\text{kWh}$: $323.58\text{MWh} \times 1,000 \times \text{R}1.4377/\text{kWh} = \text{R}465,203$. These savings represent 24.84% of the existing fan system and 1.49% of the annual facility consumption.

6. CONCLUSION

The high cost of energy in industrial operations could be lowered by improving the efficiency of fan systems. The FSAT software could be integrated into a comprehensive motor management strategy to identify opportunities to optimise fan systems. The FSAT is a simple and effective tool that is designed to help users to evaluate the performance of their fan systems. It requires only basic information about the fan system, allowing facilities to conduct a gap analysis on its performance and energy consumption. The optimisation assessment helps facilities to establish a resilient roadmap and to justify capital investments in improving their fan systems, either through process optimisation or by integrating modern EE fan designs. These upgrades could reduce energy consumption while providing effective thermal and environmental management capabilities.

The FSOA undertaken in this study examined a fan system consisting of five fans (Fans 1, 2, 3, 4, and 5). According to the data, Fans 1, 4, and 5 are optimisable and run well outside their ideal efficiency point on their characteristic curves. According to the findings, using an EE motor in conjunction with the optimised fan would result in yearly energy savings of 24.84% (323,5 MWh) compared with the selected fans, and 1.49% compared with overall facility consumption. The cost of energy savings at the facility's consumption profile rate is $\text{R}465,203$ per year. By just swapping the conventional motor with an energy-efficient one and leaving the fan unchanged, the annual energy savings would be 1.58% (323,5 MWh) compared with the specified fans and 0.09% compared with overall facility usage. In this case, the cost of energy savings for the facility's consumption profile would be $\text{R}29,582$ per year. The results show that optimising the entire system (fan and motor) would yield a significant fiscal return. This approach would provide quick returns and decrease susceptibility to rising energy costs and carbon footprints. The larger the facility and the more fans deployed, the greater the potential for cost savings. Thus, any fan system must be operated at its peak efficiency level, at which it becomes cost-effective in respect of running expenses. It must also be customised and developed for a specific application to avoid system oversizing.

Although this paper focuses on optimising the existing process, it is important to highlight that, as industrial production shifts to the era of smart manufacturing, the strategic deployment of cutting-edge fan technologies would continue to improve energy efficiency. Using modern fan systems, facilities could attain even higher levels of performance, creating a strong roadmap for a future in which fans serve as critical catalysts in enhancing energy efficiency.

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