Fan Systems Audit Standard

A STANDARD FOR THE AUDITING OF THE ENERGY EFFICIENCY OF ELECTRIC MOTOR-POWERED FAN SYSTEMS

VERSION 1.0

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CONTENTS

0.0 PURPOSE STATEMENT

This Fan System Audit Standard ("Audit Standard") is provided by the Energy Efficiency and Conservation Authority (EECA), for the purpose of providing a quality 'whole-system' auditing methodology for fan systems in common use in New Zealand industry.

It is expected that, when used by suitably qualified parties, adherence to this Audit Standard will provide the procurer of the audit with the confidence that the services received are comprehensive and of high quality.

0.1   Fan Systems Audit Standard

The Audit Standard is designed to guide the collection and analysis of fan system data for the purpose of identifying opportunities for improving the system's energy efficiency and providing relevant technically and commercially sound recommendations.

The Audit Standard is technology-neutral and measurement-method neutral, although the measurement methods used will be important in the context of the scope and measurement accuracy required of an audit

0.2   Disclaimer

As owner of this Audit Guideline, EECA will exercise due care in ensuring that it is maintained as fit for purpose.

However, EECA accepts no responsibility or liability for any direct or consequential loss or damage resulting from, or connected with, the use of this Audit Standard by any party.

Further, this Audit Standard does not seek to represent the obligations of any parties entering into any agreement for services relating to a fan system audit.

0.3   Further information

The Energy Management Association of New Zealand (EMANZ) has been commissioned by EECA to develop and maintain this Audit Standard in conjunction with relevant industry stakeholders.

If you have questions in relation to this Audit Standard, you may email info@emanz.org.nz , including reference 'FS Audit Standard" in the subject line. You may request to be notified when a new version is created.

The current version of the Audit Standard and other relevant information is available by visiting www.emanz.org.nz.

1.0 OVERVIEW OF THE FAN SYSTEM AUDIT STANDARD

Fan systems are used extensively to provide ventilation, extraction, cooling, and for product transport — essential to the daily operation of many businesses. They are often part of broader systems such as HVAC or manufacturing processes.

This Audit Standard provides an approach to fan system auditing and analysis. The objectives of the standard are to:
   a) Provide the framework for the systematic collection of data relevant to the efficient operation of fan systems, and;
   b) Enable the fan system auditor to fully analyse the performance of the fan system, identify potential electricity savings and provide sound recommendations for implementation of energy efficiency initiatives.

In addition, Appendix 8 includes a recommended report outline for the purpose of assisting concise, consistent and complete presentation of the analysis, findings and recommendations arising from a fan system audit.

1.1 Scope of the Audit Standard

The scope of the Audit Standard is fan systems that transport or circulate gas within an open or closed system. Assessing the efficiency of a fan system amounts to assessing the efficiency of the system in *performing the purpose that the transport of the gas is serving.*

The scope is therefore beyond the fan and motor; it extends from the power input to the fan motor to the point where the business purpose of transporting the gas can be considered achieved. For example, that purpose may be temperature maintenance (in the case of cooling towers) or a sufficient ventilation flow rate (in the case of HVAC systems).

The system boundary includes the gas use, the ducting network (including valves) and the fan itself. Improvements to any part of this system impact the wider system and must therefore be viewed holistically. Figure 1 shows a complete fan system; the system boundary should incorporate all components within.
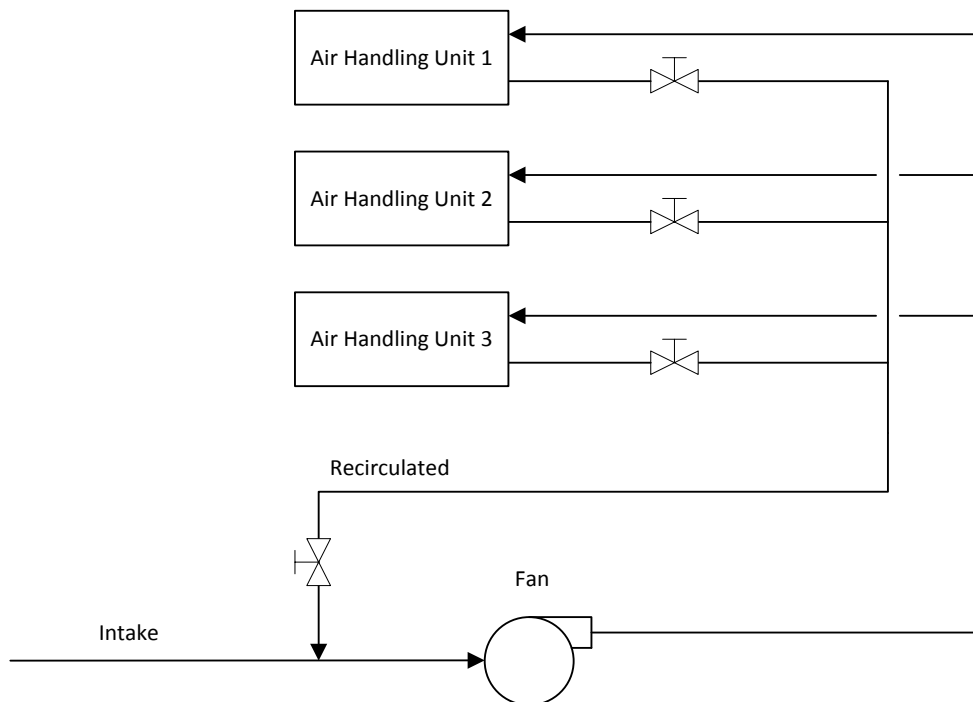
Figure 1: Fan System Boundary

No compressed air systems are within the scope of these guidelines. They are the subject of a separate auditing standard. Venturi-type vacuum devices are also excluded from the scope of this standard.

Care is required when evaluating and modifying fan systems that are coupled with other processes or may be subject to additional application specific standards and/or minimum or maximum performance parameters. A situation may arise where a fan power change results in an unintended failure or impairment of an associated system. Therefore, an auditor must have extensive knowledge of these types of systems or seek external assistance prior to reporting recommendations for systems beyond their field of expertise.

Refer to Appendix 6 for further definitions of concepts used within this document. For full descriptions of terms used within this document, refer to the glossary of terms in Appendix 7.

1.2 Accuracy and Measurement

This Audit Standard includes guidance on the expectations of audits conducted according to various levels of accuracy requirements - – a 'base-level' and an 'investment-level'. These levels are representative of the two ends of an accuracy requirement continuum. Where on that continuum the audit fits is a matter for agreement between the auditor and the client, and will be determined by the client's purpose in commissioning the audit.

The implications of measurement accuracy on audit accuracy are described in Appendix 5.

The measurement and analysis applicable for an audit primarily intended to identify areas of inefficiency and opportunity in the system (a typical base-level audit) generally does not include extensive use of flow, pressure and power measurement equipment.

A base-level audit may be the appropriate level to use to define the scope and measurement requirements of a subsequent investment-level audit of the same system.

Whereas the Audit Standard does not specifically cover the skills required of the auditing party, the accuracy level requirement of the audit will have an effect on the level and scope of the skills required of the auditor.

2.0 PLANNING THE AUDIT

2.1 Audit Objectives and Scope

Consulting with the client to identify and record the client's objectives in having the audit performed is a critical prelude to defining the scope of the audit and the associated measurement requirements.

An audit for a client who is seeking merely to understand where the fan system's efficiency opportunities exist in a factory may have lesser scope and measurement requirements than one that is required for a client who needs the audit findings as input into a capital investment proposal.

Agreement on objectives and scope should also include agreement on the content and structure of the audit report for subsequent presentation to, and discussion with, the client.

AS/NZS 3598:2000 may be used to guide expectations for both the client and the audit team in terms of what is expected from the audit and required of the audit team.

2.2 Business Context

The business context of the fan system(s) to be audited, or what is required of the system(s) in the wider business operation, needs to be established in order to define the measurement requirements for the audit and any post-implementation phase.

If (as is generally the case) one of the purposes of the audit is to provide information that will identify ways to improve the efficiency of the fan system, then the requirement of the system, and what is driving that requirement, must be understood from the outset. This is important for useful post-implementation monitoring of the fan system's energy performance.

For example, the requirement of a fan extraction system may be to remove the particulate or unwanted gases at a rate that renders the workplace safe and usable. The efficiency of the extraction system (from an energy perspective) will be maximised by minimising the amount of energy required to deliver that requirement.

When planning the audit, the relationship between the output of the fan system (and therefore the energy input to the system) and the business driver of the fan system, should be identified. The driver may be measured through one of a range of factors, such as hours of operation, production input (e.g. daily kg of material), production output (e.g. daily kg of product) or other measures such as temperature.

2.3 Resources and Responsibilities

2.3.1 Resource Requirements

The audit scope and accuracy requirement agreed with the client will determine the people and other resources required to perform the audit. The audit quotation presented to the client (which will form the basis of the service agreement subsequently established with the client) needs to include an assessment of the resource requirements.

The general expectation is that investment-level audits generally require more significant amounts of data collection, measurement equipment use and skilled people time than a base-level audit. However, a lower level audit does not mean a lower level of auditor competence; the less firm the data, the more pressure on auditor experience for correct interpretation of observations.

2.3.2 Audit Functions and Responsibilities

The audit requires 'management' and 'expediting' functions to be performed and, where an audit team is involved, it requires an allocation of the various audit responsibilities. The functions included within each of those areas are as follows:

Audit Managing: to ensure that the audit overall is managed to deliver a quality output, on schedule. This includes ensuring that:

   a.   the audit is appropriately scoped and priced;
   b.   the audit resource requirements are accurately identified;
   c.   a service agreement is established with the client;
   d.   audit tasks are allocated to appropriately skilled individuals;
   e.   a clear work schedule exists for the onsite activities and delivery of the final audit report;
   f.   the client delivers on its responsibilities under the service agreement;
   g.   any third-party contracts are facilitated and managed; and
   h.   the client- and peer reviews are completed.

Audit Expediting: to ensure the required data is collected according to the audit scope and objectives, in a manner that is consistent with the requirement of this Audit Standard. Expediting includes:

   a.   liaising with the site operations, maintenance and engineering staff to ensure site procedures are recognised in the logistics of the audit;
   b.   analysis of the audit data; and
   c.   drafting and finalising the audit findings and recommendations.

It is expected that these functions will be performed by a person who has the requisite fan systems qualifications, experience, and abilities to undertake the data collection, analyse the data, draw sound conclusions and provide quality recommendations. These responsibilities coincide with the expectations from a certified or accredited fan systems auditor.

2.3.3 Communications

An initial meeting between the audit manager and relevant site management should clarify the audit objectives and scope.

A second meeting, including the audit expeditor and site management and operations staff, should be used to:

   a.   review any preliminary (pre-audit) information that has been collected;
   b.   assist refinement of the measurements, tools and methods required for the audit to ensure client expectations will be met; and
   c.   ensure that there is an understanding of what resources are required onsite as well as employee involvement.

2.4 Peer Review

The audit process may include a peer review by a third party also competent in fan systems auditing.

The inclusion of such a peer review would either be a requirement of the agreement between the auditor and the client or at the auditor's discretion for internal quality assurance purposes.

2.5 Audit Costing

Costing of the fan system audit is an important part of the audit planning process.

For an investment-level audit, the cost will depend on the size of the site, the number of fan systems and system boundaries that have been defined in the scope, the level and duration of energy, flow and pressure measurements required, and any third-party contractors required to undertake measurements. It might also need to include recognition of post-audit performance monitoring that may be required by the client.

For a base-level audit, the measurement and reporting requirements will be significantly less — with a flow-on effect on the auditing cost estimate.

The quoted cost to the client should also take into consideration any support available from third parties. For instance, there may be services or funding provided by fan manufacturers, energy retailers, and potential project grants from EECA or other parties.

2.6 Audit Approach in Summary

Figure 2 outlines the general audit approach that should be followed. It commences with client consultation regarding the objectives and scope of the audit (as covered in 2.1 above).
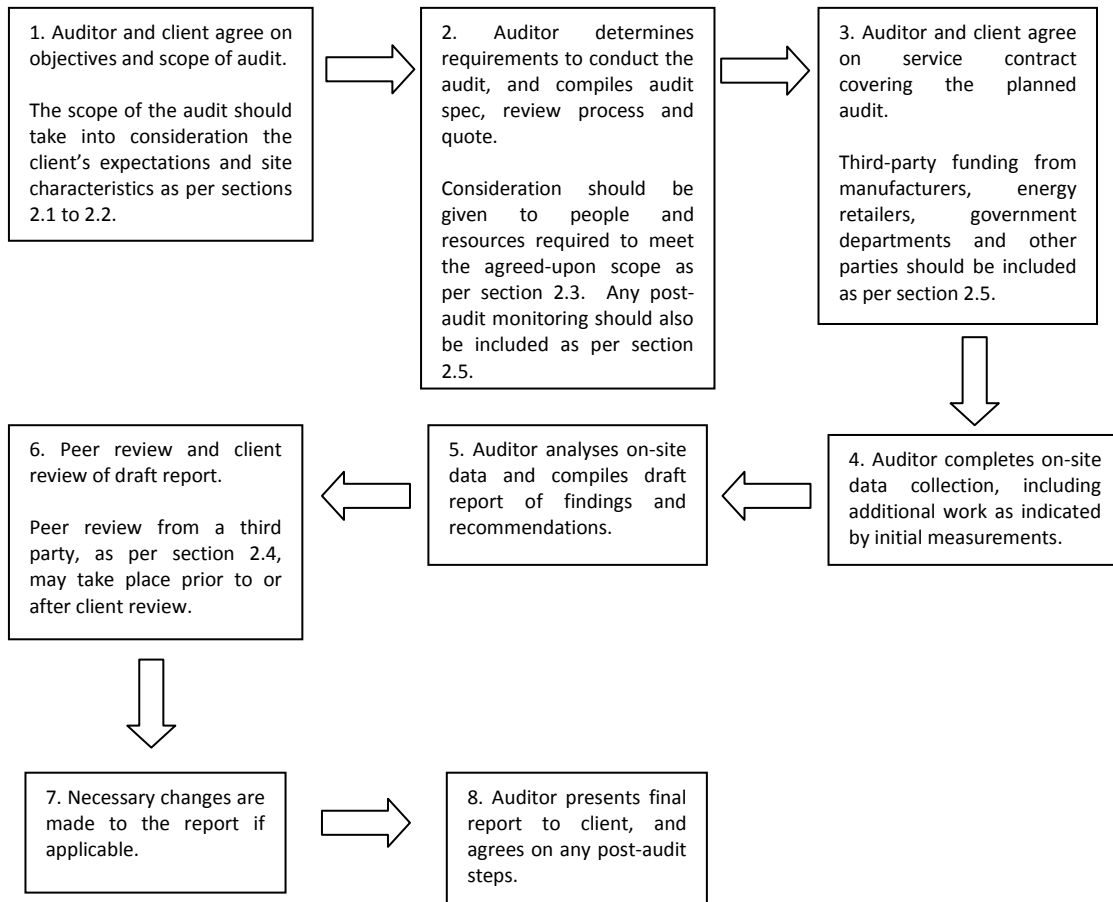
Figure 2: Flow Diagram of Audit Approach

2.7 Post-implementation Monitoring

Post-implementation monitoring of electricity usage relative to the fan system requirements or business driver is generally important to the client to enable the value of post-audit design or operations changes to be measured on an ongoing basis.

The nature of the post-implementation monitoring should be established as part of the audit planning, as it is likely to influence some aspects of the audit design and location of temporary or permanent measurement equipment. The key driver of fan system electricity input should govern the nature of the monitoring, whether that driver be production output, another input or merely hours of operation.

3.0 ON-SITE MEASUREMENTS AND DATA COLLECTION

This section details the measurement requirements for a fan system audit conducted to investment-level accuracy, and provides some guidance on what may be sufficient when auditing to the (lower) base level of accuracy.

In the first part, the measurement methods are outlined, followed by the measurement requirements for the site and systems being audited.

3.1 Measurement Methods

3.1.1 Electricity Usage Measurements

For investment-level audits, electricity usage (the input power to the fan system) should (if possible) be measured at the terminals of the motor driving the fan. For each fan motor, a three-phase electricity meter (data-logging) should be used to record electricity (kW) usage. Particularly where the fan system exhibits variable flow demand characteristics, it is recommended that the power readings are logged at intervals of not greater than 10 seconds.

If the electricity line charges are based on kVA measurement and the site does not have power factor correction upstream of the fans, kVA demand should be either directly measured or otherwise assessed.

Measurements should be taken for a period of time sufficient to capture the weekly operational pattern of the fan system. In addition, in order to put the weekly profile into an annual usage context, it is necessary to obtain an annual profile of production and/or electricity use. Investment-level accuracy of the annual usage estimate requires consideration of both the weekly and annual profile data.

For base-level audits, the 'Baseline Consumption Table' provided in Appendix 3 identifies the data required to estimate a fan system's annual electricity use.

3.1.2 Flow and Pressure Measurements

Where flow rates are constant, the flow rate in each part of the system can be measured separately, although in a dynamic system simultaneous measurements are needed to ensure accuracy. Measurements of airflow and pressure difference across the fan are required, although in some instances the best method of flow measurement is indirect, such as from heat loss or gain across a heat exchanger - using mass/energy balance. For direct measurements, it is important that they be taken at points where there is minimal turbulence.

From these measurements, and using the relevant fan performance curve, the fan input power can be determined.

For a base-level audit, it is recommended that values are noted if there are gauges already in the ducting.

3.1.3 Electricity Cost Estimation

Wherever the audit findings are likely to be used in any investment analysis undertaken by the client, the electricity costs used in valuing the electricity consumption of the fan system should be based on future contract or forecast prices and adjusted for any other relevant variable pricing factors, as agreed with the client.

Annual average prices can generally be used unless there are considerable seasonal variances in production (fan system consumption) patterns. Any seasonal electricity price variations should be recognised in any calculation of production-weighted annual average prices.

The effect of any demand and/or capacity charges should also be accounted for. Where differences in electricity use are being valued, the valuation needs to consider that some elements of the delivered electricity price may be independent of the consumption level. Any fully fixed elements of the electricity price need to be removed from the cost used to value a consumption difference.

For the purposes of a base-level audit, if the client does not have a standard electricity cost figure for project analysis purposes, it is generally acceptable to use the most recent 12 months' gross average electricity cost (total cost divided by total energy consumed) for the valuing of electricity use.

If relevant, the effect of power factor on delivered electricity costs to the fan system should be recognised. On most electricity distribution networks, a premium is chargeable if a power factor of less than 0.95 is measureable at the site-entry metering point. The audit should identify if the site would benefit from the installation of power factor correction

equipment at the main switchboard (or any sub-board for the supply of fan and fan systems), as that information is important to the assessment of existing and future delivered electricity costs for the site concerned.

The absence of power factor correction equipment on the site would normally result in a recommendation to the client to investigate the economics of correcting that situation.

3.1.4 Works Cost Estimates

Particularly where the audit is undertaken for investment proposal purposes, the findings will include recommendations for works to be performed to exploit efficiency opportunities.

With guidance from the client with regard to whom to consult with, it is expected that compiling budget estimates for such will require consultation with a range of equipment suppliers or maintenance engineering companies. The level of accuracy of the cost estimates should meet the client's requirement. For investment proposal purposes, the accuracy expectation will typically be in the order of ±15%.

3.2 Fan System Measurements

3.2.1 Site-level Data Collection

Appendix 1 contains a form outlining the key site-level data that should be recorded for the audit, irrespective of the accuracy level of audit concerned.

3.2.2 Business Requirement of the System

Understanding the requirement that the business has for the fan system being audited is a prerequisite to identifying areas of inefficiency. It is useful to commence the audit with quantification of that requirement, which necessitates collection of the following information:
- the functional (flow and pressure) requirements of the system in relation to the main business driver (e.g. production, safety and comfort specifications in the case of HVAC systems or minimum velocity requirements to ensure particles remain in suspension in the case of extraction systems); and
- any changes to system design since initial installation and the reasons for these changes

A duct layout diagram is important to provide a clear picture of the interrelationships between the system components and how the requirements may be delivered. Other information may be required to enable further analysis, such as cooling tower capacities, AHU specifications, heat exchangers, driers, fluidised beds and any other interconnected process parameters related to gas use.

3.2.3 Operating Characteristics

An understanding of the actual (as opposed to the required) operating characteristics requires data collection across the demand, network and supply components of the system, and quantifying the relationship between electricity use and the relevant business driver of system demand.

Appendix 2 contains forms that identify the data required to gain such an understanding and that are potentially useful for an investment-level audit. More detail on the measurements of that data is provided below.

For base-level audits, Appendix 3 provides several forms that identify:

- a minimum level of data needed to estimate a fan system's annual electricity use; and

- a checklist that could be used to assess the key components of the system as they affect system efficiency.

Fan run-hour data should be verified by site personnel wherever possible, as the economics of potential efficiency opportunities will depend heavily on that information.

3.2.4 Electricity Use and Business Driver Relationship

For investment-level audits, the baseline electricity usage measurement obtained from the audit should quantify the Fan System Energy Intensity (FEI), expressed as fan motor energy consumption per unit of the associated business driver (e.g. kWh per kg of production output). In addition, the audit should determine (and quantify) any relationship between the FEI and different levels of production activity.

The nature of the monitoring should be governed by the key driver of fan system electricity input, whether that is another production input, output, ambient temperature or merely hours of operation.

For practical purposes (particularly for post-implementation monitoring), the FEI may be established by metering a single or small number of key 'reference fans' rather than attach electricity meters to all fans within a system.

3.2.5 Demand Measurements

Determine the gas that is being delivered and the nature of its use. This includes observing and/or recording:
- Flow and pressure measurements at points of demand requirement. Note that extreme caution needs to be taken when measuring gas flow rates in ducts, especially with turbulent flows. Alternative methods are often best, such as measurement of the temperature rise across a water-to-air heat exchanger where the input energy and flow can be more accurately recorded (i.e. water flow rate, and the inlet and outlet temperatures of both streams can be used to deduce air flow).
- Operational information such as production run hours and system demand over the full range of plant operating conditions
- In the case of cooling water towers, water flow through the cooling tower is also important
- When available, check the observed/measured data against system design specifications, and note any significant deviations in system operation/performance.

In the case of air-assisted heat transfer systems and HVAC systems, temperature is a key system requirement and demand measure. This includes:
- Seasonal ambient wet-bulb and dry-bulb temperatures*
- In the case of water towers, water temperatures entering and leaving the tower

*Where the site is located within a 10km radius of a NIWA weather station, NIWA Cliflo data may be used for ambient wet- and dry-bulb temperatures.

3.2.6 Ducting and Delivery Measurements

For each fan system, the next step is to determine the delivery of the gas and the effectiveness of this delivery. This includes observing and/or recording:
- Filter pressure drops (where a differential gauge has been installed to monitor this)
- Duct supply pressure (static pressure)
- Observe and/or measure duct leakage
- Damper positions, static supply pressure (make use of SCADA/BMS data where possible). This is especially important on multiple-outlet systems, as they are often over-damped as a way of compensating for an oversized fan as well as even distribution of gas flow.
- Ascertain whether the fan was sized for its application and whether the ducting network has been changed since installation
- Record duct sizing, transition geometry such as diffusers and corners, and any other relevant features affecting delivery
- System trials where applicable, e.g. closing/opening outlet dampers while measuring fan electrical power consumption

3.2.7 Supply Measurements

For each fan system, the final step is to determine the supply of the gas and the nature of its delivery. This includes observing and/or recording:
- Fan make, model, motor size, control method, drive system (an AHU typically has one centrifugal fan, but may use multiple fans or axial fans)
- Obtain fan curve data and manufacturer's specifications
- Motor information – includes rpm, kW rating
- Motor electrical logging over extended period, especially for variable-flow applications
- Variable Speed Drive (VSD) information
- Fan differential pressure
- Filter differential pressure (in the case of an AHU)
- Fan electrical power consumption
- Anemometer readings
- Pulley diameters (if applicable)
- Belt type and tension (if applicable)
- Fan blade material

4.0 DATA ANALYSIS

For a base-level fan system audit, observations and measurements are relatively low in detail, and analysis consequently relies on significant assumptions. In many cases, it will be impossible to make any further conclusions about the operation of the system without equipment to take more in-depth measurements.

For an investment-level fan system audit, observations and measurements must be in much higher detail than for a base-level audit. This minimises assumptions that must be made for subsequent analysis. In some cases, it may still be impossible to make any further conclusions about the operation of the system if information such as relevant fan curves, electrical loggings, pressure measurements and flow measurements cannot be obtained.

4.1 Demand versus Requirements

Analysis of gas demand requires the optimisation of gas use. Solutions to improve the efficiency of gas use include:
- Assess the appropriateness of each demand for air/gas relative to the specified requirements from the system
- Automated isolation of gas users
- Scheduling of fan system operation outside electricity network peak charge periods
- Reduction of gas consumption by users
- Reduction in gas leaks
- For extraction systems, is the system delivering the requirements at each of the locations?
- For cooling towers, are the cooling demands reflected in the water temperature setpoint?

Any improvement in the use of air/gas on the demand side ultimately reduces the energy input required from fans within a system. Calculations of power consumption reductions must be based on the fan's associated performance curve. The use of affinity laws (see Appendix 4) can only occur if it is accurate to assume that any shift in operating point moves along the system curve. Care must also be taken to consider the correct relationship to use based on the type of fan in use.

For base-level audits, reduction in power consumption can be calculated using the fan equation or in some cases with the use of affinity laws.

4.1.1 System Demand Duration Curve

A duration curve is a useful data analysis tool for assessing air demanded or delivered over the period of the audit. Depending on what aspect of the system is being analysed, the duration curve may measure flow rate, pressure or power consumption – see Figure 3 on following page.

The duration curve provides an understanding of several relationships:
1. Between actual demand profile and required demand profile
2. Between actual demand and the system's delivery capacity

For example, the curve in Figure 3 might indicate the need to consider the options for meeting the short duration of high demand. Is this a case where a large fan is operating for only a small proportion of time at its BEP at maximum flow, and where one or more smaller fan(s) could be used with much greater efficiency for the majority of the time?

If system pressure is plotted with respect to time, it may be apparent that the system is not able to maintain the 'nominal' system pressure for some proportion of the time, suggesting that the system pressure setpoint could be permanently reduced.
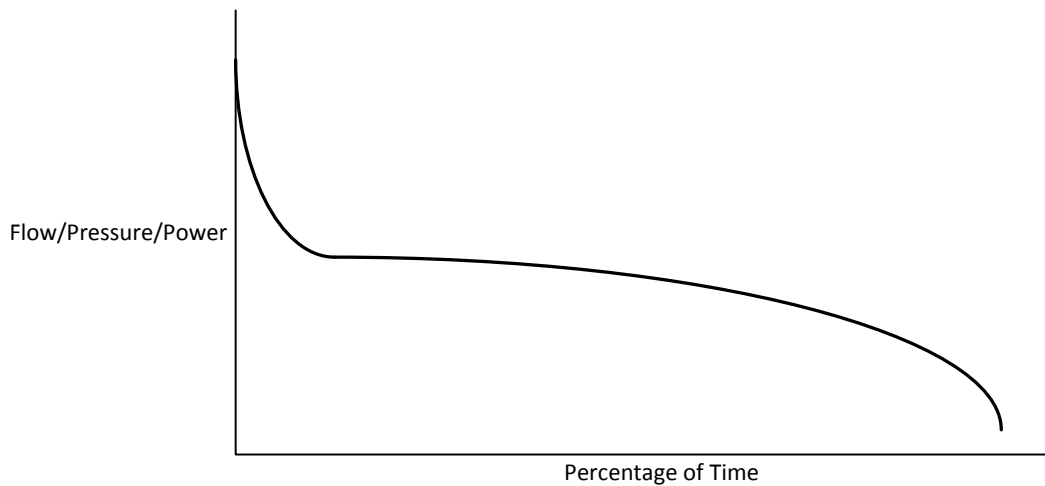
Figure 3: Example of Duration Curve

4.1.2 Flow Balance

A flow balance is a useful tool in analysing system demands and requirements, and accounting for gas flows (energy) once the gas has left the fan. This involves the measurement of air flows at various key delivery points in the fan system.

Using simultaneous flow rate measurements, a gas flow balance analysis will enable a reconciliation of where the gas is being delivered and if there is unnecessary demand on fan output due to leakage or other areas of wastage.

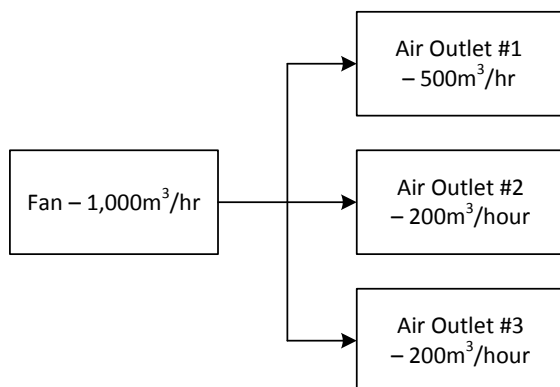An example of how a flow balance may be constructed is shown in Figure 4.

Figure 4: Flow Balance Example

A review of the hypothetical data from this example identifies that:
- the 100m^3/hour of air not accounted for from the measurements is being lost in leakage or is due to flow measurement errors; and
- the flow at Air Outlet #1 is 150m^3/hour greater than the maximum flow required at that point (i.e. the flow requirement at Air Outlet #1 is 350 m^3/hour or less).

The analysis therefore indicates that there is an opportunity to reduce the fan output flow by 250m^3/hour.

Repairing leaks and adjusting the damper to Air Outlet #1 will likely be the most economical way of capturing the benefits. However, a more complete picture of the efficiency opportunities (and then the design or operation improvement options) will be available once the analysis of the system upstream of the fan output is completed. A flow balance may reveal whether a fan system is:
- delivering excess fan output due to leakage
- consuming excessive power due to pressure loss through sub-optimal duct sizing, filter pressure drops or excessive flow dampers/fan control devices
- in the case of cooling towers, consuming excess fan power due to lack of differential temperature control between the ambient wet-bulb and tower water temperatures

4.2 Fan System Ducting and Delivery

Analysis of fan system ducting requires the determination of gas delivery efficiency. This requires the measurement of pressure losses and flow through different sections of the network.

Solutions to improve the efficiency of gas delivery include:
- Reducing pressure drops across filters – often filters are not replaced as frequently as is ideal
- Reducing system pressure drops as a result of excessive frictional losses (often caused by undersized ducting and poor duct transition design)
- The optimising of duct configuration – best practice dictates that fan inlets and outlets are installed away from duct elbows, joints, and tee intersections to avoid unwanted and inefficient turbulence
- Improved network maintenance

It is recommended that software specific to duct design is used to analyse the system's delivery effectiveness. Modelling the system using software will quickly identify areas with excessive frictional losses as a result of undersized ducting, and areas with pressure losses as a result of incorrect filters or suboptimal duct configuration.

It is very difficult to determine the effectiveness of gas delivery without accurate measurements of flow and pressure, let alone calculate potential energy savings.

If it is noted that network maintenance practices are poor, it is suggested that a percentage improvement in system energy efficiency can be expected as a result of improved practices.

4.3 Fan System Supply

Analysis of a fan system supply requires the optimisation of fan maintenance, suitability and control. This may be difficult to determine without accurate measurements, although assumptions can be made to estimate potential energy savings. Solutions to improve the fan supply efficiency include:
- Replacing a fan with a fan operating closer to its BEP
- Improve fan maintenance; up to 15% reduction in fan efficiency can be expected for an un-maintained fan, especially with respect to belt tensioning losses
- Improve fan capacity control, in particular to avoid dampened / bypassed flow
- Consider an impeller change where applicable – especially for fixed-flow applications.
- Replace fan motor with a more efficient motor
- Improve fan coupling; a 5% improvement in efficiency can be expected by moving from V-belt to direct coupling
- Improve system operation control; ideally automating when the system switches on or off (or changes speed via VSD), depending on wider system variables such as temperature

4.3.1 Fan Maintenance

It is best practice to perform regular maintenance on fans. This includes the cleaning of blades, replacing worn blades, monitoring belt wear and tension loss, monitoring drive alignment and ensuring bearing lubrication. This will not only maintain their energy efficiency but will also ensure they operate to system requirements and do not prematurely fail, which increases overall life-cycle costs. Failure may also result in production downtime, which also has associated costs.

It can be assumed that un-maintained fans are between 5% and 10% less efficient than regularly maintained fans. This is especially true for belts that are worn or lost tension or for applications involving abrasive particles in the airstream. This is also due to impeller wear, casing wear and increasing clearance between fixed and moving parts. Inefficiencies can be confirmed using pressure, flow and electrical loggings to determine the operating point of the fan.

4.3.2 Fan Suitability

A manufacturer's fan curve is critical in assessing how well a fan is operating relative to its BEP. If a fan has been well sized and no significant changes have been made to the system, the fan should be operating in the blue region in Figure 5, close to its BEP.
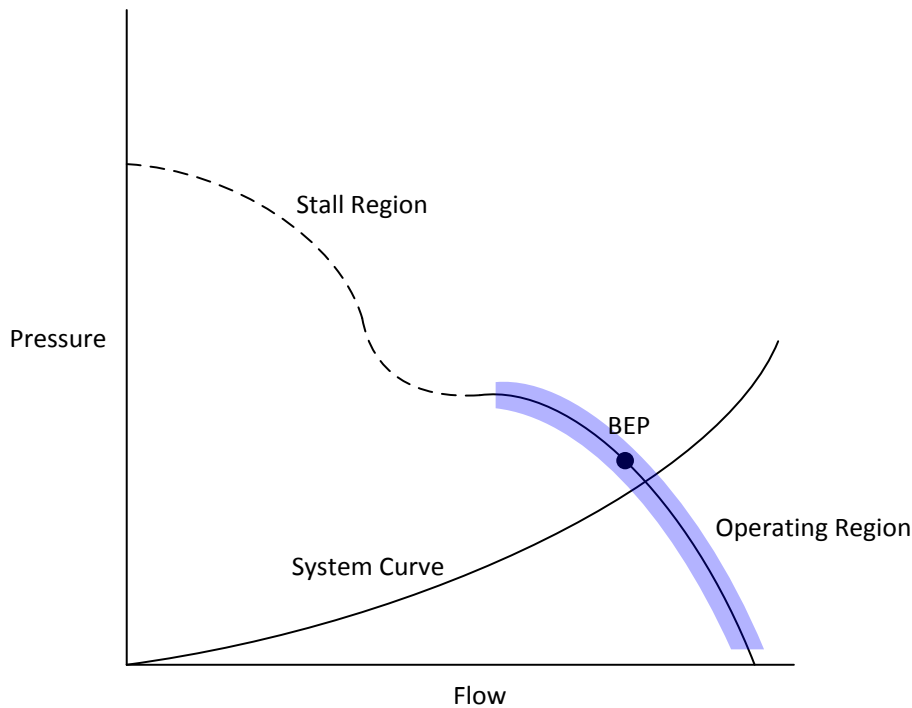
Figure 5: Fan Curve (axial fan example)

Fans operating in the stall region (or 'region of instability') are likely to be operating inefficiently and with higher wear than a fan operating near its BEP. Most fan curves will include efficiency and power lines, and it is important to verify whether the power line represents shaft or motor input power. The example above is typical of an axial fan. Other fan types will have differently shaped fan curves, but all have an optimum BEP.

While the fan performance curve shows the best possible efficiency of that particular fan model, comparing this best efficiency to alternative fan models is recommended, as in some cases it is economically viable to replace a fan completely. For extraction systems it may be beneficial to consider multiple smaller systems where demands occur at different times or in different places. In some cases, fan noise may also be an important consideration in determining what the optimum delivery level is.

It may also be beneficial to replace the fan blades with a more efficient type. More recently, developments have been made that result in fan blades that are more energy efficient. This includes blades made from fibre-reinforced plastic that improves fan profile accuracy and fan efficiency, as well as blades with improved designs that have better aerodynamic efficiency. Blade replacement may be applicable for large fans that are in operation for long periods of time, in which case there is potential for significant energy reductions.

4.3.3 Fan Control

Fan control methods are central to the efficiency of fan operation, particularly because many control methods are inherently inefficient. While data specific to a fan (and its control system) should be used wherever possible, Figure 6 provides approximate turn-down values for situations where data is not available or for base-level analysis.
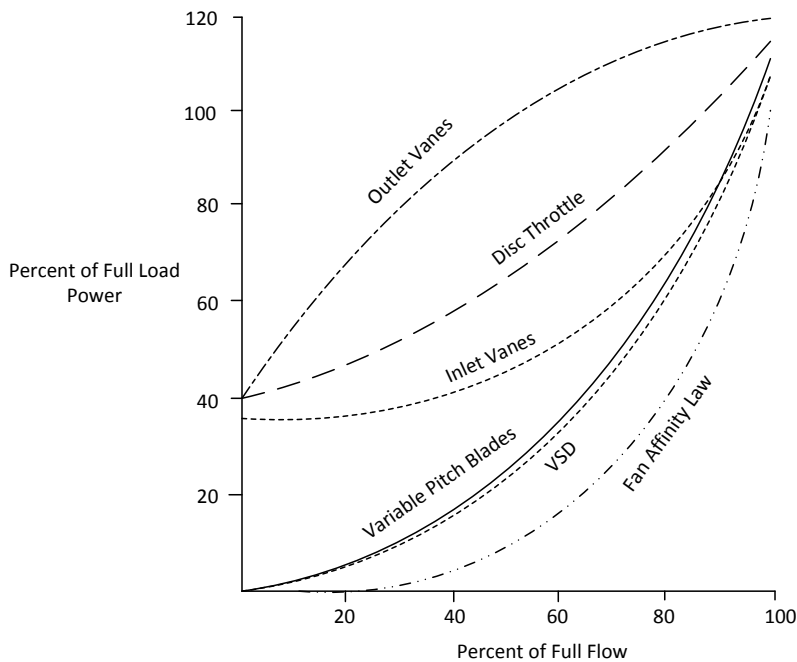
Figure 6: Fan Control Efficiency

Outlet vanes are by far the least efficient control method, while inlet guide vanes have a moderate energy penalty at higher flows. Variable-pitch blades can have a similar efficiency to VSD though are not generally a retrofit option, making them more attractive in new applications. It is noteworthy that none of the control methods shown are as 'efficient' as the fan affinity law would predict, which is why this law is suitable only as a guide in base-level audits and for small changes in system parameters.

Calculations of power consumption reductions should be based on the fan's associated performance curve. The use of affinity laws (see Appendix 4) can only occur if it is accurate to assume that any shift in operating point moves along the system curve. This is the case for fans controlled by variable-speed drives, as illustrated in Figure 7.
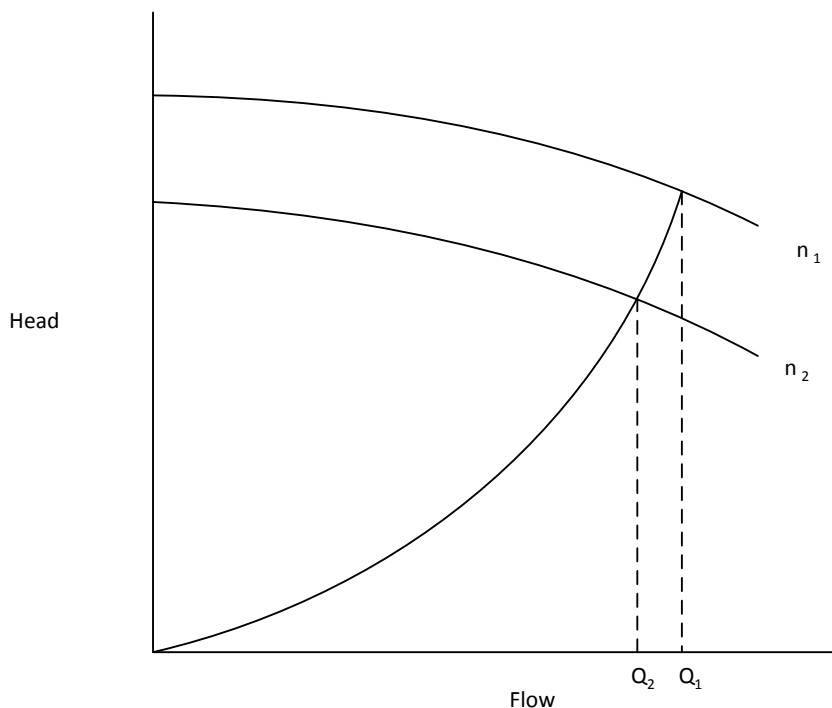
Figure 7: Change in Fan Operating Point as Speed is Reduced from n_1 to n_2

Reviewing the current fan system and methods for fan control improvement may result in:
- Improving system control by implementing VSD control and better matching variable system demands;
- Improving system control by implementing VSD in place of on/off control;
- Impeller replacement/resizing to better meet load requirements (especially for fixed-load applications)
- Installing PLC control such that the fan is switched off when there is no demand, or controlled to meet demand;

- Damper installation on each inlet/outlet, either automated or manual, and ensure that these are closed when extraction/ventilation is not required;
- For cooling towers, reviewing demands for cooling, including water temperature setpoint and off-peak or overnight cooling demands, and improve controls to suit these conditions.

It is important to note that other factors must be taken into account when altering system control. In some cases, minimum gas flows or pressures must be maintained. An example of this occurs in dust extraction systems, where minimum air velocities must be maintained to ensure particles do not settle within ductwork.

4.3.4 Motors and Coupling

In most cases a motor will be sized to operate within 75%–100% of its rated capacity, as well as allowing for the starting torque requirements of the device being driven. Motors are correctly sized for their application in most cases, since fans are often supplied as a fan/motor package, although there will be instances where motors are oversized.

The efficiency of fan motors has been targeted with mandatory Minimum Energy Performance Standards (MEPS) required for new installations. AS/NZS 1359.5:2004 contains efficiency requirements for three-phase motors rated between 0.73kW and 185kW.

The type of fan-motor coupling should also be considered. The most efficient drive method is direct mechanical coupling, although space, layout and motor speed requirements (the use of pulleys) will not always allow this.

For the various components of a motor/fan system:

- motor controller losses (non-bypassed soft starter devices or variable speed drives) can be taken from manufacturer specifications;

- motor losses can be assessed from a combination of the manufacturer's motor efficiency data (at the load percentage applicable to the system), and making allowance for the maintenance/rewind history of the motor if available;

- losses from the drive system between the motor and the fan vary with the type of drive employed. Direct drive (shafts directly linked) losses can be assessed at zero. Where belts are used, the losses vary depending on choice of belt and how well it is fitted, its age/condition and the size of the pulleys used.

The fan shaft input power can be determined using the fan curve from the measurements of flow and pressure measurements across the fan. This enables the fan's operating point on its characteristic curve to be determined, and by comparison with the motor input power measurements, the energy loss between the fan shaft and the motor input.

For a base-level audit that does not have flow, pressure or motor loading measurements, an assessment of energy consumption and the identification of opportunities will need to rely on the fan affinity laws and general observations and expected relationships between pressure, flow, power, shaft speed and pulley diameter. Refer to Appendix 4 for a summary of fan affinity laws.

4.4 Whole-system Considerations

Each part of the fan system analysis may include findings that can have some relation to another part of the system.

Consequently, the analysis needs to identify 'dependent' and 'mutually exclusive' opportunities across the whole system, to ensure that the most cohesive and well-specified recommendation set is made to the client.

Where two opportunities are dependent (one must be done in order for the other one to be possible), they may be presented as one saving with one total associated cost. For example, if a fan is consuming 10kW of power and reductions of 20% of the demand for air and 30% control efficiency improvements can be made, they should be applied as follows:

Power use after demand reduction   = 10kW x 0.8
        = 8kW

Power use after control improvement   = 8kW x 0.7
        = 5.6kW (or 56% of the original consumption)

If the savings had both been applied to the original 10kW, total savings of 5kW or 50% would have been calculated, overestimating savings by 6% of the original energy use.

APPENDIX 1 – SITE INFORMATION FORM

Business Name	
Site physical address (Street, Suburb, City)	
Nature of site / business operation	

First day of onsite loggings	
Final day of onsite loggings	
Production during period of loggings	
Electricity Supplier	
Power factor correction equipment in use	
Delivered electricity cost per kWh	

Site contact 1: Name	
Designation	
Telephone (DDI)	
Email	
Site contact 2: Name	
Telephone (DDI)	
Email	

Comments:

APPENDIX 2 – SYSTEM DATA COLLECTION FORMS

Network Schematic		
System Reference		note: include dimensions, dampers etc
note: for cooling tower systems it will be useful to also draw the cooling water fan system schematic		
Operational Information		
Maintenance Information		
Other notes		

Fan Supply Form			
		Unit	*Comments*
Fan Details			
System Reference			
Manufacturer			
Model			
Serial			
Year			
Fan Type			
Impeller Diameter			
Photo #			
Motor Details			
Driver Coupling			
Rated kW			
RPM			
Poles			
Measurements			
Electrical Measurement / Logging Reference			
Flow Measurement / Logging Reference			
Pressure Measurement / Logging Reference			
Operational Information			
Estimated Run Hours			
Flow Control Method			
Pressure Control Method			
Maintenance Information			
Production Information			
Other notes			

Specific Fan System Form		
	Unit	**Comments**
HVAC Systems		
Filter Differential Pressure		
Flow Leakage Estimate		
Other notes		
Cooling Tower Systems		
Water Temperature: Inlet		
Water Temperature: Outlet		
Water Flow Through Tower		
Fan Control		
Blade Material		
Other notes	e.g. fan details if required	
Extraction Systems		
Designed Minimum Velocity		
Damper Positions		
Flow Leakage Estimate		
Other notes		
Blower and Vacuum Systems		
Flow Leakage Estimate		
Misuses		
Other notes		
Other Industrial Process Systems		
Flow Measurement/Estimate		
Pressure Measurement/Estimate		
Other Measurements/Estimates		
Flow Control		
Pressure Control		
Other notes		

APPENDIX 3 – BASE LEVEL AUDIT COLLECTION AND CHECKLIST

One per fan system

Baseline Consumption

Fan System:	1				Description:	Dust Extract.	Open/Closed System:		Open
Fan ID	**Model**	**Type**	**Impeller Diameter**	**Motor Speed**	**Rated (kW)**	**Average Load Factor**	**Annual Run Hours**	**Annual Consumption (MWh)***	
#1	e.g. fanabc123	Axial	200mm	1,490rpm	75	0.8	4,000	240	
#2								0	
#3								0	
#4								0	
….								0	
Total								**240**	

* Where Annual Consumption = (Rated kW / 1000) x (Average Load Factor) x (Annual Run Hours)

	Assessment Checklist	**Potential for Efficiency Improvement**				
	Efficiency Opportunity Element	**N / A**	**LOW**	**MED**	**HIGH**	**Further Comments**
DEMAND	Gas user isolation					
	Peak load shedding opportunity[1]					
	Appropriate end use of gas					
	Pressure requirement[2]					
	Flow requirements					
	Gas leaks					
NETWORK	Changes to initial system design [3]					
	System pressure drop					
	Network maintenance					
	Valve suitability					
	Duct configuration / zoning					
SUPPLY	Changes to initial system design[4]					
	Fan suitability					
	Fan maintenance					
	Fan control - variable flow[5]					
	Fan blades[6]					
	Motor efficiency					
	Motor coupling					
	System operation / scheduling					

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[1] Includes opportunities related to the shedding or shifting of electrical loads from peak demand periods where the electricity supply costs (energy and/or network costs) are high, e.g. cooling tower fan system load shifted outside peak demand charge periods.

[2] Includes opportunities related to dirty filters, etc., in which case pressure is artificially increased.

[3] Includes opportunities related to changes in fan system design since original system installation, e.g. changes to ductwork to supply more gas users.

[4] Includes opportunities related to changes in fan system design since original system installation, e.g. fan replacement in order to meet new demands or change in fan control methods.

[5] Includes opportunities related to the elimination of dampened and/or bypassed flow through improved fan system control methods (such as VSD control). This could also be in relation to improved temperature control.

[6] Includes opportunities related to high-efficiency fan blade materials or minimising housing clearances.

APPENDIX 4 – FAN AFFINITY LAWS SUMMARY

1) Flow is proportional to shaft speed change and the cube of pulley diameter change;

$$\frac{Q_1}{Q_2} = \left(\frac{n_1}{n_2}\right)\left(\frac{d_1}{d_2}\right)^3$$ Where pulley diameter remains constant, $$\frac{Q_1}{Q_2} = \left(\frac{n_1}{n_2}\right)$$

Where; Q_1 = Initial Flow n_1 = Initial Shaft Speed d_1 = Initial Pulley Diameter

Q_2 = New Flow n_2 = New Shaft Speed d_2 = New Pulley Diameter
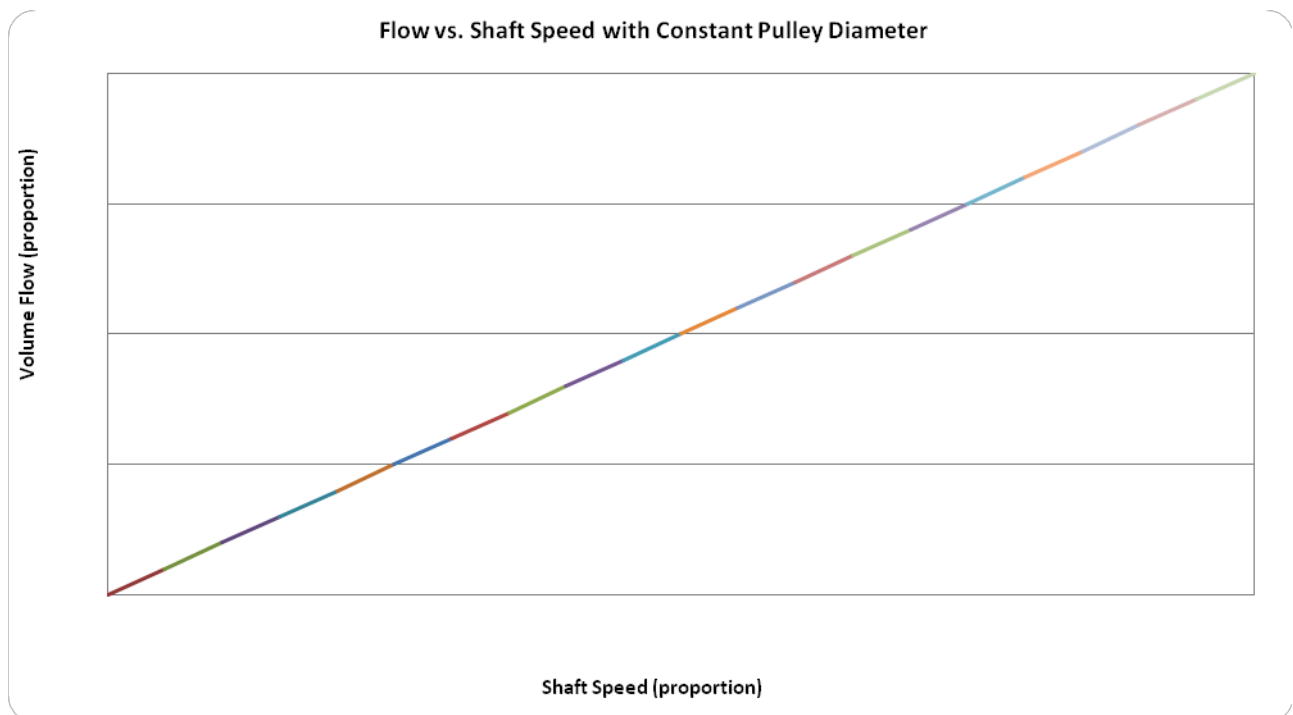
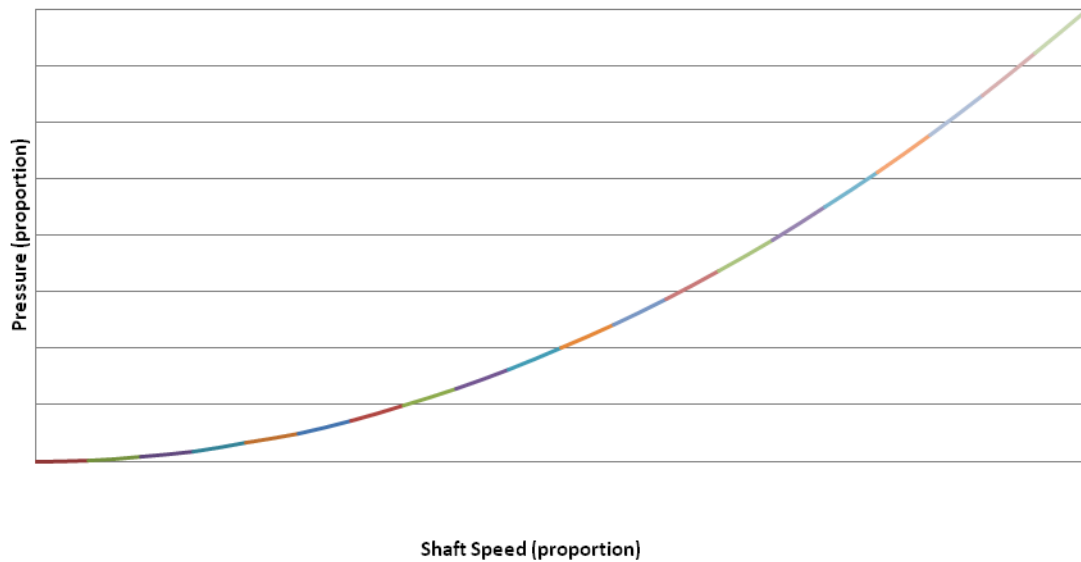Graph 1: Flow vs. Shaft Speed Fan Affinity Law

2) Pressure is proportional to the square of shaft speed change and the square of pulley diameter change;

$$\frac{dp_1}{dp_2} = \left(\frac{n_1}{n_2}\right)^2\left(\frac{d_1}{d_2}\right)^2$$ Where pulley diameter remains constant, $$\frac{dp_1}{dp_2} = \left(\frac{n_1}{n_2}\right)^2$$

Where; dp_1 = Initial Pressure n_1 = Initial Shaft Speed d_1 = Initial Pulley Diameter

dp_2 = New Pressure n_2 = New Shaft Speed d_2 = New Pulley Diameter
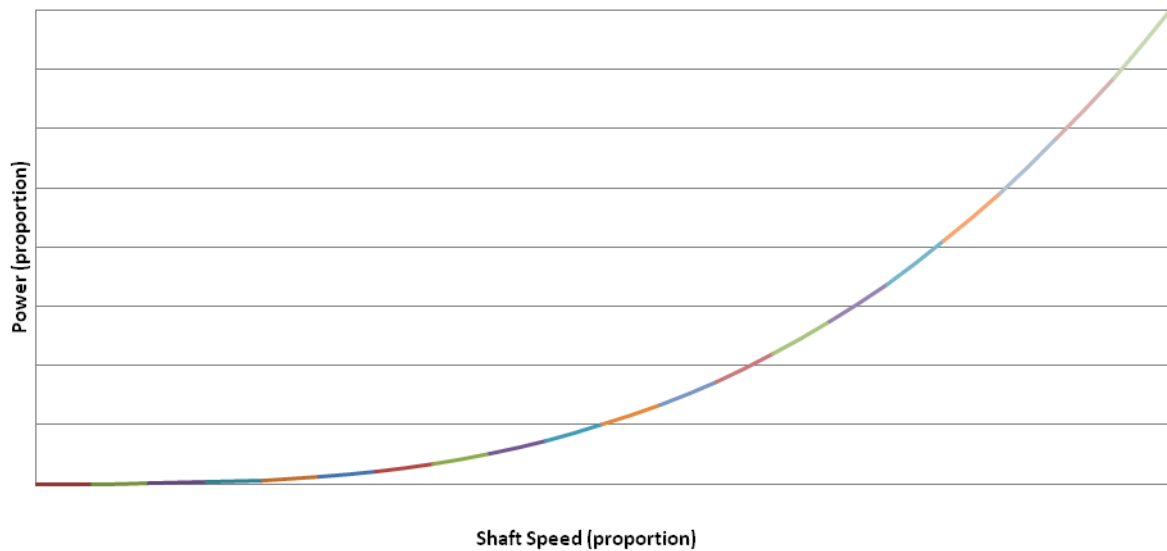
Graph 2: Pressure vs. Shaft Speed Fan Affinity Law

3) Power is proportional to the cube of shaft speed change and the fifth power of diameter change;

$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3 \left(\frac{d_1}{d_2}\right)^5$$

Where pulley diameter remains constant,

$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3$$

Where;　　　P_1 = Initial Power　　　n_1 = Initial Shaft Speed　　　d_1 = Initial Pulley Diameter

　　　　　　P_2 = New Power　　　n_2 = New Shaft Speed　　　d_2 = New Pulley Diameter

Graph 3: Power vs. Shaft Speed Fan Affinity Law

APPENDIX 5 – MEASUREMENT ACCURACY IMPLICATIONS

When considering an overall audit accuracy requirement, the effect of cumulative measurement errors and fan curve inaccuracies must be taken into account.

As an example, the components of the fan power equation are used below to demonstrate how to assess the effect of each component's accuracy on the overall accuracy:

$$P = QH\rho g\eta^{-1}\varepsilon^{-1}$$

Where,

P = Electrical Input Power Q = Volume Flow Rate

H = Pressure Head ρ = Fluid Density

g = Gravitational Acceleration

η^{-1} = Fan Efficiency ε^{-1} = Motor Efficiency

The total accuracy of the combined equation can be expressed as follows:

$$\frac{\Delta x}{x}$$

Where Δx is the 'maximum inaccuracy' possible for a given absolute measurement x.

For each term of the fan equation, the maximum possible percentage inaccuracies are added.

$$\frac{\Delta P}{P} + \frac{\Delta Q}{Q} + \frac{\Delta H}{H} + \frac{\Delta \rho}{\rho} + \frac{\Delta g}{g} + \frac{\Delta \eta}{\eta} + \frac{\Delta \varepsilon}{\varepsilon}$$

Examples of how each term can be evaluated are as follows:

If a data logger used for electrical power measurement has a rated accuracy of ±0.01kW and an average absolute measurement of 12kW has been recorded, maximum percentage error would be:

$$\frac{\Delta P}{P} = \frac{0.01kW}{12kW} = 0.083\%$$

Alternatively, if the data logger stated an accuracy of ±0.2%, then the term $\frac{\Delta P}{P}$ would simply equal 0.2%.

Adding each term provides the total maximum possible error.

Where estimates are used, common sources of error include use of:
- Fan characteristic curves, which may have an error range of 2-6%
- Assessment of drive system efficiency, for example a pulley/drive belt setup
- Assessment of motor efficiency

It is recommended that error be minimised by taking as many relevant measurements as practical; for example, by measuring flow rate, differential pressure and motor electrical power, the operating point and motor efficiency of a fan can be more accurately determined.

Given that accuracy is a combination of a number of variables, the auditor needs to be aware what the main sources of inaccuracy are for the measurements and system concerned.

APPENDIX 6: DEFINITIONS

Fan Types

The American Society of Mechanical Engineers (ASME) defines fans, blowers and compressors by their ratio of suction to discharge pressure, shown in Table 1.

Category	Specific Ratio	Equivalent Pressure Rise* (kPa)
Fans	Up to 1.11	Up to 11.15
Blowers	1.11 to 1.20	11.15 to 20.27
Compressors	Greater than 1.20	Greater than 20.27

Table 1: ASME Definitions

*When suction pressure is equal to standard atmospheric pressure.

While these definitions are useful, they will only be used broadly in this case.

Fan Curves

Fan curves are supplied by the fan manufacturer and act as a graphical representation of the fan's pressure, hydraulic efficiency and power over a range of flow conditions. Through the use of fan curves, several key calculations can be made to determine how a fan system is operating.
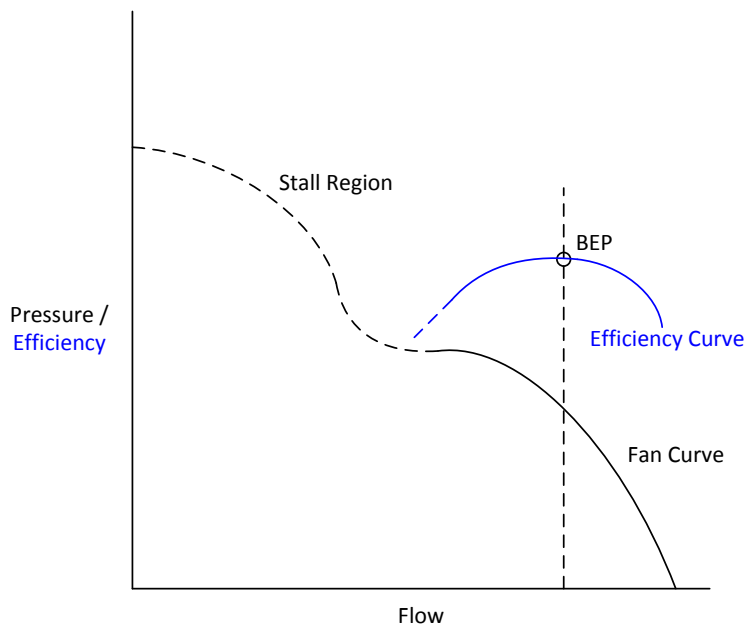
Figure 8 shows an example of these curves.

Figure 8: Best Operating Point –Axial/Centrifugal Fan

Fan (or Performance) Curve – The fan curve is the specific pressure / flow relationship which is unique to each model of fan. The point of intersection between the system curve and the fan curve is the point at which a fan system will operate.

System Curve -The system curve is the relationship between the pressure and flow of the fan system. This relationship is determined by the amount of static pressure in the system, and the dynamic pressure, which is comprised of major (ducting) losses and minor (fitting) losses. A system curve only passes through the origin of the fan performance curve if the system has no static pressure.

Best Efficiency Point (BEP) -The best efficiency point (BEP) refers to the most efficient operating point for an axial/centrifugal fan as depicted in Figure 8. This is the point at which each fan should operate for optimal system design, although fans are often oversized (operate to the left of the BEP) as the result of a design safety factor or to future-proof the system in case of future expansion. This is not considered best practice.

Fan Capacity Control Methods

On / Off Control – This is one of the simplest forms of fan control, where a fan motor's contactor is linked with a control signal, such as a signal from a SCADA / BMS system. On / off control is often employed for fans that are only required periodically.

Eddy Current Coupling Control – Eddy current couplings are a form of slip-controlled drive. An eddy current drive consists of a fixed-speed motor and an eddy current clutch. The clutch contains a fixed-speed rotor and an adjustable-speed rotor separated by a small air gap. A direct current in a field coil produces a magnetic field that determines the torque transmitted from the input rotor to the output rotor. The controller provides closed-loop speed regulation by varying clutch current, only allowing the clutch to transmit enough torque to operate at the desired speed.

Variable-Pitch Control – This is a less common form of fan control. While this form of fan control can provide good efficiency, it is mechanically complex, and as such is only applicable for large axial or mixed-flow fans.

Inlet / Outlet Dampening Flow Control - Flow restricted by an inlet vane or outlet damper. This is a common cause of fan system inefficiency by artificially increasing system pressure. Variable inlet vanes or blades, located on the inlet to the fan, are varied in pitch to restrict the fan entrance flow. Outlet dampers are mounted on the fan outlet, with flow being controlled by adjustment of the damper position. The use of inlet vanes is generally more efficient than outlet dampers, although neither is as efficient as fan speed control.

Figure 9 shows the leftward shift in operating point of the fan as flow is throttled. It can be seen that as the system curve moves to the left, the pressure is artificially increased and the flow is reduced. Reducing the fan speed is a much more energy efficient method of achieving a reduced flow.
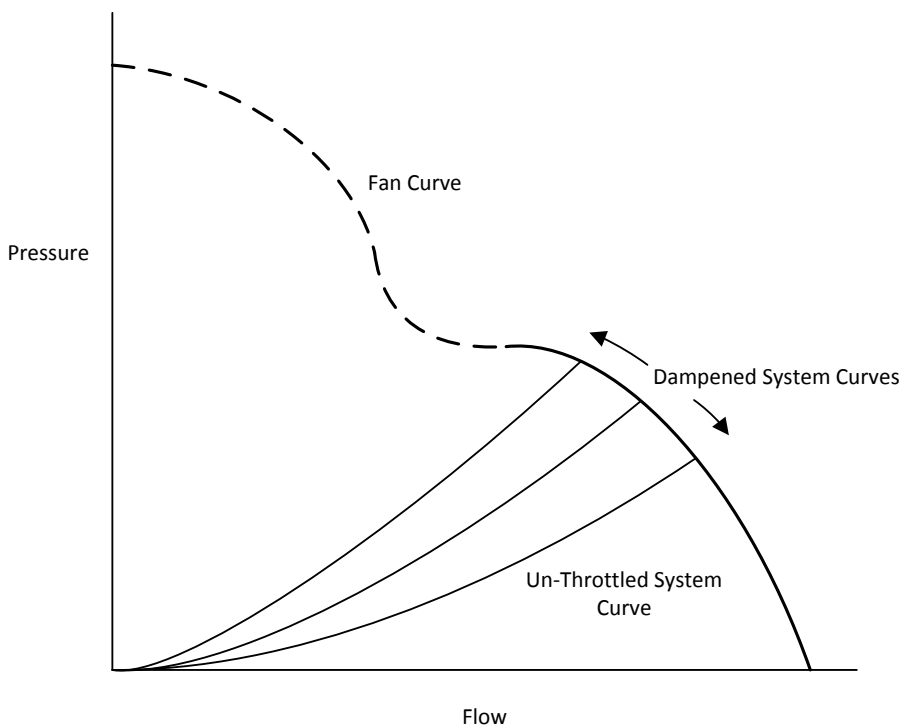

Figure 9: Dampened Flow — Fan System Curves

VSD Flow Control – VSD flow control involves controlling the flow delivered by a fan by altering the fan's speed via a VSD (variable speed drive). This is a much more energy efficient alternative to dampened flow. This is depicted in Figure 10, where the operating point of the fan moves down the system curve.
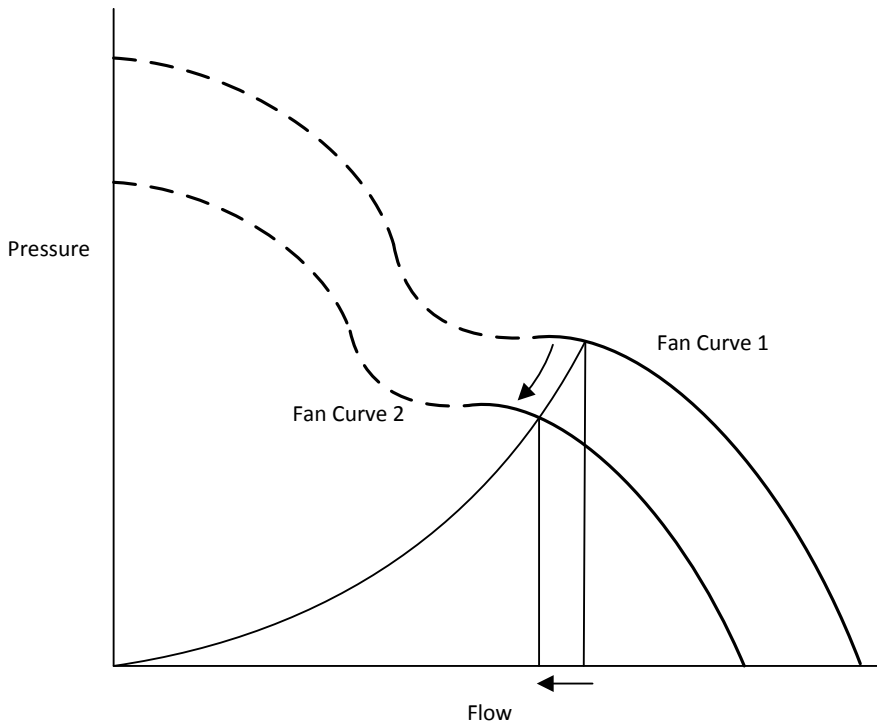
Figure 10: VSD Flow Control – Flow Reduction

Pressure Control – It may also be desirable to control a fan system's supply pressure rather than its flow requirements. In systems such as VAV HVAC and positively pressurised clean rooms, maintaining a constant supply pressure throughout a variable system may be desirable to ensure process stability. It is possible to control a system's pressure through all of the aforementioned control systems, though at varying levels of efficiency. Figure 11 shows an example of a pressure-controlled fan system through the use of a VSD.
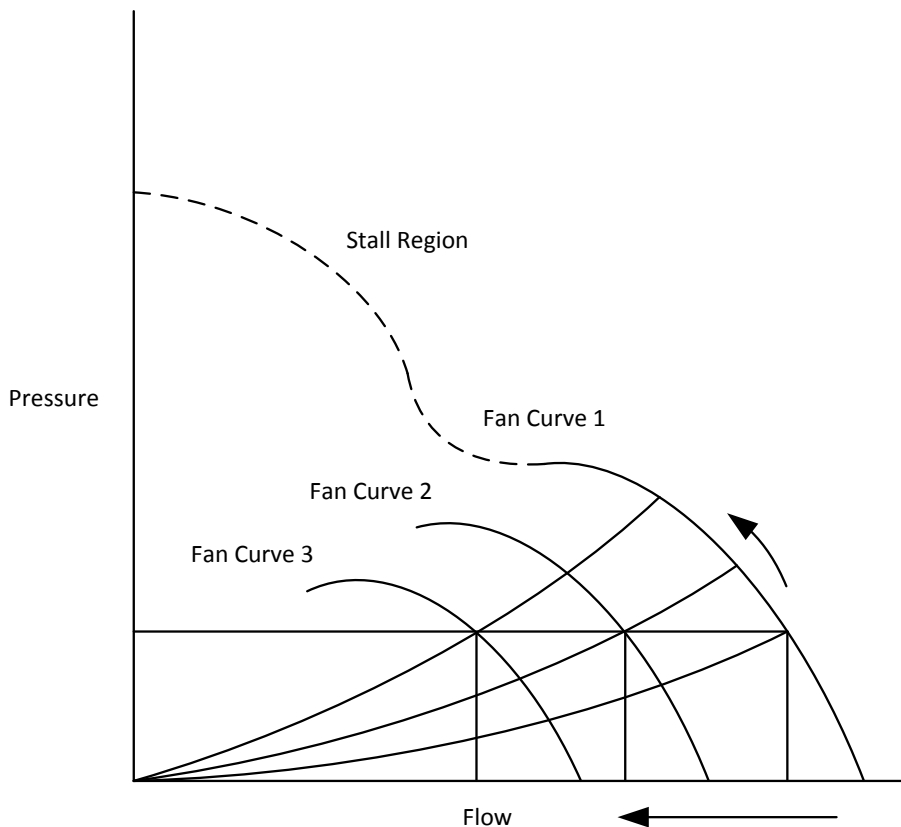

Figure 11: VSD Pressure Control

Fan Types

HVAC Fans - All industrial fans relating to air handling, such as those in Air Handling Units, Fan Coil Units, fresh air and return air fans.

Cooling Tower Fans - Cooling tower fans are used to reject heat from process water systems. This is achieved by evaporating water, aided by fan-forced airflow over a water stream.

Extraction Fans - Fans used in particle and fume extraction systems. These fans are often sized to meet minimum velocity requirements throughout a duct network in order to ensure particles remain suspended or sufficient gas is removed.

Blower/Vacuum/Pneumatic Conveying Systems – Includes all low-pressure blower applications such as dilute-phase conveying. Low pressure can generally be defined as less than 1.2 bar(g), although it is acceptable to analyse higher-pressure blower systems if the auditor believes there is good reason to do so.

Refrigeration Fans – This includes refrigeration-related fans such as condenser, air-cooled condenser, evaporator, blast freezer, air curtain and air circulation fans. Special consideration must be made for fans of this nature in the context of the wider system they operate within, as any local improvements in energy consumption may have detrimental effects elsewhere in the system.

Fan Equation

The following equation describes the relationship between the parameters that determine the power consumption of the fan driver (e.g. motor):

$$P = \frac{\rho \times Q \times H \times g}{\eta_m \times \eta_{tr} \times \eta_p}$$

Where:

P is the driver power consumption

ρ is the gas density

Q is the gas flow rate

H is the system total head/pressure

g is acceleration due to gravity

η_m is the motor efficiency

η_{tr} is the transmission or coupling efficiency

η_f is the fan efficiency

This equation holds true for calculations involving SI units.

Figure 11depicts the losses between the input electrical power of the driver and the useful pneumatic output delivered to the gas.
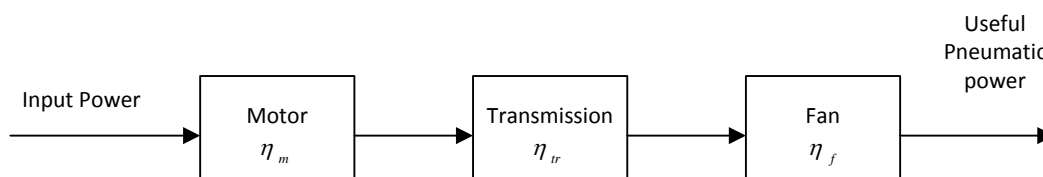

Figure 12: Fan System Transmission Efficiencies

APPENDIX 7 – GLOSSARY OF TERMS

Air Handling Unit –Encased fan system used to cool, heat, humidify, dehumidify, filter or mix air passing through it.

Anemometer –Device used to measure air velocity.

Axial Fan –Airflow through the impeller is parallel to the axis of its rotation.

Baseline Consumption –Estimated fan system annual energy consumption.

Best Efficiency Point (BEP) -The best efficiency point (BEP) refers to the most efficient operating point (defined by a certain rate of flow and system pressure) for a fan. This is the point at which each fan should operate at optimal system design.

Blower –In the context of this document, a blower is defined as a mechanical device used to impart motion on gases, increasing their pressure by a ratio of between 1.11 and 1.2 (higher than for a fan). In other words, a blower moves volumes of a gas with moderate increase of pressure. Use of the word 'blower' in the Audit Standard refers to a lobe, rotary screw, rotary vane, side channel or other blower type.

Centrifugal Fan -Airflow through the impeller is perpendicular to the axis of its rotation.

Closed-Loop Fan System -A closed-loop fan system has gas that is recirculated around a path with the same start and end points.

Compressor, Air –In the context of this document, an air compressor is defined as a mechanical device used to impart motion on gases increasing their pressure by a ratio of over 1.2 (higher than for a fan or a blower). Compressed air is addressed in a separate audit standard.

Condenser, Refrigeration–Apparatus used within a vapour-compression refrigeration system that rejects heat from the refrigerant, condensing it back to its liquid phase.

Cooling Tower –In the context of this document, this refers to devices that remove heat from a working fluid by evaporating water, aided by fan-forced airflow over a water stream.

Coupling – Coupling refers to the connection or transmission of power between motor and fan. This includes types of coupling such as direct coupling or drive belts.

Coupling Efficiency–The coupling efficiency is defined as the ratio of the energy delivered by the motor to the coupling divided by the energy delivered to the fan shaft.

Damper–Device installed at a fan's inlet or outlet to modulate flow.

Design Point–The operating point as calculated for a fan during the system design. The actual operating point is often not at the design point.

Differential Pressure, Fan–The difference in pressure between a fan's inlet and outlet.

Differential Pressure, Filter–The difference in pressure between a filter's inlet and outlet.

Duration Curve–A graph depicting the amount of time that the gas flow exceeds a certain value.

Dynamic Pressure –The pressure associated with frictional losses within the fan system duct network.

Evaporator, Refrigeration –Apparatus used within a vapour-compression refrigeration system that imparts heat into the refrigerant, evaporating it to its vapour phase.

Extraction -Removing gas within a space using mechanical force imparted by a fan.

Fan –In the context of this document, a fan is defined as a mechanical device used to impart motion on gases, increasing their pressure by a ratio of up to 1.11. In other words, a fan moves large amounts of gas with low increase in pressure. It can generally be said that a fan's purpose is to mobilise air rather than to compress it. Use of the word 'fan' in the Audit Standard refers to an axial or centrifugal fan.

Fan Efficiency –The ratio of the power imparted to the gas divided by the fan shaft input power (power delivered to the fan via motor coupling).

Fan Power Equation –The equation used to determine the power consumption of a fan based on gas density, flow, pressure, motor efficiency, coupling efficiency and fan efficiency.

Fan System–A fan or group of fans along with the other components relevant to the moving gas. This includes the motors, coupling, ducting and valves.

Fan System Energy Intensity (FEI) –The energy intensity of a fan system with respect to the key business driver, e.g. kWh/kg production.

Flow Balance–A diagram or table showing the measured or estimated gas flows through different parts of a fan system.

Gas–In the context of this document, a compressible fluid of low density and viscosity.

Gas User– Any device relevant to business operations that requires the use of a gas within a fan system to perform an appropriate task, such as heat transfer.

Key Business Driver–The parameter against which the fan system's energy consumption is measured for benchmarking and monitoring purposes. This determines the system Fan Energy Intensity (FEI). Examples of this may be production (kg) or temperature (°C).

kVA– Common unit for apparent power, which is the total power that appears to be flowing from a source to a load.

kW-Common unit for real power, which is the actual net power that is flowing from a source to a load.

HVAC–Heating, Ventilation and Air Conditioning.

Impeller – The rotating component within a fan used to increase the pressure and flow of a gas.

Motor Efficiency-The motor efficiency is defined as the ratio of the energy delivered to the motor divided by the energy delivered from the motor to the coupling.

Open-Loop Fan System-An open-loop fan system has both an input and an output, with gas being moved from one point to another.

Operating Point–The flow and head of a gas delivered by a fan. This can be depicted as the intersection of the fan performance curve and the fan system curve.

Peak Load –The peak power consumption of a site. This often determines the demand charges incurred by the site and should therefore be taken into account when considering the operating times of fan systems.

Performance Curve –Graph plotting the pressure required as a function of flow rate for a given fan. Also often depicted on performance curves are the shaft power and fan efficiency. The term "fan curve" often refers to the performance curve.

Power Factor –Ratio of real power to apparent power.

Shaft Input Power –The power delivered to the shaft of a fan.

Stall Region-Characterised by the sudden detrimental change in fan efficiency below a certain flow. The reduction in flow (or fan speed) effectively increases the blade's angle of attack to the gas. Below a critical flow (and therefore above a critical angle of attack) the force imparted on the gas decreases significantly.

Static Pressure -The pressure associated with the height difference between fan entrance and system discharge. This takes into account both the suction and discharge pressure.

System Boundary–Boundary defined by the auditor, which encompasses the fan system components to be analysed. Note that boundaries around individual fans are considered unsatisfactory.

System Curve –A curve indicating the pressure required to deliver a certain flow rate during a fixed set of system conditions.

System Efficiency –The ratio of pneumatic power required by the system divided to the power consumed by the fan motor.

Temperature, Dry-Bulb –Temperature of a volume of air as measured by a thermometer shielded from radiation and moisture.

Temperature, Wet-Bulb –Temperature of a volume of air as measured by a thermometer exposed to moisture. This indicates the temperature of the air if cooled adiabatically such that it reaches water vapour saturation as a result of water evaporation.

Variable Speed Drive (VSD) - A variable speed drive (VSD) is a system for controlling the rotational speed of an alternating-current electric motor through adjusting the electrical frequency supplied to the motor. VSDs usually have inbuilt PID controllers which allow them to automatically adjust their speed based on a digital input signal.

Ventilation –Removing and replacing air within a space using natural convection or mechanical force imparted by a fan.

Venturi –Device used to alter the pressure through a tube by restricting gas flow.

APPENDIX 8 -RECOMMENDED REPORT OUTLINE

This appendix provides a recommended outline of the structure and contents of the report used for reporting of the process, findings and recommendations from an audit, conducted according to this Fan Systems Audit Standard.

The following describes the recommended structure and content of the audit report, section by section.

Executive Summary

Provide here a summary of the objectives, scope, findings and recommendations.

In particular, this should highlight the key recommendations for the client to action and a rationale for action that is concise, understandable and compelling – recognizing the client's decision-making processes.

Tabular (and possibly pie chart) presentation of the annual saving and net present value available from pursuing each recommendation can be useful.

1. Business Context

This section should cover basic information about the business and the objectives and scope of the audit.

Basic information

Include here the:
- identity of the client and site location, for which the audit is performed;
- date of the fan system audit
- name of the client manager and other key personnel interfacing with or assisting the fan system audit;
- name, credentials and contact details of the fan system auditor.

Site operating characteristics

Describe here the operating characteristics of the site, including:
- a brief outline of the current operations of the plant, with description of the main site activity that the fan systems are required to support;
- the effects of any expected future changes to the nature or volume of the site activity that may have an effect on the site fan system requirements.

Objectives and scope of the audit

Describe here:
- the objectives of performing the audit. For example, It may be to provide the client's management with a general understanding of areas of potential (as would be expected from a base-level audit) or it may be to support a capital expenditure proposal on a substantial refurbishment or redesign;
- the scope of the audit. This may range from being one component of one fan system or full systems audits of all fan systems on the site.
- any useful background to the objectives and scope, including any prior scoping work and key clauses from any agreement between the client and the auditor;

2. Fan System Overview

Include a high-level description of the system and identification of the business drivers and the means by which the audit results can be extrapolated to annual operating characteristics.

Description and requirements

Include a description of the fan system(s) and its configuration, with reference to schematic drawings in an appendix to the report.

Describe the requirements that the business expects from the audit, including:
- a description and quantification (flow and pressure) of what the fan system(s) need to deliver to enable the business to operate efficiently;
- identification of the site activity (e.g. production output or raw material input) that will be used as the key driver of fan system use and that will be used in the energy intensity measure for the fan system;
- identification of whether the fan system requirements can be characterised as constant demand, multi-stage demand or variable demand;

- information on the operating profile of the main site activity (e.g. volume of production), showing weekly and monthly/seasonal profiles; and
- any relevant benchmark information that may be available from site history or from intercompany comparisons on the fan systems energy intensity.
- description of any management policies or practices (e.g. safety or community matters) that influence the fan system design or operational requirements.

Baseline energy intensity

This involves quantification of the relationship between the site activity (e.g. production output or raw material input) identified as the key driver of fan system and the system's electricity usage, using the daily data collected during the audit period.

This should include the:
- method for quantifying the daily site activity driving the fan system energy usage;
- method for quantifying the daily kWh usage from the fan data-loggings or other measurements taken during the audit, and;
- the audit-period average and (where feasible) each day's value of the fan system electricity intensity value (the baseline FEI) for the period of the audit.

Having each day's value of the FEI relationship may enable the effect of variations in activity level on the FEI to be quantified and included in any subsequent analysis of the system where the activity level is different from the average during the audit period. The relevance of the individual days FEI figures will be dependent on the driver and the ability to obtain activity levels of sufficient accuracy at a daily level.

If the client considers activity figures too commercially sensitive for inclusion in the report, include only the baseline FEI

3. Audit Measurement Methods

This section should cover the measurement methods used during the audit and identify (and rationalise) any variations between the actual measurement methods and those recommended in the Audit Standard.

Electricity usage measurement

Include a description of electricity measurement methods used for the audit period, including any metering installed for subsequent (post-implementation)performance monitoring and the extent of any reconciliations performed between temporary and permanent meters.

For each fan system involved, describe:
- the metering and data recording methods used, and the units measured;
- the fan motors datalogged; and
- the period(s) and duration(s) of the measurements.

Electricity cost measurement

Describe the method of quantifying the unit cost of electricity as appropriate for valuing any reduced consumption resulting from implementing a recommendation.

Costs should be based on future price expectations and recognise the fixed and variable (per-kWh) components of delivered electricity prices. Where the client is subject to time-of-use and/or peak demand pricing, consideration should also be given to the time periods in which the systems operate - and therefore in which any energy savings are likely to occur. These considerations are most relevant when the audit results are to be used for investment proposal purposes.

Pressure measurement

Include here:
- a description of the pressure and pressure difference measurement methods used for each of the measurement point locations;
- the method and currency of the calibration of the pressure measurement instruments;
- identification of where pressure differences are estimated, the method of estimation and reason for estimation.

Flow measurement

Include here information on:
- the location and timing of any flow measurements taken;
- the flow measurement method and technology employed (intrusive or other),
- the method and currency of the calibration of the pressure measurement instruments; and
- identification of where flows are estimated, the method of estimation and reason for estimation.

Measurement of leakage and inappropriate use

Describe here how the flow rate and energy waste from leakage and inappropriate uses was identified, and how the energy use of the alternative technologies and energy sources is quantified.

Estimates of implementation costs

Provide here the method or methods used to estimate the costs of implementing the actions included in the recommendations. This should include:
- the sources of the cost estimates;
- the level of accuracy that can be expected; and
- whether or not any preferred suppliers are involved.

4. Audit Findings

For each of the systems within scope, this section should describe, analyse and quantify opportunities for efficiencies in a logical sequence from demand through the network to supply. Discussion of opportunities for change should include consideration of other viable options along with the recommended action.

For each recommended action, there should be:
- a description of the efficiency opportunity;
- transparent calculations of the energy and other savings potential;
- a cost estimation of implementing the proposed action;
- a simple payback period (or other net benefit measure) quantified shown -as applicable to the audit scope/accuracy requirement;
- identification of any alternatives to the recommended action; and
- identification of dependencies, where a particular recommendation may be dependent on the implementation of some other recommendation or other plan

The detailed cost-benefit calculations that support each recommendation should be included as part of an appendix.

System demand side

From the measurements of flow and pressure at key points of demand on the fan system, and from the (power) demand profile taken at the fan motor, discuss the various opportunities relating to system features driving demand.

Peak load trimming or shifting
Include here a description of any opportunities related trimming or shifting of peak demand of gas flow.

Inappropriate end use
Identify and describe the applications where the gas is being used in an inappropriate (energy-efficient) manner or gas transport is not the most appropriate means of achieving the business purpose.

Isolation opportunities
Identify and describe the applications where the gas transport use can be isolated (transport suspended) between their operating periods.

Pressure reduction
Identify and describe the applications where the localised pressure can be reduced. These are distinct from opportunities to reduce pressure at the supply source, as such system-wide opportunities would be covered in the 'supply-side' section of the report.

Flow Reduction
Identify and describe the applications where the localised gas flow can be reduced. These are distinct from opportunities to reduce flow at the supply source, as such flow system-wide opportunities would be covered in the 'supply-side' section of the report.

Leakage
Identify and quantify the amount of leakage, and specify the priorities in terms of leak repairs, prevention and ongoing timely (efficient) detection.

System network

Ducting condition and configuration

Describe the audit findings relating to:
- the physical condition of the network;
- any ducting features significantly notable impacting on demand or pressure; and
- ducting maintenance practices.

For each of the above main findings:

- quantify the effects on pressure and/or flow associated. For example, quantify the pressure losses resulting from the condition of the particular configuration, constrictions, length or corrosion feature.

Duct sizing

Include here the audit findings relating to duct sizing. In particular, identify:

- the extent and location of undersized ducting;

- the effect on pressure and/or flow of each incorrectly sized section of ducting.

This information should lead to calculations of potential savings, and identification and costing of cost-effective solutions.

Vane suitability

Include a discussion on where any vanes being used, and the purpose of their use. In addition, quantify the effects on pressure and/or flow associated with the use, misuse, poor maintenance of vanes and filters.

Where a recommendation is made, include a description the vanes concerned, the effect of the recommendation on pressure and/or flow, a budgetary cost of the solution and the payback for the client.

System supply side

The supply side of the fan system (the motor, fan and drive system) delivers demand that is the sum of the productive requirements of the business as well as the demand from sub-optimal uses and waste.

This section of the report should focus on the supply-side solutions that are economic once the downstream demand has been specified – net of the demand from sources that will be eliminated by the economic solutions specified in earlier recommendations.

The demand profiles obtained from the electrical logging, and the analysis conducted on the downstream demand drivers, should provide the basis for identification of the supply side opportunities.

Fan performance capability

Using fan design data and relevant available fan curves, describe and analyse fan performance capabilities relative to the system requirements and actual demand. Refer to fan curves and/or data sheets provided as appendices.

For each fan/motor setup the information should include: rated power of motor (kW); fan output flow at rated load (m^3/minute); fan efficiency at average load (%); and flow and total pressure at fan BEP[7](m^3/minute and kPa).

Fan electricity demand characteristics

Provide a summary (e.g. a table) of the key information collected and derived from the fan motor electricity datalogging and any other metering of the fan motor over the audit period.

This information should include: average power loading (kW)[8] and a description and analysis of any flow control methods used - such as outlet and inlet vanes, and disc throttling. The logging records should be included in an appendix to the report.

Also include information on fan configuration, fan impeller suitability, and drives and drive couplings.

Supply-side recommendations

Recommendations may include solutions to flow throttling or flow bypass, such as where a multi-stage motor or variable speed drive might provide a cost-effective solution to matching the business requirements.

Other recommendations that might arise include: trimming or changing of impellers; changing the fan unit, having parallel fan configurations; and addressing drive inefficiencies.

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[7] BEP means 'best efficiency point"
[8] Average power is the weighted average kW value calculated during plant operating hours, and is independent of the method of flow control.

5 Ongoing Performance Monitoring

In this section of the report, consider and recommend what on-going fan systems performance measurement systems should be put in place by the client.

Recognising the need to measure power consumption of each fan to establish the baseline FEI, the recommendations here in relation to electricity metering should be influenced by the metering decisions taken at the commencement of the audit and discussed earlier.

The Audit Standard outlines the options for ongoing electricity usage metering.

6 Summary of Recommendations

Include a summary table of the actions recommended – drawing from all previous sections. An example is shown below:

Recommendation Identifier and Report Section Ref	Depend-ency[9]	Electricity Saving (kWhpa)	Annual cost saving ($)	Implementation Cost ($)	Simple payback period (years)
Demand-side recommendations					
Rec #1 Sec x.x.x					
Rec #2 Sec x.x.x					
Network recommendations					
Rec #3 Sec x.x.x					
Rec #4 Sec 4.x.x					
Supply-side recommendations					
Rec #5 Sec x.x.x					
Rec #6 Sec x.x.x					
Ongoing monitoring recommendation					
Rec #7 Sec x.x.x					

7 Appendices

The appendices should include:
1. Schematic of each of the fan systems
2. Audit data records, including relevant fan curves and fan logging records – for electricity, pressure and flow.
3. Cost benefit details of options and recommendations

In relation to the cost-benefit details, particularly where the audit will be used to support business investments, the relevant appendix should provide a summary of the data and calculations performed for each option and recommendation. In addition, this should be accompanied by:
- any supplier or installer quotations that support the implementation cost estimates, and any assumptions that could materially affect the accuracy of the payback period; and
- where there are the several options for the same outcome, clear flagging of the options as being mutually exclusive.

This level of detail can be important to the subsequent development of an investment proposal.

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[9] Dependency – meaning that any recommendation that to be viable is dependent on some other action, must be identified as being dependent on that other action and some identification of that action must be provided.