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Review of fan efficiency in meat chicken sheds

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by Mark Dunlop and Grant Brown

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Researcher Contact Details

Mark Dunlop
Department of Agriculture and Fisheries (DAF)
PO Box 102
TOOWOOMBA QLD 4350

Phone: 07 4688 1280
Fax: 07 4688 1192
Email: mark.dunlop@qld.gov.au

Grant Brown
Department of Agriculture and Fisheries (DAF)
PO Box 102
TOOWOOMBA QLD 4350

Phone: 07 4688 1521
Fax: 07 4688 1192
Email: grant.brown@qld.gov.au

In submitting this report, the researcher has agreed to RIRDC publishing this material in its edited form.

RIRDC Contact Details

Rural Industries Research and Development Corporation
Level 2, 15 National Circuit
BARTON ACT 2600

PO Box 4776
KINGSTON ACT 2604

Phone: 02 6271 4100
Fax: 02 6271 4199
Email: rirdc@rirdc.gov.au.
Web: http://www.rirdc.gov.au

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Foreword

Meat chicken farms rely heavily on ventilation fans to exhaust heat and moisture from the growing sheds. Exhaust fans are designed to move large volumes of air efficiently, but some fans are more efficient than others. Using energy efficient fans will reduce farm operating costs and will reduce the industry's energy usage and associated carbon footprint.

This investigation reviewed performance and efficiency data for ventilation fans that are available in Australia to identify the most energy efficient fans. Each fan was given an energy efficiency rating and costs to operate the fans were estimated. It was found that some ventilation fans were more than twice as energy efficient as others. Using more energy efficient fans will reduce the amount of power used for ventilation and could potentially save the farmer up to $30,000 per shed over a 10 year operating period. Replacing fans with more efficient ones is unlikely to be cost effective, so it is important to choose the right fan the first time. Farmers can compare different fans on the basis of air flow, energy efficiency and operating costs for their specific farm using the '*Tunnel Ventilation Fan Comparison Spreadsheet*', which was developed during this project and is available for download from the RIRDC website.

In addition to the review of new fans, methods to measure air flow rate and energy efficiency have been identified and were used to assess a selection of older fans in meat chicken sheds. Methods to accurately measure air flow rate and power consumption are complex and require specialised equipment. Simpler methods to identify underperforming fans, such as measuring fan rotational speed (rpm) with a tachometer, are more likely to be successful and yield useful results. These methods have been described in detail in a complementary report: *'How to' guide for measuring fan performance and efficiency in meat chicken sheds'*, which is available from the RIRDC website (RIRDC publication no. 15/035).

Fans assessed in this report, for the most part, performed well compared to newer fans despite years of service. Some of the fans had worn components and required maintenance to restore their performance.

Meat chicken growers looking to purchase new fans will benefit from this report by being able to review the performance and efficiency of fans currently available. Applying some of the methods identified to assess and monitor fan performance will give growers confidence in knowing that their fans are operating at their best and help them to schedule maintenance for underperforming fans as required.

This project was funded from industry revenue which was matched by funds provided by the Australian Government.

This report is an addition to RIRDC's diverse range of over 2000 research publications and it forms part of our Chicken Meat R&D program, which aims to stimulate and promote R&D that will deliver a productive and sustainable Australian chicken meat industry that provides quality wholesome food to the nation.

Most of RIRDC's publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation

Acknowledgments

The authors would like to thank the meat chicken growers who permitted us to use their fans to measure performance and efficiency. Their cooperation is greatly appreciated.

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What the report is about

This report is all about ventilation fans (exhaust fans) used on tunnel ventilated meat chicken sheds. The report has two themes: reviewing the performance and efficiency of new fans currently available in Australia; and identifying methods to assess fans and help to identify fans that are underperforming.

Who is the report targeted at?

This report is targeted at meat chicken growers, to provide them with information about performance, energy efficiency and costs associated with ventilation fans. Growers and industry personnel will also benefit from knowing more about methods to assess and monitor fan performance.

Background

Large diameter axial fans are used to ventilate meat chicken sheds. They need to operate reliably and deliver their rated air flow rate to ensure that shed ventilation requirements are not compromised. Exhaust fans are designed to move large volumes of air efficiently, but some fans are more efficient than others. Using energy efficient fans will reduce farm operating costs, the industry's total energy usage and associated carbon footprint.

Overseas meat chicken growers have access to resources to help them select energy efficient fans. Growers in Australia however, need to undertake the challenging task to independently obtain and interpret fan performance and efficiency data and identify locally available fans that are energy efficient and will suit their needs. Access to fan performance data needs to be improved to assist growers with fan selection. Other factors such as construction quality, warranty, local dealer reputation, spare parts, after sales support, and previous experiences also need to be considered when purchasing new fans.

Once fans are installed in sheds, growers should assess and monitor the ongoing performance of their fans to ensure they are operating properly. Techniques are available to help growers inspect their fans to ensure that shed ventilation capacity is maintained and reduce operating costs.

Aims/objectives

The aims of this project were to:

- Conduct an assessment of exhaust fans currently available in Australia in terms of performance and efficiency. This was to provide a comprehensive list of exhaust fans to aid in the selection of efficient and economic fan models for the Australian meat chicken industry; and an economic analysis of operating the most efficient fans compared to less efficient fans.
- Identify methods to assess fan performance while installed in meat chicken sheds.
- Undertake an on-farm assessment of fan performance to identify efficiency gains.
- Conduct an economic analysis of the feasibility of operating older fans compared to newer fans, together with an analysis of replacing old fans with newer and more efficient fans, outlining the payback period.

Methods used

Fan performance and efficiency data were obtained from manufacturers, suppliers or publicly available test results. A spreadsheet was used to rate the fans and estimate the likely costs associated with using these fans based on a common scenario. This spreadsheet, the '*Tunnel Ventilation Fan Comparison Spreadsheet*', is available for download from the RIRDC website.

Methods to measure fan performance and efficiency were identified and used to assess fans installed in meat chicken sheds. Air flow rate, power consumption and fan rotational speed (rpm) were measured, with drive belts and sheaves also being inspected for wear.

These methods have been described in detail in a complementary report: *'How to' guide for measuring fan performance and efficiency in meat chicken sheds*, which is available from the RIRDC website (RIRDC publication no. 15/035).

Results/key findings

The majority of fans reviewed in this report were given a poor energy efficiency rating. It was found that some ventilation fans were more than twice as energy efficient as others. Using more energy efficient fans will reduce the amount of power used for ventilation and could potentially save the farmer up to $30,000 per shed over a 10 year operating period. Replacing fans with more efficient ones is unlikely to be cost effective unless replacing worn or damaged fans as part of normal maintenance.

Methods were identified to measure air flow rate, power consumption, fan rotational speed (rpm) and quantify wear on fan belts and sheaves.

Fans in thirteen different sheds were assessed to measure their performance and energy efficiency. Most of these fans performed well compared to newer fans despite years of service and thousands of hours of operation. Some of the fans had worn components and were in need of maintenance to restore their performance. These under-performing fans were easily identified by measuring fan rotational speed. Testing to measure fan air flow rate and power consumption was more challenging, provided little extra benefit and would likely be impractical in most situations.

Implications for relevant stakeholders

Challenges obtaining relevant, accurate and trustworthy fan performance and efficiency data from multiple fan suppliers may make it too difficult for Australian meat chicken producers to make informed decisions about which fan will be the most suitable and cost effective for their situation. From an industry view point, supporting growers to install energy efficient fans in new sheds will reduce the chicken meat industry's total power usage and associated carbon footprint. Meat chicken producers who are looking to purchase new fans have the opportunity to select a fan that may be substantially more energy efficient than others.

Selection of an energy efficient fan could potentially save up to $30,000 per shed in electricity costs in the first 10 years of operation. Producers have one opportunity to select the most energy and cost effective fan for their situation, so they need to get it right the first time. The cost of replacing inefficient fans will, in general, outweigh the potential electricity cost savings associated with more energy efficient fans.

Measuring fan air flow rate and energy efficiency is likely to be too difficult and unnecessary for most chicken growers. Drive belt and sheave wear (or adjustment issues) can easily be detected with a tachometer used to measure blade rotational speed—this test takes only 10–30 seconds per fan.

Recommendations

Fan suppliers should be encouraged to present their fan data in an appropriate format and supply actual test reports to inform customers of the fan configuration and test conditions underlying their data. A central database of this data would simplify the process for meat chicken growers to compare multiple fans from different suppliers. Growers should pick the most energy efficient fan that suits their situation. **A more energy efficient fan may cost more to purchase; however, it is likely that savings in electrical power will more than pay back the original investment.**

Farms should have a tachometer to measure fan rotational speed (RPM) as a way of identifying underperforming fans. This test should be repeated regularly using the same conditions, especially shed static pressure, and the values should be recorded as a reference for future measurements.

Introduction

Background

Large diameter axial fans are used on tunnel ventilated meat chicken sheds to regulate in-shed temperature, draw fresh air into the shed and exhaust moisture laden air from the shed. Meat chicken producers rely on these fans to have consistent performance and operate efficiently. Poorly performing ventilation fans may make it difficult to control the in-shed environment, leading to poor bird growth and feed conversion, and may lead to increased running costs.

Performance and efficiency of poultry ventilation fans has been a topic of global interest for years. Research and extension activities have been undertaken to help producers to select energy efficient fans and improve operation of existing fans. Research activities have also led to the development and testing of methods to accurately measure fan performance in wind tunnels and in-shed. Much of the research and extension has been undertaken by researchers, engineers and extension officers based at universities in the United States of America, and information is readily available from their respective internet sites:

- University of Georgia (Poultry Housing)—http://www.poultryventilation.com
- Auburn University—http://www.aces.edu/dept/poultryventilation
- The Pennsylvania State University—http://www.abe.psu.edu/extension/informationindex.html [follow the links to 'Animal Housing Systems'].

Much of the background information, methods, and recommendation in this report will be based on this research and extension material.

This report will focus on:

- Fan performance and efficiency;
- Methods for measuring fan performance;
- Selecting energy efficient ventilation fans; and
- Feasibility of replacing old fans with more efficient fans.

Fan performance and efficiency

Fan *performance* is a general term that is commonly used to refer to *air flow rate*, which is a measure of how much air a fan moves in a given timeframe under specified operating conditions such as static pressure. Air flow rate is commonly measured in cubic metres per hour (m^3/h) (or cubic feet per minute (cfm) if using imperial units). Fans with higher air flow rate or performance will move more air.

In contrast to performance, fan *efficiency* is determined by how much air a fan can move with one watt (W) of power, commonly measured in cubic metres per hour per watt ($m^3/h/W$) (or cubic feet per minute per watt (cfm/W) if using imperial units). It is desirable to have the most efficient fan possible, that is, a fan that moves the most air for the least amount of power because this will help to minimise ventilation costs.

Fan performance will vary if there is a pressure difference between the inlet and the outlet of the fan, which is commonly referred to as the 'static pressure'. Performance of a fan will reduce as the static pressure increases and electrical power consumed by the fan will increase. The combined effect is reduced fan efficiency with increasing static pressure (see Figure 1).

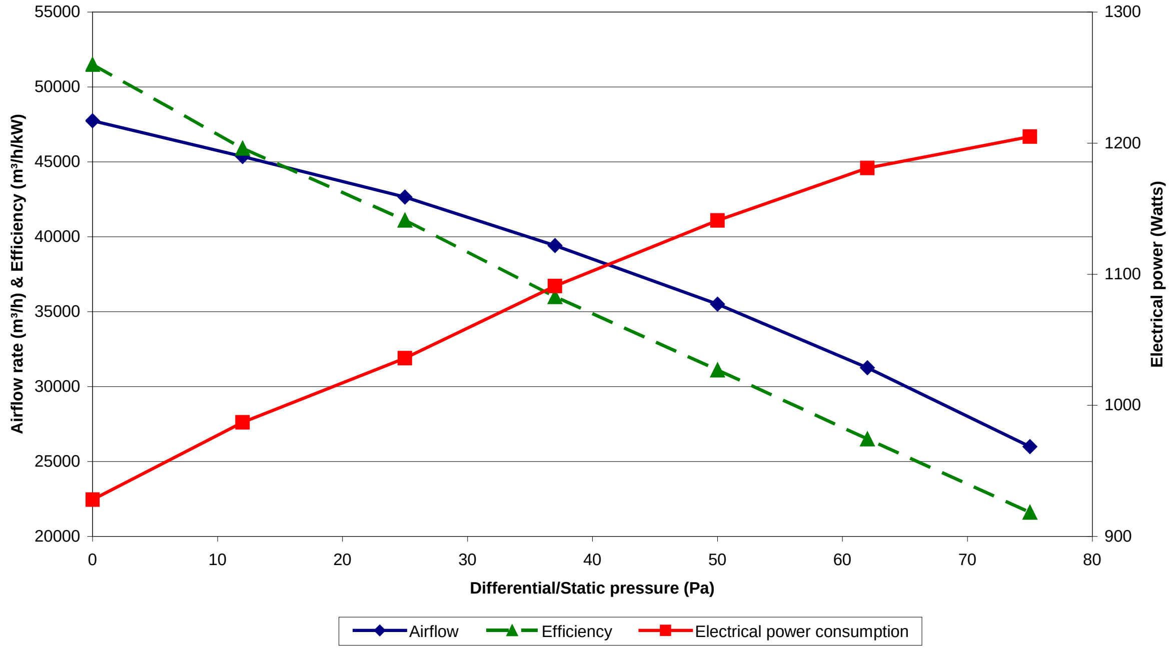


Figure 1. **Example of how fan performance, electrical power consumption and efficiency changes with static pressure for poultry shed ventilation fans**

Because static pressure affects the performance and efficiency of poultry ventilation fans, it is important to know the static pressure conditions under which fans will be operating. Static pressure needs to be measured in the shed about 6 m upwind of the fans when assessing fan performance (Czarick and Fairchild, 2010). This is because it will usually be greater than in the middle of the shed, where a shed pressure sensor may be located, because of extra resistance to air movement caused by baffles and friction along the walls, ceiling and floor. This extra resistance may reduce fan performance by increasing the shed static pressure (for example set at 25 Pa) by an additional 10–15 Pa at the fans.

Maintenance and cleanliness of a fan will also affect performance and efficiency (Casey *et al.*, 2008; Czarick and Lacy, 1995; Donald and Campbell, 2004; Janni *et al.*, 2005; Person *et al.*, 1979; Simmons and Lott, 1997; Wheeler, 1996). It is therefore very important to clean and maintain fans in order to maintain performance and efficiency as close as possible to the manufacturer's specifications.

One way to rate how well a fan maintains its air flow capacity with increasing static pressure—especially for comparison to other fans—is with the *air flow ratio* (ASABE, 2012; BESS Laboratory; Czarick and Lacy, 1999a). The air flow ratio is calculated using Equation 1:

$$Air\ Flow\ Ratio = \frac{Air\ flow\ @\ 50\ Pa}{Air\ flow\ @\ 12.5\ Pa}$$ **Equation 1**

Where:

Air flow is the air flow rate through the fan at the specified static pressure (m^3/h)
Pa is the unit for static pressure across the fan (Pascals)

Most poultry ventilation fans will have an air flow ratio between 0.5 and 0.85, and ideally fans should have an air flow ratio greater than 0.73 (Czarick, 2006). An air flow ratio of 0.6 indicates that the air flow rate of the fan is reduced by 40% as the static pressure increases from 12.5 Pa to 50 Pa. A fan that maintains its performance very well as pressure increases will have an air flow ratio closer to 1.0.

Performance and efficiency do not necessarily go hand-in-hand when comparing different fans. It is sometimes the case that fans with lower performance will operate more efficiently than fans with higher performance.

Who's responsible for fan performance and efficiency?

Three parties are responsible for ensuring maximum efficiency is achieved by ventilation fans installed in a meat chicken shed:

1. *Fan manufacturers* are responsible for ensuring that fan design and selected components (i.e. motor, pulleys, bearings, drive belts) allow the individual fan to be as efficient as possible while having adequate performance. If the design is lacking to begin with, high efficiencies will never be achieved.

2. *Designers/installers of the shed and ventilation system* must ensure the overall shed and system design will maximise the efficiency of the fan *as installed* in the shed (i.e. fan position; proximity of fans to each other; fitting of guards and shutters; wall and ceiling design and surface roughness; ceiling baffles; inlet vents; interference from other fans; and operational static pressure will all influence fan performance and efficiency). While the ventilation 'system', including inlets and shed design will affect fan performance, this report will focus only on individual fans as stand-alone units and will exclude all other system variables.

3. *Farm owners/operators* have the responsibility to ensure that the fans and shed are maintained and operated appropriately to maximise performance and efficiency (i.e. operate the shed at the correct static pressure; clean or replace evaporative cooling pads; and ensure inlet vents are operating properly).

This report focuses primarily on the performance and efficiency of fans as designed by the manufacturer (using manufacturer's specification) as well as how efficiency may change with normal wear due with extended use.

This report will not cover topics such as how to maximise fan performance and efficiency with good shed design or ventilation system operation and maintenance. These are critical to fan performance and detailed, quality information can be sourced from http://www.poultryventilation.com and http://www.aces.edu/dept/poultryventilation.

Choosing fans that are energy efficient for least cost operation

In Australia, the only resource available to assist meat chicken producers with selecting the most energy efficient and cost effective fans for their sheds is fan performance data supplied by manufacturers. Individual producers then need to interpret and understand the fan data and compare the different fans. Comparing air flow and efficiency of different fans (for example; at 25 Pa static pressure) is relatively straight forward assuming the data is available; however, estimating the likely running costs of different types of fans over the life of the fan is far more challenging. The '*Tunnel Ventilation Fan Comparison Spreadsheet*' has been developed to help producers compare different fans on the basis of air flow, energy efficiency and operating costs for their specific farm and is available for download from the RIRDC website. The spreadsheet is based on one developed by University of Georgia to assist producers to compare different fans ('*Tunnel Fan Comparison Spreadsheet 2014'*, available from http://www.poultryventilation.com/spreadsheets). Using this spreadsheet, producers can input fan performance and efficiency data, fan purchase costs, local electricity costs and the dimension of their poultry sheds. The spreadsheet then estimates the total cost of running that type of fan over a ten year period, allowing the user to identify the most efficient and cheapest fan for their situation.

The range of fans available in Australia is relatively limited compared to the United States. To assist poultry growers in the United States to readily identify the best performing and most efficient fans available, the University of Georgia publishes a list of fans representing the top 7–10% of fans tested by the BESS Laboratory (Czarick, 2012). Unfortunately for Australian producers, this list is of little value because few if any of the fans on the list are available in Australia.

Only a handful of manufacturers sell a limited range of fans into the Australian market. Consequently, there are not many fans to compare and it would be a valuable investment in time for a poultry grower looking to purchase new fans to compare efficiency and estimate running costs for a selection of fans. Of course there are other factors to consider when choosing fans such as construction quality; warranty; local dealer reputation; after sales parts and support; and previous experiences (Czarick, 2012).

Methods to measure fan performance and efficiency

Assessing fan performance and efficiency requires measurement of:

- air flow rate;
- electrical power; and
- operating conditions, including static pressure, barometric pressure and temperature.

There is no perfect method for assessing fan performance and efficiency. Each method will include compromises in terms of accuracy, precision and repeatability; costs; labour and equipment requirements; and comparability to the real-life in-shed conditions. In general, fan assessments can be performed in a laboratory setting or following installation in a poultry shed.

The advantage of laboratory testing is that fans can be tested in controlled and repeatable conditions; however the disadvantage with laboratory testing is use of a wind-tunnel style test rig does not simulate the conditions under which fans will be operated in a meat chicken shed (i.e. proximity of other fans; poorly controlled inlets and exits; and external wind effects). A possible result of this is that laboratory test results for a particular fan will likely show slightly higher performance and efficiency than in-shed test results for the same fan. Also, laboratory testing of fans already installed in sheds is impractical because it would require fans to be removed from a shed for testing.

The advantage of in-situ testing of fans is that any or all fans can be tested using actual operating conditions. The disadvantages of in-shed testing are that conditions may not be well controlled or repeatable; tradespeople may be required to invasively measure power consumption; dust on the fan components may cause temporary reduction of performance or efficiency (not representative of 'normal' conditions); and a duct or cowling may be required to create a suitable sampling plane for air flow measurements.

Regardless of where the fan is assessed, there are several standards and guidelines that should be followed to ensure that the assessment is as accurate and as repeatable as possible.

Standards for measuring fan performance

Standards are available for assessing the performance and efficiency of fans (any and all types of fans, not specifically just those used to ventilate meat chicken sheds). The Australia Standard for fan testing in a controlled laboratory setting is AS ISO 5801—2004, *Industrial fans—Performance testing using standardized airways* (Standards Australia, 2004). This standard is identical to International Organization for Standardization (ISO) ISO 5801-1997, which is recognised in many countries throughout Europe, Asia, Australasia and America. The United States of America also recognises ANSI/AMCA 210-07 (ANSI/ASHRAE 51-07) *Laboratory Methods of Testing Fans for Certified Aerodynamic Performance Rating* (ANSI/AMCA/ASHRAE, 2007), as the Standard for laboratory testing of fans. These standards have a strong focus on thermodynamic and mechanical performance of a fan and terms such as *efficiency* have a different meaning to the definition of efficiency used in this report. In the standards, efficiency is the ratio of fan power output to fan power input rather than air flow output per electrical power input. For fan specialists, the technical definition is useful but it does not tell a fan end user, such as a meat chicken farmer, how much the fan will cost to run. Anyone reading fan test reports based on the laboratory testing standards must ensure that they understand what terms are used and precisely what they mean.

While laboratory standards are available, they are complex, require strict conditions to be met and require elaborate, specialised testing equipment. These strict requirements are likely only to be met by dedicated testing facilities and are impractical or impossible for general researchers, consultants and fan users to apply. For in-situ testing of ventilation fans in poultry sheds, there are other standards that may be applied to provide a reasonable assessment of particular aspects of fan performance and energy efficiency, for example air flow rate. Australian Standard AS 4323.1—1995, *Selection of sampling positions* (Standards Australia, 1995) provides guidance on measuring air flow within a duct and can be adapted to measuring air flow through a fan or poultry shed by assuming the fan or shed can be considered as a duct. The American Society of Agricultural and Biological Engineer's *Agricultural Ventilation Constant Speed Fan Test Standard*, ASABE S565 OCT2005 (R2011) (ASABE, 2005) is applicable for measuring the performance and efficiency of single speed ventilation fans used on poultry sheds. This standard complements ANSI/AMCA 210-07 (which is one of the lab testing standards mentioned in the previous paragraph). Some notable benefits of ASABE S565 over laboratory based testing standards include the measurement of electrical power compared to fan shaft power, a requirement to mount the fan in a manner more similar to 'normal' field installations and consistent reporting format showing the essential data to enable comparison between fans. These allow the output data to be simpler and more useful to fan users, and ensure the operating conditions for testing are more realistic than in a laboratory test situation.

Published methods for assessing poultry shed ventilation fan performance and efficiency

Three methods for assessing the performance and efficiency of ventilation fans in intensive animal housing have been well described in research literature. These include a laboratory method (BESS Laboratory); an in-situ method using specialised equipment (Fan Assessment Numeration System, FANS); and an in-situ method using readily available anemometers (traverse method). Selection of an appropriate method will depend on desired accuracy, availability of the testing facility or equipment, whether or not the fan is installed, and intended use of the data (inherent performance for rating/sales purposes or performance of fan in-situ for estimating ventilation rates).

These are not the only methods available to test ventilation fans from poultry sheds. There are other fan testing laboratories that test fans to international standards, usually on behalf of manufacturers. Larger fan manufacturers may have their own testing facilities. Performance and efficiency data supplied by manufacturers may not always state who performed the testing, what the test conditions were, especially in terms of what accessories were fitted to the fan (i.e. grills and shutters) or if the fan was tested using a 50 Hz (Australian and European) or 60 Hz (North American) AC power supply.

BESS Lab

The Bioenvironmental and Structural Systems Laboratory (BESS Lab), University of Illinois, http://bess.illinois.edu, has been testing fans since 1990 and has tested over 800 commercially available fans including fans available for use in meat chicken sheds. Many fan manufacturers submit fans to the BESS Lab for 'independent' testing and test reports are made publicly available. BESS Lab tests are conducted in accordance with the standard ASABE S565 OCT2005, *Agricultural Ventilation Constant Speed Fan Test Standard*.

Advantages of BESS Lab testing include the ability to control testing conditions and provide a repeatable test environment to enable the comparison of different fans. In addition, the test reports from each BESS Lab test provide thorough detail regarding the fan configuration to ensure readers know exactly what fan has been tested and under what conditions. It is relatively simple to compare the performance and efficiency of fans tested by the BESS Lab because the test reports are in the same format.

Possible disadvantages with BESS Lab tests include the fact that the test rig is essentially a duct/wind tunnel and this may assist the fan to perform slightly better than if installed in a chicken shed where aerodynamics may be more complex. Also, there is the requirement to send fans to the BESS laboratory and pay for the testing, which effectively excludes the use of the BESS Lab when measuring shed ventilation rates is the objective. Finally, from an Australian perspective, the vast majority of BESS Lab fan tests are performed at an AC power frequency of 60 Hz, which makes the electric motor spin faster than it will in Australia where AC power frequency is 50 Hz. While manufacturers alter pulley sizes to make the fan blades spin at a similar speed (RPM), it is difficult to achieve an exact match with V-pulleys and the performance of the electrical motor may be slightly different due to the different ratio of motor speed to fan blade speed (assuming that the same make and model of electrical motor are used). Consequently, BESS Lab tests results at 60 Hz may not be strictly applicable for use in Australia.

Fan Assessment Numeration System (FANS)

Fan Assessment Numeration System (FANS) is a specialised instrument purpose built to measure air flow through large diameter ventilation fans while they are installed. It was first described by Simmons *et al*. (1998) and ongoing testing, modifications and usage of the instrument has been well described in the literature (Casey *et al.*, 2007; Casey *et al.*, 2008; Casey *et al.*, 2002; Gates *et al.*, 2004; Gates *et al.*, 2002; Janni *et al.*, 2005; Li *et al.*, 2009a, b; Li *et al.*, 2004; Lim *et al.*, 2010; Wheeler *et al.*, 2004; Wheeler *et al.*, 2002; Xin *et al.*, 2003).

FANS comprises a square metal frame that couples with the ventilation fan, preferably on the inlet side. Five or six vane anemometers measure airspeed across the width of the fan and automatically traverse the entire fan face providing a very accurate and repeatable method for measuring air flow through the fan. There are several sizes of FANS available to suit different sizes of fan. Purchase cost for a FANS unit is approximately US$10,000 (plus shipping and calibration).

Each test takes about 5 minutes plus approximately 10 minutes to install the FANS unit. Duct tape is used around the perimeter of the fan to achieve an airtight seal.

FANS does not measure electrical power consumption. Additional equipment is required to allow calculation of energy efficiency.

Traverse method

The traverse method is used for measuring air flow in ducts and fans. It requires measuring the airspeed at multiple locations across the cross-section of the duct or fan at specific locations. Traverse methods can be applied to circular, square or rectangular shaped ducts or fans that are described in detail in AS 4323.1—1995 (Standards Australia, 1995) and *ASHRAE Handbook—Fundamentals (chapter 36)* (ASHRAE, 2009). Both of these methods are slightly different but the fundamental concept is essentially similar. Future reference to traverse methods in this report will be directly related to the method described in AS 4323.1—1995. The traverse method has previously been used by researchers to estimate shed ventilation rates (Calvet *et al.*, 2010; Dunlop *et al.*, 2011; Estellés *et al.*, 2010; Lankering *et al.*, 2003; Wheeler and Bottcher, 1995; Wheeler *et al.*, 2003).

The first decision to be made with application of a traverse method is whether to use a square or round sampling plane (i.e. a cross-sectional plane in the duct where the airspeed measurements are made). Fans used in poultry sheds typically have a round fan section with a blade diameter in the range of 915-1372 mm (36–54 inches) but have a square housing with side length 1090–1580 mm. Due to challenges involved with attaching a round duct to a square fan housing, use of a square sampling plane is likely to be simpler.

The number of measurement points across the sampling plane requires careful consideration in accordance with AS 4323.1—1995. Given the dimensions of a typical ventilation fan and considering that there will be insufficient upstream and downstream flow stabilising distance between the sampling plane, fan and inlet/discharge point, a 5 x 5 or preferably 6 x 6 point sampling grid is required (total of 25 or 36 sampling points respectively). If a circular sampling plane could be applied, two transects at 90° to each other and each with a minimum of 10 sampling points is required (total of 20 sampling points) (see Figure 2).

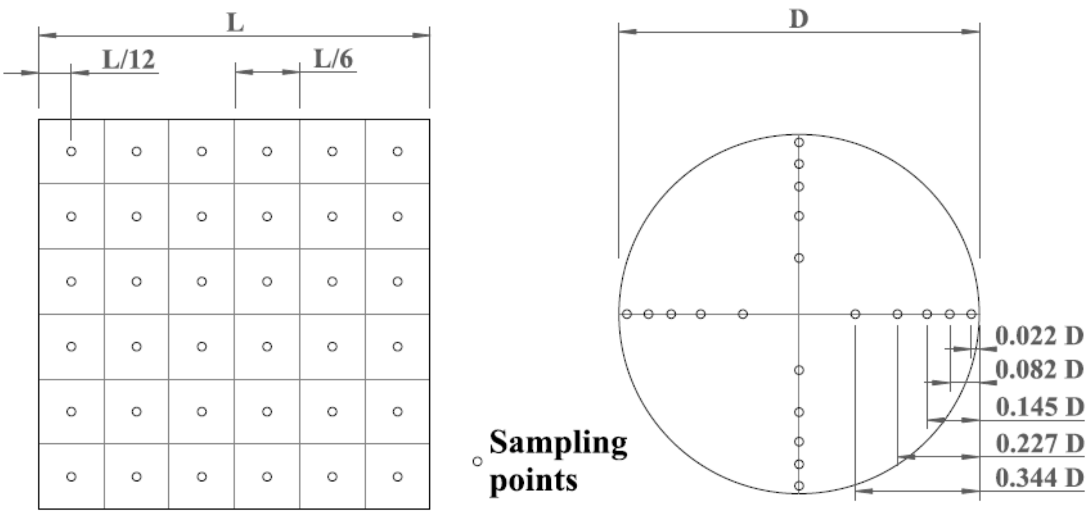


Figure 2. Square and round sampling planes for application of the traverse method for measuring air flow though a meat chicken shed ventilation fan (6 x 6 point square and 10-point, 2-transect round traverses)

To measure the airspeed, a hotwire anemometer, vane anemometer or pitot tube air velocity meter is required. The instrument needs to be calibrated and have sufficient precision to enable accurate and repeatable measurement.

As with the FANS method, electrical power isn’t measured so additional equipment and methods are required to enable calculation of energy efficiency.

Measuring electrical power consumption

Calculating the energy efficiency of a fan requires knowing how much electricity the fan is using. The only way to know this is to measure it with a power meter (or watt meter). Power meters simultaneously measure voltage and current and calculate the instantaneous power being used in a circuit. Measuring three phase power consumption requires specialised equipment, which can only be installed by a licensed electrician. Fan measurement standards (AS ISO 5804—2004 and ANSI/AMCA 210-07) specify required accuracy and precision of instruments used to measure electrical power. Outside of a fan testing laboratory setting, however, it is unlikely that electrical measurement equipment with the required specifications will be commonly available, and may not be strictly necessary depending on the intended use of the data.

AC power measurement is complex. There are three dimensions of power to consider: *active power*, *reactive power* and *apparent power* (see the diagram of the power triangle in Figure 3). Specifically relating to ventilation fans:

- *Active power* is the electrical power that is converted by an electric motor into mechanical power, i.e. drives the fan blades. Active power is also the power recorded by conventional power meters and is what electricity bills are usually based on. Active power uses units 'watts' (W) and is calculated using the equation: *Active power = VI cosØ* (where V is voltage, I is current in a circuit and Ø is the phase angle).

- *Reactive power* could be viewed as power 'lost' in the windings of an electric motor. Power users currently are not charged for reactive power (unless under specific arrangements by power supply companies). Reactive power uses units 'reactive volt-amperes' (VAR) and is calculated using the equation: *Reactive power = VI sinØ* (where V is voltage, I is current in a circuit and Ø is the phase angle).

- *Apparent power* is the total 'complex' or 'vector' sum of the active and reactive power components. Apparent power uses units 'volt-amperes' (VA) and is calculated using the equation: *Apparent power = VI* (where V is voltage and I is the current in a circuit)

Phase angle (Ø) and *power factor* are terms related by the equation: *power factor = cosØ*. Phase angle is a mathematical term that explains the difference between voltage and current in an AC power circuit and will change according to what types of loads are on a circuit (e.g. induction motors as commonly used on ventilation fans). Power factor is the ratio of the active power used by a load to apparent power in a circuit. In practical terms, electric motors with high power factor (close to 1.0) will use little reactive power, i.e. the power triangle will be very flat and apparent power will be minimised. Power factor is commonly stamped on electric motors (described as *power factor, PF or cosØ*) and is usually in the range of 0.6 to 0.85. This is the power factor of a motor at full rated load. An electric motor that isn't fully loaded will have a lower power factor than what is stamped on its compliance plate, and will draw relatively more total current for the same amount of output power.

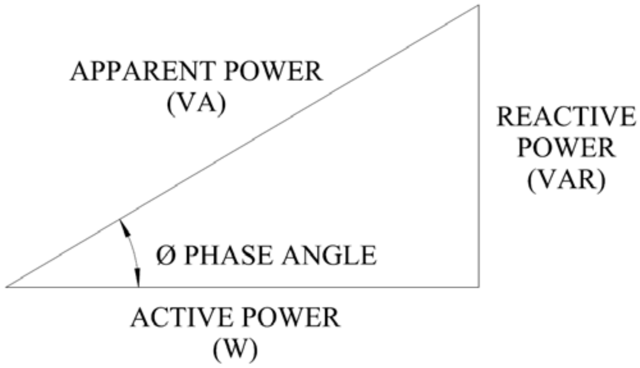


Figure 3. Power triangle for AC power

In some ways, discussion of the three dimensions of power (apparent, reactive and active) is academic because at the present moment, most power meters used by electricity suppliers only measure active power. This means that electric motors with poor power factor will not cost more to run than motors with good power factor. However, with electricity suppliers introducing ‘smart’ electricity meters that are able to measure both active and reactive power, it may be possible that users will be charged for reactive power in the coming years. If that happens, using electric motors with low power factor will result in higher running costs for ventilation fans.

It is because of the three dimensions of power that measuring instantaneous power becomes challenging and requires a purpose built power meter. Many electricians *will not* have a suitable power meter with the capacity to measure instantaneous electrical power, especially for three phase systems. Electricians will usually have a ‘clamp meter’ that is able to measure current and a multimeter that is able to measure voltage. Measuring the current and voltage will enable calculation of apparent power but without accurate measurement of power factor (which will be measured by a specially designed three phase power meter), there is no way to accurately measure the active power, which is the dimension of power of greatest interest when measuring fan efficiency.

Three phase power meters can be purchased for a few hundred dollars. These can either be for temporary use (hand-held instrument) or can be installed in a circuit board. Regardless of the type, only a licensed electrician will be able to install and use them. One challenge with using power meters for measuring the energy consumption of a single fan is being able to isolate the relevant circuit for that particular fan.

Measuring operating conditions

Operating conditions such as shed static pressure, temperature, relative humidity and barometric pressure need to be controlled or measured during fan performance testing. Of these conditions, shed static pressure can be controlled using shed inlet vents while temperature, relative humidity and barometric pressure can be measured and adjusted for mathematically.

Shed static pressure will likely have the greatest effect on fan performance. ASABE S565 *Agricultural Ventilation Constant Speed Fan Test Standard* (ASABE, 2005) requires testing at six equally spaced static pressure points, which allows a detailed understanding of a fan’s performance curve over its normal operating range. This is an ideal outcome but unnecessarily arduous for less critical purposes. To enable comparison of different fans and tracking the performance of the same fan over time, fans need only be measured at 25 Pa as this is considered a common operating static pressure for ventilation fans (BESS Laboratory; Czarick, 2012). Also for in-shed testing, 25 Pa is relatively easy to achieve and maintain while air flow measurements are being taken. For calculation of the air flow ratio, air flow measurements at 50 Pa and 12.5 Pa would also be required.

Static pressure should be measured with a differential pressure meter that can measure the very low static pressure difference between the inside and outside of a shed (0–100 Pa). Differential pressure gauges have previously been used successfully to measure static pressure within chicken sheds and can be purchased for about $200 (Czarick and Lacy, 1999b). Czarick and Fairchild (2010) provide recommendations on how to use a differential pressure gauge. In summary, differential pressure gauges have two ports, which allow them to measure the difference in pressure between two places, such as the difference between the inside and outside of a chicken shed. The 'negative' port on the gauge should be connected to a tube that is placed inside the shed, six metres upwind from fans while the 'positive' port should be connected to a tube that is placed outside the shed in a location that won't be greatly affected by the fans or wind, such as on the ground several metres from the shed. Using this tubing configuration, the gauge will show a positive pressure when the pressure inside the shed is negative relative to outside. With the fans to be tested turned on, the static pressure inside the shed can be adjusted using the tunnel curtain inlets and mini-vents until the correct static pressure is achieved on the pressure gauge. Note that the pressure gauge may indicate a different static pressure to the ventilation controller used in the shed because of the placement of the static pressure sensor or tubing used by the ventilation controller. It may be possible to use the pressure sensor in the ventilation controller by using temporary tubing and positioning the tubes as described above.

Air flow rates, should be standardised to standard air conditions (including standard temperature and pressure, STP). According to AS ISO 5801—2004 *Industrial fans—Performance testing using standardized airways* (Standards Australia, 2004), standard air has density 1.2 kg/m³ at 20 °C, 40% relative humidity and 101.325 kPa. Equation 2 may be used to adjust the air flow rate from the temperature and pressure conditions at the time of testing to the standard conditions (Standards Australia/Standards New Zealand, 2001).

$$Q_{STP} = Q \times \frac{(273+20)}{(273+T)} \times \frac{P}{101.3}$$ **Equation 2**

Where:

Q_{STP} is the volumetric air flow rate at standard conditions (m³/h)
Q is the volumetric flow rate at test conditions (m³/h)
T is the temperature at test conditions (°C)
P is the pressure (barometric) at test conditions (kPa)

Temperature in the shed is relatively easy to measure but determining the barometric pressure may not be quite as simple. Barometric pressure must be measured at the site rather than the 'mean sea level' (MSL) pressure reported by the Bureau of Meteorology. One way to estimate the barometric pressure is to use daily observation MSL pressure reported by the Bureau of Meteorology and adjusting for the altitude of the site using Equation 3 or Equation 4 (Daily weather observations, including daily average MSL pressure for Queensland locations and links to other states can be found at http://www.bom.gov.au/climate/dwo/IDCJDW0400.shtml).

$$P \approx 0.1 \times \left(P_{MSL} - 1013.25 \left(1 - \left(1 - \frac{E}{44307.69231} \right)^{5.25328} \right) \right) \qquad \textbf{Equation 3}$$

$$P \approx 0.1 \times \left(P_{MSL} - 0.1175E \right) \qquad \textbf{Equation 4}$$

Where:

P is the barometric pressure at the test site (kPa)
P_{MSL} is the mean sea level barometric pressure for the test location (hPa, *note:* daily average P_{MSL} data may be obtained from the Bureau of Meteorology)
E is the elevation of the test site above sea level (m)

The result of these calculations will be an air flow rate standardised to 20 °C and 101.3 kPa that can be compared to other standardised air flow rates measured on different days or under different testing conditions.

Summary of methods for assessing fan performance and efficiency

- *Fan performance* refers to the air flow capacity of a fan at different static pressures (units: cubic metres per hour, m^3/hr)

- *Fan efficiency* refers to how much air a fan moves per watt of electricity (units: cubic metres per hour per watt, m^3/h/W)

- Shed static pressure will affect fan performance and efficiency. As the static pressure increases (higher negative pressure in the shed), fan performance will reduce and the fan will run less efficiently.

- Fans can be tested in testing laboratories or in-shed.

  A traverse method may be applied to estimate air flow rate by using an air speed meter (anemometer) to measure air speed through the fan. A six-by-six square traverse should be sufficient based on guidance from the Australian Standard (AS 4323.1—1995).

  Other techniques are possible but require specialised equipment that is not commonly available (i.e. laboratory wind tunnel or FANS unit).

- A power meter (or watt meter) is used to measure electrical power usage for the calculation of energy efficiency (note that only licensed electricians can install and use a power meter). AC electrical power, especially three phase, is complex and comprises three components: active power, reactive power and apparent power.

  Conventional power meters (totalising meters) only measure active power and this is the basis of billing for electrical supply, which means there is little benefit in using electric motors with high power factor. New generation digital ‘smart meters’ may be able to measure reactive power. If power suppliers start to charge customers for reactive power in future, using electric motors with higher power factor will provide users with cost savings.

- Fans should be tested at multiple static pressure values. Less arduous testing can be performed at 25 Pa for comparison to other fans and also at 12.5 Pa and 50 Pa for calculation of *air flow ratio*.

- Air flow rate should be adjusted to standardised conditions (e.g. air density 1.2 kg/m^3 at 20 °C, 40% relative humidity and 101.325 kPa) for comparison to other fan test results.

Objectives

This project had five objectives:

1. Conduct an assessment of exhaust fans currently available in Australia in terms of performance and efficiency. This will:

    a. Provide a comprehensive list of exhaust fans to aid in the selection of efficient and economic fan models for the Australian meat chicken industry.

    b. Provide an economic analysis of operating the most efficient fans compared to less efficient fans.

2. Identify a method to assess fan performance in-situ.

3. Undertake an on-farm assessment of fan performance to identify efficiency gains.

4. Conduct an economic analysis of the feasibility of operating older fans compared to newer fans, together with an analysis of replacing old fans with newer and more efficient fans, outlining the payback period.

5. Develop a '*how to*' guide to be used by producers and industry service personnel for the in-situ assessment of fan performance and efficiency. This method will allow those fans currently installed to be assessed presently and into the future.

Methodology

Assessment of ventilation fans available to Australian meat chicken farms

Compiling fan performance and efficiency data

Fan performance and efficiency data was requested from suppliers of *Munters*, *American Coolair*®, *Hired-Hand*®, *Multifan*, *Fanquip*, *Eurofan*, *Skov*, *Titan Poultry* and *Gigola and Riccardi* brand ventilation fans. These fans were identified as the fans most commonly used in meat chicken sheds following conversations with producers and equipment suppliers. Fans were assessed using data—in order of preference—from independent test lab reports, manufacturer's test reports, manufacturer's brochures or data provided by the supplier. Polynomial regression was used to interpolate performance data if required. Fan suppliers were also requested to provide an indicative price for each of the fans.

Criteria for rating and comparing fans

The criteria used for rating different fans was based on the recommendations by Czarick and Lacy (1999a, c) and ASABE Standard EP566.1 AUG2008: *Guideline for selection of energy efficient agricultural ventilation fans* (ASABE, 2012):

- *energy efficiency* ($m^3/h/W$) at 25 Pa static pressure (an alternative static pressure may be more appropriate for individual situations but 25 Pa is generally suitable for comparing tunnel ventilation fans);
- *air flow ratio* (see Equation 1); and
- estimated total costs over a 10 year period, including purchase and electricity costs.

A rating system derived from Czarick (2008) was used for energy efficiency and air flow ratio. Fans that do not meet the 'minimum acceptable' rating for both energy efficiency and air flow ratio should be more thoroughly scrutinised for the specific application where they will be used.

Table 1. Rating system used for energy efficiency and air flow ratio (Czarick, 2008)

Rating	Energy Efficiency @ 25 Pa ($m^3/h/W$)	Air flow ratio
Poor !	Less than 32.3	Less than 0.70
Minimum acceptable *	32.3 - 33.8	0.70 - 0.72
Good * *	34.0 - 35.6	0.73 - 0.77
Excellent * * *	35.7 - 37.3	0.78 - 0.82
Outstanding * * * *	37.4 +	0.83 +

Costs to purchase and run a fan (electricity only) were considered in this assessment. Fan purchase prices were obtained from fan suppliers based on supplying only a small number of fans and **exclude GST, delivery costs, and bulk-purchase discounts**. Electricity costs were estimated using the cost of electricity ($ per kW·h), annual average operating hours per fan, the number of fans required for an assumed shed scenario (see Table 2) and the energy efficiency of the fans at 25 Pa static pressure. Electricity cost was assumed to be $0.15 per kW·h based on feedback from producers in southeast Queensland. Maintenance costs were not considered because the fans did not have defined service schedules. Replacement or repair of fan parts occurs on an as-needs basis.

The 'Tunnel Ventilation Fan Comparison Spreadsheet'

The '*Tunnel Ventilation Fan Comparison Spreadsheet*' was developed to enable comparison of multiple fans on the basis of air flow, energy efficiency and costs. This spreadsheet was based on '*Tunnel Fan Comparison Spreadsheet 2014*' (http://www.poultryventilation.com/spreadsheets), which was developed by University of Georgia. The original spreadsheet used imperial units (feet, cubic feet per minute (cfm), cfm/watt, gallons) and enables the comparison of only four fans. Consequently, the spreadsheet was modified to enable the use of metric units (metres, m³/h, Pascals, m³/h/W, litres) and expanded so many more fans could be input and compared at a single glance.

Using the '*Tunnel Ventilation Fan Comparison Spreadsheet*', fan efficiency and air flow ratio were given a rating (using the above rating system) on a fan by fan basis. Operating costs were calculated for a specific shed scenario. Details of the shed and required ventilation capacity were typed in the input sections. Table 2 shows the input parameters used in the spreadsheet for the cost comparison analysis in this report. The input values were selected based on the research team's observations of common shed dimensions and feedback from industry personnel regarding electricity costs and shed ventilation requirements.

Table 2. Inputs used in the *'Tunnel Ventilation Fan Comparison Spreadsheet'*

Input poultry house information			
House Length (m) =	*150*	*Electricity Rate ($ per kW·h) =*	*$0.15*
House Width (m) =	*15.3*	*Estimated Yearly Operating Hours per fan =*	*2,000*
Side Wall Height (m) =	*2.6*	*Minimum Design Air Velocity (m/s) =*	*3.0*
Ceiling Peak Height (m) =	*2.6*	*Minimum recommended fan capacity m³/hr (air exchange) =*	*461,700*
Open/Dropped Ceiling (o/d) (m) =	*o*	*Change minimum fan capacity ("0" if you don't wish to modify) =*	*429,625*

Explanatory notes for inputs

House length, house width and side wall height — length, width and wall height of the chicken shed.

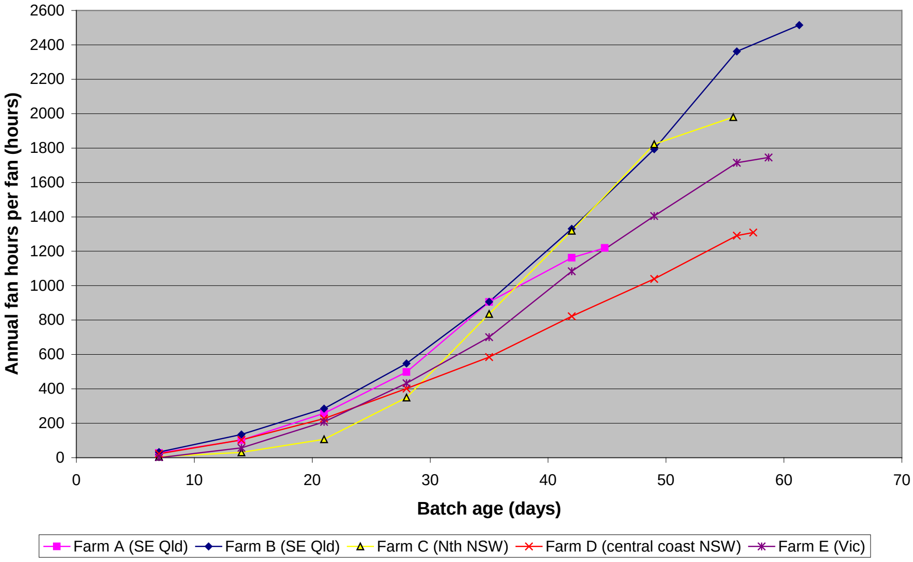
Ceiling peak height — the height of the ceiling peak in the shed. Value of 2.6 m was used to simulate ceiling baffles positioned 2.6 m above the shed floor.

Open/dropped ceiling — dropped ceilings (separate ceiling that is lower than the roof) are used in American shed but rarely seen in Australia. An open ceiling (i.e. roof is the ceiling) was selected. This value influences the 'minimum recommended fan capacity (air exchange)' described below.

Electricity rate — the cost of electricity. This was an assumed value based on feedback from several poultry farms in southeast Queensland.

Estimated yearly operating hours per fan — The value of 2,000 was calculated based on data from monitoring fan activity on five different chicken sheds in eastern Australia, see the following chart.

This chart shows the number of hours each tunnel ventilation fan (on average) was active for a 12 month period, at five different sheds in eastern Australia, accumulating throughout each batch (Dunlop and Duperouzel, 2014).



Minimum design air velocity — this is the minimum tunnel ventilation airspeed required in the shed.

Minimum recommended fan capacity m³/hr (air exchange) — this value is calculated by the spreadsheet based on the shed floor area. It was overwritten by the value 429,625 m³/h in this scenario, which is the total flow rate required to theoretically produce an airspeed of 3.0 m/s in the shed using the specified shed dimensions. If the original value was used (i.e 461,700 m³/h), maximum tunnel air speed in the shed would reach 3.25–3.40 m/s.

The next input section on the spreadsheet requires fan performance data (derived from manufacturer's specifications or test reports) as well as prices provided by the suppliers. Table 3 shows an example of how data was input into this section of the spreadsheet. It is recommended to record the data source (i.e. test report) so that when the user finally selects a fan, they can provide the data source to the supplier to request exactly that type of fan (model, electric motor, pulley sizes, blade configuration etc) (Czarick, 2006).

Table 3. Example of the input section for fan performance, efficiency and cost data in the *'Tunnel Ventilation Fan Comparison Spreadsheet'*

Input tunnel fan information							
Fan Model	**Air Flow 12.5**	**Air Flow 25**	**Air Flow 37.5**	**Air Flow 50**	**Energy Efficiency m³/h per watt @ 25 Pa**	**Price of Fan ($)**	**Data Source**
Fan A	44,523	41,463	37,179	30,906	28.0	1,970	Indep. Test lab AA123
Fan B	32,188	30,124	27,752	23,999	33.0	1,406	Indep, Test lab AA456
Fan C	28,917	27,463	23,645	20,565	38.0	1,242	Manufacturers test 12345

The spreadsheet then rates each fan's energy efficiency and air flow ratio according to the 'criteria for comparing fans' described previously in Table 1. Table 4 is an example of the output by the '*Tunnel Ventilation Fan Comparison Spreadsheet*' showing how each fan is assigned a rating for air flow ratio and energy efficiency.

Table 4. Example of fan rating outputs by the *'Tunnel Ventilation Fan Comparison Spreadsheet'* according to the criteria for comparing fans

Fan Model	**RATINGS**			
	Air Flow Ratio	**Air Flow Ratio**	**Energy Efficiency (m³/h/watt @ 25 Pa)**	**Energy Efficiency (m³/h/watt @ 25 Pa)**
Fan A	*0.69*	*POOR*	*28.1*	*POOR*
Fan B	*0.75*	*GOOD*	*33.0*	*MIN ACCEPTABLE*
Fan C	*0.71*	*MIN ACCEPTABLE*	*38.0*	*OUTSTANDING*

The next output of the spreadsheet relates to the costs of operating each fan over a ten year period. The spreadsheet firstly determines how many fans are required for the specified shed scenario (specified previously in the input section, Table 2). The spreadsheet uses assumptions regarding the static pressure at the required shed air speed. For example, at shed airspeed 3.0 m/s, the spreadsheet assumes the pressure drop at the fans is 37.5 Pa and consequently uses the air flow rate of the fan at 37.5 Pa. At this stage, the user can over-write the spreadsheet and nominate a different number of fans. The spreadsheet estimates the maximum possible air speed in the shed and annual fan operating costs. Table 5 is an example from the spreadsheet showing how it estimates the required number of tunnel fans based on each fan's air flow capacity and then calculates annual running costs for the shed.

Table 5. Example of the *'Tunnel Ventilation Fan Comparison Spreadsheet'* estimating the required number of fans, maximum shed air speed and annual running costs

TUNNEL FANS REQUIRED							
Fan Model	**Design static pressure**	**Tunnel fan capacity**	**Number of fans required**	**Change number of fans? (no=0)**	**Total air moving capacity at design static pressure**	**Total fan operating cost (yearly)**	**Average air speed (all fans operating)**
Fan A	*37.5*	*37,179*	*12*	*0*	*446,100 m³/h*	*$5,320*	*3.12 m/s*
Fan B	*37.5*	*27,752*	*16*	*0*	*444,000 m³/h*	*$4,380*	*3.10 m/s*
Fan C	*37.5*	*23,645*	*19*	*0*	*449,300 m³/h*	*$4,120*	*3.14 m/s*

Table 6 is an example of the spreadsheet output, which estimates the total cost associated with the fans **per shed** based on the number of fans required, purchase costs, fan energy efficiency, electricity costs and assumed annual fan hours (as specified previously in Table 2). Total cost estimates are highly dependent on the input parameters so it is very important to use values specific to the user's situation, otherwise inaccurate conclusions may be drawn.

Table 6. Example from the *'Tunnel Ventilation Fan Comparison Spreadsheet'* ' estimating the total fan costs per shed over a ten year operating period

	TOTAL FAN COSTS PER SHED		
Fan Model		**Ten year costs**	
	Purchase cost	**Electricity**	**Total**
Fan A	$23,641	$53,200	$76,841
Fan B	$22,502	$43,800	$66,302
Fan C	$23,598	$41,200	$64,798

Each fan was ranked against the other fans in terms of energy efficiency @ 25 Pa, air flow ratio and 10 yr costs (based on the assumed scenario); see Table 7 for an example of the spreadsheet outputs. Ranking enables the best and worst performing fans to be identified at a glance. Energy efficiency and air flow ratio data was derived from the data provided by the manufacturers/suppliers and is independent of the assumed scenario and assumptions made in the spreadsheet. Fan operating costs over 10 years, however, are highly dependent on the scenario used in the spreadsheet. The assumed scenario used in this report may result in fans being ranked in an order that is not relevant for other situations.

Table 7. Example from the *'Tunnel Ventilation Fan Comparison Spreadsheet'* ranking each fan against the others in terms of energy efficiency, airflow ratio and 10 year total costs

Model #	Fan comparison rankings		
	Energy Efficiency @ 25 Pa	Air flow ratio	10 Yr Cost
Fan A	3	3	3
Fan B	2	1	2
Fan C	1	2	1
Colour Key	Best	Top 5	Worst

From this point, a user of the '*Tunnel Ventilation Fan Comparison Spreadsheet*' can select one or more fans based on energy efficiency, air flow ratio and total costs. Other factors such as quality of construction, local dealer reputation, parts availability, after sales support and warranty also need to be considered prior to making a final selection (Czarick, 2012).

Methods to measure fan performance on-farm

There are several methods to assess the performance and energy efficiency of ventilation fans. Selection of the most appropriate methods for a particular situation will depend on reliability, repeatability, accuracy, usability and cost effectiveness. This section will outline the methods that were ultimately selected for assessing fan performance on-farm and the reasons for their selection.

These methods have been described in detail in a complementary report: '*How to' guide for measuring fan performance and efficiency in meat chicken sheds*, which is available from the RIRDC website (RIRDC publication no. 15/035).

Consideration of laboratory testing methods

Testing the performance and efficiency of fans in a laboratory provides the most controlled testing environment to provide accurate repeatable and complete (air flow and electrical) measurement of fan performance and efficiency to recognised Australian and international standards. However, as a method for testing the performance of fans installed in meat chicken sheds, laboratory testing requires removal of the fan from the shed and freighting to the test laboratory. Conditions in the test lab are likely to be different from the shed environment and therefore the test results will not necessarily be representative of the performance expected in-shed. Finally, the cost of laboratory testing would be in the order of a few thousand dollars considering costs to uninstall the fan, freight, testing costs (facility and labour) and then costs to return and re-install the fan into the shed. For these reasons, laboratory testing of ventilation fans is not considered a suitable method for on-farm assessment of fan performance and received no further investigation.

Consideration of FANS (Fan Assessment Numeration System) testing method

FANS is an air flow measurement that has been developed specifically for measuring air flow rate through large diameter axial ventilation fans while installed in intensive animal buildings. FANS has undergone intensive development, testing, comparison to laboratory test methods and is well recognised as an accurate, repeatable and user-friendly method for measuring fan air flow rate. Unfortunately, there are no FANS units in Australia and at a cost of more than $10,000, it is unlikely to receive widespread use. Additionally, FANS only measures the air flow and additional equipment such as a static pressure gauge and power meter are still required to measure power usage and enable testing of a fan under a range of static pressure conditions. Because FANS is not readily available in Australia, it will not be considered any further in this investigation.

Combined methods for fan assessment: air flow, power, operating conditions, rotational speed and component wear

With laboratory and FANS testing methods all but ruled out for on-farm assessment of fan performance and efficiency, other methods were required to measure air flow rate, electrical power, operating conditions (static pressure, temperature, humidity and barometric pressure), fan rotational speed (rpm) and assess the wear of critical fan components.

Fans were operated for 20–45 minutes before conducting any air flow, power measurement or rotational speed measurements to allow them to reach normal operating temperature. During this warm up period, the static pressure in the shed was adjusted using the shed inlet vents to achieve 25 Pa at the fans.

Test conditions

The performance and efficiency of each fan was tested using a series of static pressures—12.5 Pa, 25 Pa and 50 Pa. This provided a good understanding of how well the fan performed under a range of conditions and provided sufficient data to rate the fan in terms of *air flow ratio* and *energy efficiency @ 25 Pa* as per Table 1.

Measuring air flow using a traverse method

Air flow rate through individual fans was measured using the traverse method described in Australian Standard AS 4323.1—1995 *Stationary source emissions—Method 1: Selection of sampling positions*. To enable application of this method, assumptions were made that a sampling plane could be established where the air flow would be sufficiently steady, uniform and without a significant cyclonic component (>15°) to enable accurate measurement of airspeed. The sampling plane was chosen to be on the inlet side of the fan for three reasons:

1. Most ventilation fans used in poultry sheds have a square inlet shape but the outlet may be square or round depending on whether the fan has a discharge cone fitted. Sampling on the inlet side therefore offered a repeatable technique that could be applied to all fans regardless of their design (box, slant, cone etc).

2. Air flow at the discharge side of ventilation fans is more turbulent than at the inlet, and therefore less likely to be measured accurately. This is reflected in AS 4323.1—1995, which suggests that ideal sampling planes should be at least three diameters upstream or at least eight diameters downstream from an axial fan. The increased distance downstream is presumably due to increased turbulence.

   Recent testing of FANS device on the inlet and discharge side of ventilation fans has shown that downstream measurement may yield a 0.2–4.9% greater air flow measurement compared to the inlet (Li *et al.*, 2009b). This variability may seem small but it should be noted that the FANS device is less likely to be affected by non-uniform and turbulent air flow compared to the traverse method. Published methodologies for using FANS still recommend placing the FANS on the inlet side of the fan unless this is not possible.

3. Measuring air flow inside the shed is less likely to be influenced by weather and environmental variability, such as cross winds and direct sunlight (specifically for hot wire anemometers).

The number of measurement points required across the sampling plane was determined using AS 4323.1—1995 to be 36 (set out in a six-by-six square traverse, see Figure 4). This minimum number of measurement points is based on the requirement for a three-by-three traverse for ducts 0.9–1.7 m wide, plus penalty multipliers of 1.2 and 1.15 for being unable to locate the sampling plane more than 3 diameters upstream from the fan and more than 6–8 diameters downstream of any disturbance such as an 'inlet' to the sampling duct (see Equation 5). 'Diameters' is defined as the diameter of a circular sampling plane or the hydraulic diameter of a non-circular plane (equals the width of the square plane).

$$Number\ of\ measurements\ parallel\ to\ each\ side \approx 3 \times 1.2 \times 1.15 \approx 4.14$$
$$(round\ answer\ up\ to\ next\ even\ number \approx 6)$$

Equation 5

Where:

3 is the number of sampling points because of the width of the fan assuming an ideal sampling plane (Table 4, AS 4323.1—1995)

1.2 is the 'downstream penalty' for being more than 4 diameters less than the required 6–8 diameters downstream from the fan

1.15 is the 'upstream penalty' for being more than 1.5 diameters less than the required 3 diameters upstream of the fan.

'Diameters' is the diameter of a circular sampling plane or the hydraulic diameter of a non-circular plane (equals the width of the square plane)

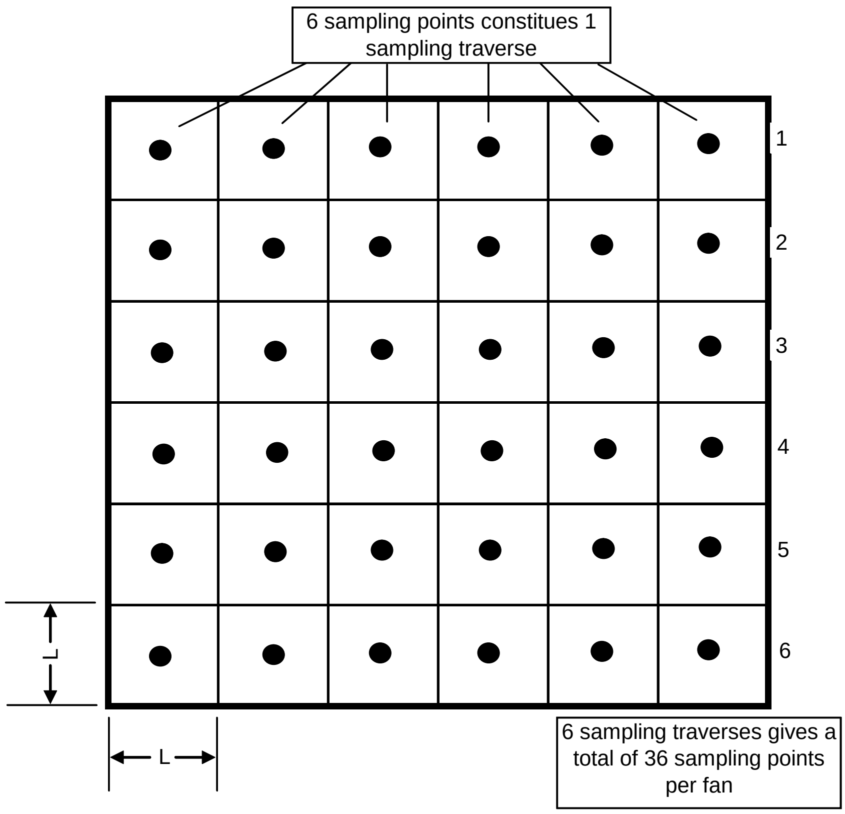


Figure 4. Arrangement of sampling points on the face of the fan, the position for which is calculated based on each individual fan's dimensions. Each sampling point represents an equal area segment of the sampling plane

A temporary 'cowling' was used during each air flow measurement to define the sampling plane and assist the operator to repeatedly position the air velocity meter in each of the 36 sampling locations.

The cowling was constructed from 5.5 mm thick Corflute® braced with lengths of timber. A new cowling was constructed for each different type of fan. Each cowling was designed to fit around the outside of the fan (see Figure 5) or flush with the face of the fan or wall around the fan. Each farm required a different configuration because of the type of fan and the way it was mounted in the wall. Cowlings were secured to the fan using duct tape and were designed to minimise obstruction of the incoming air flow. Six holes were drilled in each of the side walls of the cowling corresponding with the required sampling positions to support and positively position the air speed meter. This assisted the operator to measure the airspeed in each of the 36 sampling locations repeatedly.

Figure 5. Picture of a temporary cowling used to define a square sampling plane on the inlet side of the fan. Note the holes drilled in the cowling to positively locate the horizontal sampling traverses

Air speed was measured at each point using a VelociCalc® model 9545 (or model 8368) air velocity meter (TSI™ Incorporated, Minnesota, USA) (Figure 6). These anemometers were calibrated and had a traceable calibration certificate. Each airspeed measurement was the average over a five second time period and was reported in units of metres per second (m/s). Accuracy of the meter is specified to be ±3% of reading.

Figure 6. VelociCalc® 9545 air velocity meter. This unit has a range of 0-30m/s and can measure temperature and humidity

Air speed was measured at the centre of each of the 36 segments (from Figure 4), which was assumed to be representative of each segment. Because each segment was of equal area, total air flow through the fan (*Q*) was calculated by multiplying the average air speed across all of the segments by the total area of the sampling plane (see Equation 6). Air flow rate was then standardised to the standard air conditions (20 °C; 101.3 kPa) as defined by AS ISO 5801—2004 *Industrial fans—Performance testing using standardized airways* (Standards Australia, 2004) using Equation 2.

$$Q = V \times A \times 3600$$ **Equation 6**

Where:

Q is the volumetric flow rate at test conditions (m^3/h)
V is the average airspeed across all sampling points in the sampling plane (m/s)
A is the total area of the sampling plane (m^2)
3600 is a multiplier to convert from m^3/s to m^3/h

Power Consumption measurement

Active power was measured for each fan under each of the testing conditions (12.5 Pa, 25 Pa and 50 Pa static pressure). To isolate the power being used by each fan the electrician accessed the individual wires either in the shed sub-board or at the fan's isolator switch.

Electrical power was measured using a portable power meter (Testrite® T350, see Figure 7). This meter consists of a clamp-on current transducer ('clamp meter') and leads that were connected to each of the active phases. When measuring power, the clamp-on current transducer was put around each of the three active wires sequentially (each of the three phases has its own wire). The meter simultaneously measured the AC voltage and calculated the active power being used by that phase. The meter then automatically summed the total active power from all three phases and calculated the reactive power, apparent power and power factor (see Figure 3 for the power diagram).

Figure 7. Three-phase power meter with leads that are connected to each of the active wires by an electrician

Static pressure measurement

Static pressure across the fans was measured using a DP-Calc® model 8705 differential pressure meter (TSI™ Incorporated, Minnesota, USA) (Figure 8). The meter had two tubes connected to it. The open end of one of the tubes was placed on the floor of the shed, approximately 6 m from the fans (middle of the shed) while the open end from the other tube was placed on the ground at the tunnel fan end of the shed, several metres from the shed and away from the direct turbulence caused by the fans. Additional information about methods to measure static pressure is provided by Czarick and Fairchild (2010). The differential pressure meter continuously monitored and recorded the static pressure throughout the testing of each fan.

When adjusting the shed pressure to the specified test conditions (12.5 Pa, 25 Pa and 50 Pa), pressure was set according to this differential pressure meter rather than the pressure sensor installed in the shed. While likely to be just as accurate, the measurement tubes for the in-shed sensor were often placed half way between the fans and the tunnel inlets, which would not have been representative of the static pressure across the fans.

The precision of the DP-Calc® model 8705 is ±1% of reading +1 Pa.

Figure 8. DP-Calc® 8705 differential pressure meter used to measure static pressure

Temperature measurement and barometric pressure

Temperature and barometric pressure at the time of testing were used to standardise the measured air flow rate through the fan to standard air conditions using Equation 2.

Air temperature was measured at the time of each fan air flow measurement using the temperature measurement function of the VelociCalc® model 9545 (or model 8368) air velocity meter (TSI™ Incorporated, Minnesota, USA) (Figure 6). This meter has an accuracy of ±0.3 °C.

Barometric pressure data for each day of testing was downloaded from the Bureau of Meteorology http://www.bom.gov.au/climate/dwo/IDCJDW0400.shtml. Mean sea level barometric pressure values were adjusted to the elevation of the test site using Equation 4.

General wear and maintenance assessment

Rotational speed (revolutions per minute, rpm) measurement

Rotational speed of a fan blade, measured in revolutions per minute (rpm), is a very good indicator of worn, misaligned or poorly adjusted drive belts and other components. When the rotational speed drops, air flow will also drop (assuming static pressure remains constant).

Rotational speed was measured at the time of each air flow measurement. Rotational speed was also used to identify fans with potential wear or maintenance issues so they could be excluded from air flow testing. The person measuring fan rotational speed stood to the side of the fan to minimise obstruction of the air flow, which could affect the measurement.

Rotational speed was measured using a digital tachometer (TachIR model RPM10, Extech® Instruments Corp., Waltham, MA, USA; or Digital Tachometer model 6234P+, [unknown manufacturer])(see Figure 9). Both tachometers have accuracy stated to be ±0.05% of reading. The tachometers measured the rotational speed by counting the number of 'blades per minute'. The rotational speed of the fan was calculated by dividing the 'blade counts' by the number of blades on the fan. For example, a six bladed fan showing a blade count on the tachometer of 2100 'blades per minute' has a rotational speed of 2100 ÷ 6 = 350 rpm.

Additional information about measuring fan rotational speed with tachometers can be found in Czarick and Fairchild (2004).

Figure 9. Digital tachometers used to measure fan rotational speed (rpm)

Belt and sheave gauges

Worn v-belts and sheaves (otherwise referred to as the belt pulley) will reduce the performance of ventilation fans. Czarick and Fairchild (2004) provided detailed information on how to assess belt and sheave wear. Another method is to use belt or sheave gauges (such as Carlisle Sheave Gauges, part no. 102495, Carlisle Power Transmission Products Inc., Springfield MO, USA, http://www.cptbelts.com/tools/sheavegauge/index.html) (see Figure 10).

On the same day as air flow testing, belt sheave gauges were used to positively assess wear on sheaves and belts. This was particularly useful for determining if the belt or sheave, or both, were worn. While sheave gauges can measure wear while the fan is stationary, rotational speed testing with tachometers (as described above) quantified the fully dynamic effect of this wear on fan speed while it was operational.

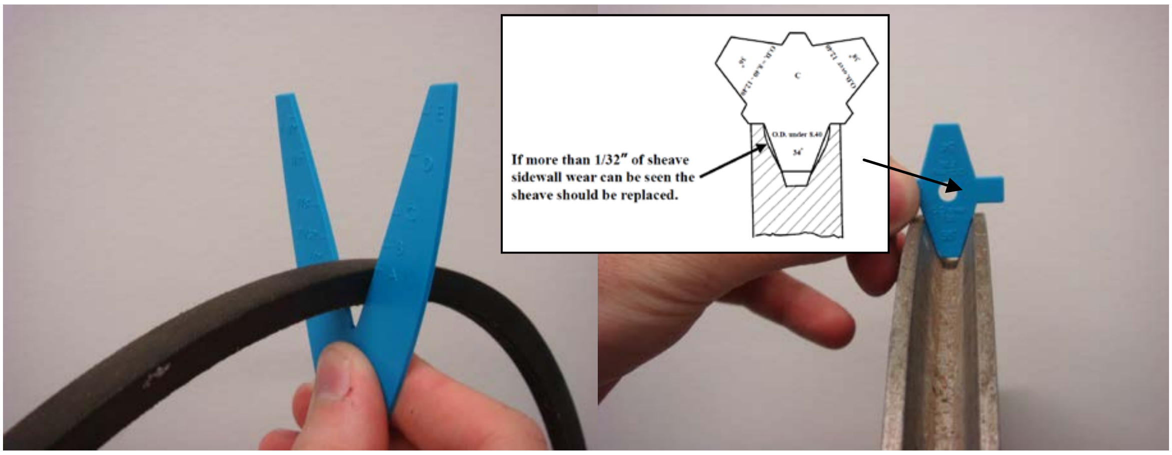


Figure 10. V-belt (left) and sheave gauges (right). These gauges can be used to quantify the wear on belts and sheaves. (Inset diagram from Carlisle Power Transmission)

Thermography for identifying slipping belts, worn bearings and overheating electric motors

Slipping belts, worn bearings and an overheating electric motor can affect fan performance. These may not easily be detected, usually relying on experience to identify particular sounds (such as a squealing belt or rumbling bearing) or other indicators such as extra vibration or belts that wear rapidly. These problems may lead to drive components increasing in heat, which may be detectable with a thermal imaging camera or infrared thermometer.

Following air flow testing, a thermal imaging camera (Thermo Shot F30S, NEC Avio Infrared Technologies Co. Ltd., Japan) and infrared thermometer (HoldPeak® HP-880EK, ZhuHai JiDa HUAPU Instruments Co. Ltd, China, see Figure 11) were used to inspect the fans to identify abnormally hot components relative to the other fans. These were noted when identified.

Figure 11. Infrared laser thermometer

On-farm assessments of fan performance and energy efficiency

Ventilation fans installed in twelve meat chicken sheds were assessed to measure their performance and efficiency. Within each shed, four fans were selected for assessment. The number of fans to be assessed was limited to just four fans because of the time required to test these fans at multiple static pressure conditions. Assessments took place between batches, allowing full control over fans and vents. Fans were washed prior to testing but no maintenance or adjustments were carried out. The following is a summary of how each set of fans were assessed:

- Before commencing any testing, shed doors were closed, all fans were turned on and the static pressure across the fans was set at 25 Pa. Static pressure was measured using a differential pressure gauge and was measured inside the shed, 6 m upwind from the fans. The fans were warmed up under these conditions for 20–45 minutes.

- With the static pressure adjusted to 25 Pa, the rotational speed of all fans in the shed was measured using a digital tachometer. The person measuring the rotational speed stood to the side of the fan being tested to minimise obstruction to the air flow, which could affect the reading. The rotational speed (rpm) of each fan was recorded.

- Four fans were selected for further testing based on safe access to the fan; minimal obstructions to air flow or installation of the temporary cowling; and on rotational speed measurement (relative to the other fans). In general, the aim was to measure the average performance and efficiency of four fans. With this in mind, the fans in the shed with the highest and lowest rotational speed (rpm reading) were excluded because it was possible that these may not be representative of the majority of the fans. Two fans close to the median rotational speed plus one slightly faster and one slightly slower fan were selected.

- With the static pressure still at 25 Pa, air flow rate was measured for each of the four selected fans. The temporary cowling (Figure 5) was installed on each fan while air flow was being measured. Air temperature and fan rotational speed was recorded during each air flow measurement. Air flow measurement required 10–15 minutes per fan at each static pressure.

- Air flow, rotational speed and temperature measurements were repeated with the static pressure adjusted to 12.5 Pa and 50 Pa.

- Electrical power was measured by an electrician. The electrician installed test leads for the power meter then measured the power through each phase (3 phase power supply) of each fan. Power was measured at 12.5 Pa, 25 Pa and 50 Pa static pressure. Power consumption was not measured at exactly the same time as air flow measurement, as this would have required the electrician to be on site for several hours. Care was taken to maintain the same static pressure conditions during both air flow and power measurements.

The types of fans available for assessment were identified through discussions with producers, integrator personnel and fan equipment suppliers. Farms with these types of fans were identified and arrangements were made with the farm owner to make a shed available for the assessments. Table 8 lists the fans that were assessed for performance and efficiency. Some fan models were tested more than once, but each group of fans was considered individually due to different age or service history.

Table 8. Fans assessed for performance and efficiency

Shed	Fan Type	Age
A	American Coolair NBFA54L 54” 1.0 hp	7–10 years
B	American Coolair NBFA54L 54” 1.0 hp	12–14 years
C	American Coolair NBFA54M 54” 1.5 hp	~6 years
D	Skov 1400 (similar to Munters Euroemme EM50, 1.0 hp)	~6 months
E	Munters Euroemme EM50, 1.0 hp	10–12 years
F	Munters Euroemme EM48, 1.0 hp	10–12 years
F*	Munters Euroemme EM48 1.0 hp (*New belts and sheaves fitted 1 batch before testing)	10–12 Years
G	Hired Hand 6603-7403 52”, 1 hp with Cone	~6 Years
H	Hired Hand 6603-7403 52”, 1 hp with Cone	4–5 Years
I	Titan 1220/1.5 kW/6B (48”, 2.0 hp)	~8 Years
J	Titan 1220/1.5 kW/6B (48”, 2.0 hp)	8–9 years
K	Titan 1372/2.2 kW/8B (54”, 3.0 hp)	~8 Years
L	Cumberland 50” 1.5 hp	~7 Years

The air flow ratio and energy efficiency of these fans were rated using the rating system in Table 1. Additionally, the likely costs associated with operating these fans in the scenario described in Table 2 were calculated (note that the described scenario was usually different to the actual shed in which the fans were installed).

Results

Assessment of poultry ventilation fans currently available

Fans included in the review

Fan performance and efficiency data was collated for 38 different ventilation fans available through Australian suppliers (Table 9). Other fans are available but performance data or pricing was unable to be acquired.

Air flow rate and energy efficiency data as well as purchase cost (excluding GST) are provided in Appendix 1. The sources of the air flow and efficiency data for each fan are provided in Appendix 2.

Where possible, performance and efficiency data was sourced for three phase models tested using 50 Hz AC electricity supply. If this was not possible, '60 Hz' has been written alongside the fan description.

Table 9. Fans assessed in terms of performance and energy efficiency

Fan Model
Hired Hand 6603-7403 52" (60 Hz) CONE 1 hp
Hired Hand 6603-6527 52.5" Butterfly damper (60 Hz) CONE 1 hp
Hired Hand 6603-3000 52.5" CONE 1.5 hp
Hired Hand 6603-8010 54" CONE 1.5 hp
Munters Euroemme EM50 1 hp
Munters Euroemme EM50 1.5 hp
Munters Euroemme EC-50 (60 Hz, 1 phase) CONE 1 hp
Munters Euroemme EC-50 CONE 1.5 hp
American Coolair MNBF60M (60Hz) 1.5 hp
American Coolair MNBFC60M (60Hz) CONE 1.5 hp
American Coolair MNBFA54L (60Hz) 1 hp
American Coolair MNBFA54M (60Hz) 1.5 hp)
American Coolair MNBFA54N (60Hz) 2 hp
American Coolair MNBFA48L (60Hz) 1 hp with
American Coolair MNCFC52L (60Hz) CONE 1 hp
American Coolair MNBCCE54L (60 Hz) CONE 1 hp
American Coolair MNCFE52L (60Hz) 1 hp
Titan WM1000/1.1/5B (1.5 hp)
Titan WM1000/1.5/6B (2 hp)
Titan WM1220/0.75/5B (1 hp)
Titan WM1220/1.1/5B (1.5 hp)
Titan WM1220/1.5/6B (2 hp)
Titan WM1220/2.2/8B (3 hp)
Titan WM1372/1.5/8B (2 hp)
Titan WM1372/2.2/8B (3 hp)
Multifan MF130 0.75kW (50.5", 1.0 hp, 3 blade)
Multifan MF130 1.12 kW (50.5", 1.5 hp, 3 blade)
Multifan MF130 0.75 kW (50.5", 1.0 hp, 3 blade) CONE
Multifan MF130 1.12 kW (50.5", 1.5 hp, 3 blade) CONE
Skov DB1400 1hp (60 Hz, 1 Phase)
Skov 1400 Cone 1.5 hp (3ph airflow data, 1 ph efficiency data)
Eurofan 36" axial fan 0.4kW - 0.75 hp 6 blade (9FJ9.1)
Eurofan 50" axial fan 1.1kW - 1.5 hp, 6 blades (9FJ12.7)
Eurofan 50" butterfly fan 0.75kW - 1.0 hp, 3 blade CONE (9FJ12.7T-4)
Eurofan 50" butterfly fan 1.1 kW - 1.5 hp, 6 blades CONE (9FJ12.7T-3)
Gigola & Riccardi ES-140 R/S 1.0 hp
Gigola & Riccardi ES-140 R/S 1.5 hp
Gigola & Riccardi ES-120 R/S 1.0 hp

Collecting the data for some fans was difficult and took **several weeks or months to obtain.** Detailed test reports, if provided, were found to be the most useful for describing the test conditions and fan configuration. Performance data is incomplete for some of the fans because they were not all tested under the full spectrum of test conditions, especially testing at 50 Pa static pressure. The exact fan configuration remains unknown for some of the fans.

Summary statistics for air flow, energy efficiency and air flow ratio

Summary statistics for air flow, energy efficiency and air flow ratio data for these fans is provided in Table 10. Figure 12 shows the airflow capacity of each fan at 12 Pa, 25 Pa and 50 Pa. Figure 13 shows the air flow ratio and energy efficiency. There is a wide spread of values, with some fans producing nearly twice the air flow of others, and some fans being more than twice as energy efficient as others.

Table 10. Summary of air flow, efficiency and air flow ratio statistics

	Minimum	**Maximum**	**Median**
Air flow at 25 Pa – m³/h (only fans 1220 mm (48”) or greater)	29,053	57,495	40,266
Energy efficiency at 25 Pa – m³/h/W	20.1	53.3	30.3
Air flow ratio	0.61	0.93	0.78

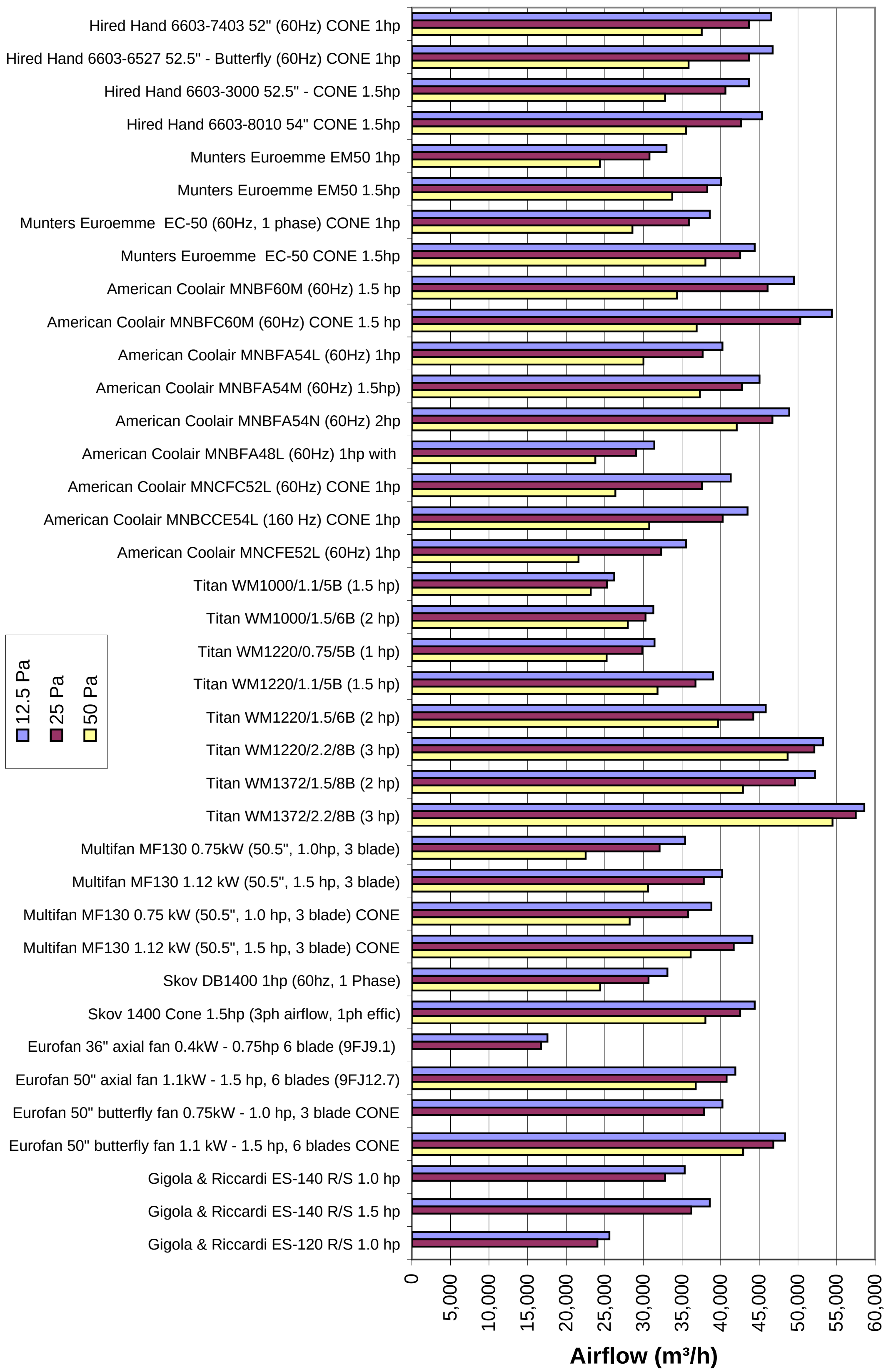


Figure 12. Air flow rate of reviewed fans (based on supplied data)

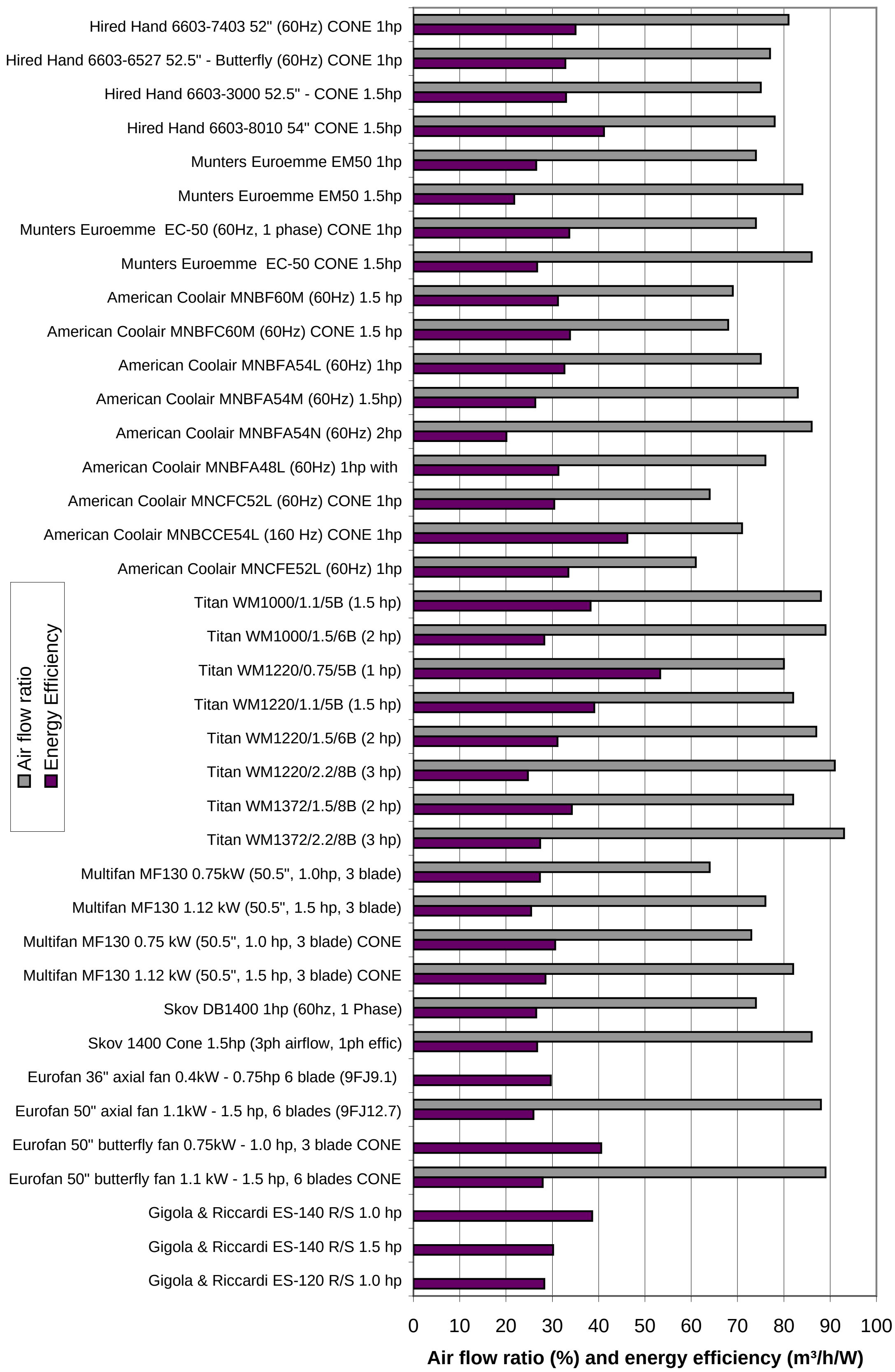


Figure 13. Air flow ratio and energy efficiency of reviewed fans (based on supplied data)

Air flow ratio and energy efficiency ratings

The rating system from Table 1 was used to rate the *air flow ratio* and *energy efficiency* of the fans. The rating assigned to each fan is provided in Appendix 3.

The majority of fans included in this review had an 'excellent' air flow ratio (see Figure 14), which means that when operating under higher pressures or pushing against headwinds, air flow will not substantially reduce. The majority of fans (61%) had 'poor' energy efficiency (see Figure 15). Only 23% of fans had an energy efficiency of 'good', 'excellent' or 'outstanding'.

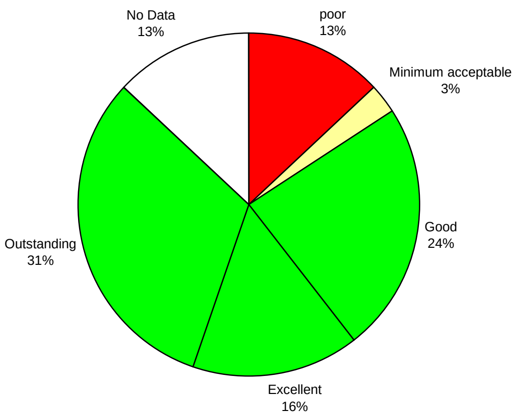


Figure 14. Pie chart showing the distribution of ratings for *air flow ratio* (% of fans)

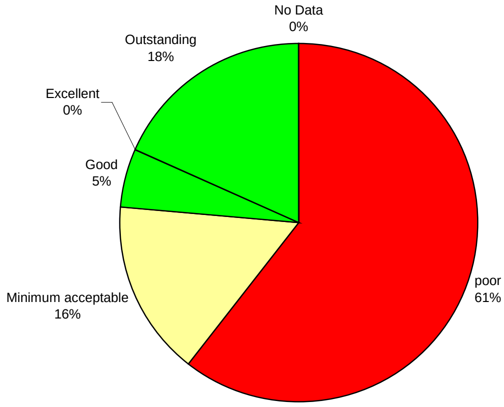


Figure 15. Pie chart showing the distribution of ratings for *energy efficiency* (% of fans)

Operating costs

The '*Tunnel Ventilation Fan Comparison Spreadsheet*' (as described in the Methodology section, including Table 2 to Table 7) was used to calculate the costs associated with each fan based on the input scenario shown in Table 2.

The spreadsheet calculated the required number of fans to deliver the specified minimum ventilation rate or tunnel ventilation airspeed (in this case 3.0 m/s). At this air speed, the spreadsheet assumed that the static pressure at the fans will be 37.5 Pa and used the airflow data for each fan at this static pressure. The spreadsheet then calculated the maximum shed ventilation rate, in-shed airspeed and annual electricity costs (see Appendix 4 for results). Fan purchase costs and electricity costs to operate the fans for 10 years were then added to estimate total operating cost for each fan over a 10 year period (see Appendix 3 for results).

There was a substantial difference between fans regarding purchase and electricity costs. Table 11 summarises the costs for all of the fans. The purchase price for some fans was nearly three times greater than others. The electricity cost to operate some fans was over two and a half times greater than other fans. The total cost (purchase plus electricity for 10 years) of some fans was nearly twice as much as other fans. Selection of the most economical fan could potentially save a farm $30,000 per shed over a 10 year period.

Table 11. Summary of costs associated with operating each fan over 10 years

	Minimum	Maximum	Median
Fan purchase costs per shed ($)	$8,640	$24,786	$15,600
Electricity costs per shed ($ per 10 years)	$26,900	$69,700	$48,700
Total cost over 10 years (per shed)	$48,500	$88,620	$64,470

A relationship exists between operating costs and fan energy efficiency. Figure 16 is a chart showing fan purchase costs, 10 year electricity costs and 10 year total costs (electricity plus purchase price) plotted against energy efficiency. Each of the dots on the chart represents one of the fans listed in this review. It can be seen that using a ventilation fan with poor energy efficiency is likely to add significant costs to a shed over a 10 year period. Some of the more efficient fans may cost more initially to purchase, but will save substantially more money over an operating period of 10 years.

This plot can also be used to identify the cost effectiveness of replacing an inefficient fan with a more efficient fan. For fans that are above the pink line drawn in Figure 16, it may be cost effective to replace these fans with one that is more efficient and has lower total costs (over the assumed 10 year period). For fans below the pink line, the electricity cost to run these fans over the next ten years is still less than what it would cost to replace them. This is a very simplistic example and does not include the costs to replace old fans with new (other than fan purchase price), which may require significant modification to the shed structure or electrical system. It also does not consider situations that might make the change-over costs more reasonable, including:

- Changing to a different fan if faced with major fan overhaul or replacement of significant components such as electric motor, impeller or shutters with the existing fans;
- Modifying existing fans by fitting the motor, pulleys or discharge cone from a more efficient fan within the same product range (same brand, physical size, style and blades). Note that if the modified fan has different airflow characteristics, additional fans may be required to maintain shed ventilation requirements.

Naturally, considerations other than cost may outweigh the potential cost savings associated with changing from one type of fan to another.

Overall, once fans are installed in a shed and are still operational, it would be difficult to justify replacing them with new or different fans from a purely economical standpoint.

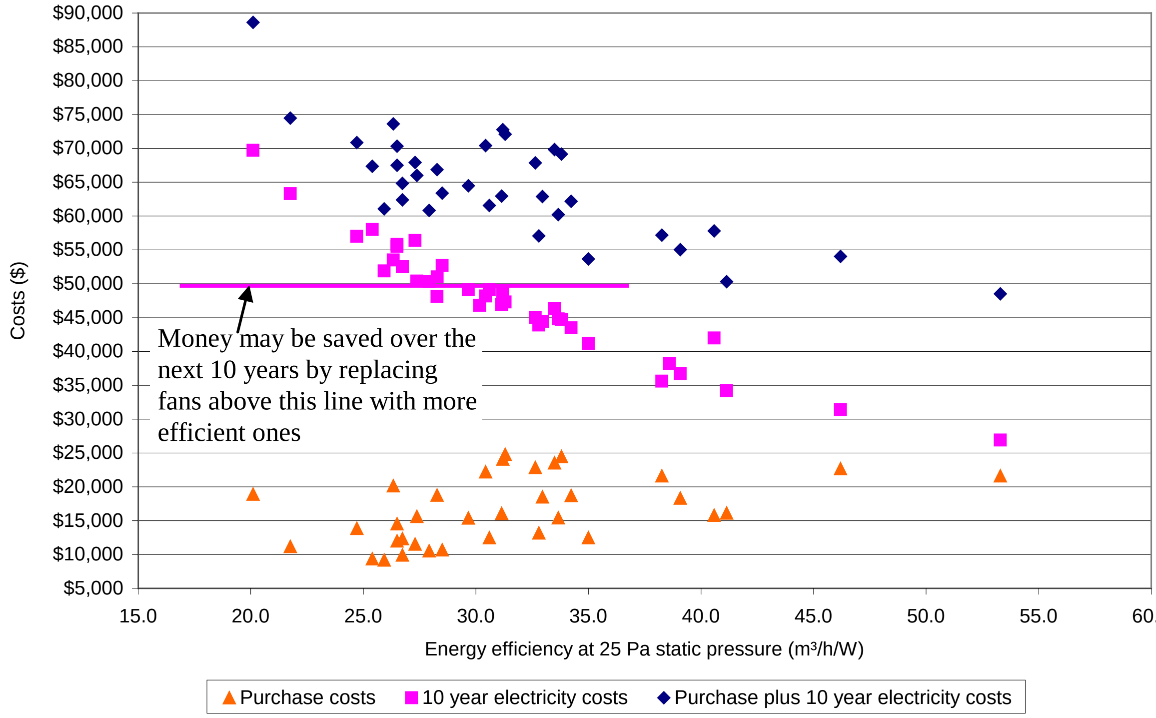


Figure 16. Chart showing 10 year fan costs—electricity costs and electricity plus purchase costs—plotted against energy efficiency

Fan comparison rankings

Fans were ranked against each other in terms of air flow ratio, energy efficiency and total operating costs over 10 years (note that the rankings in terms of operating costs were highly dependent on the assumed scenario provided in Table 2). The rankings for each fan are provided in Appendix 3. (The colour code for the rankings is shown in Table 7 on page 19).

On-farm measurement of fan performance and efficiency

Tunnel ventilation fans in 13 meat chicken sheds were assessed in terms of rotational speed (rpm), air flow and energy efficiency. The chicken sheds were located in southeast Queensland and each had fans of different type or age (see Table 8 on page 28).

Rotational speed testing (RPM)

The rotational speed (rpm) of all tunnel fans in each chicken shed was measured using a digital tachometer. Prior to the measurement of rotational speed, the fans were allowed to warm up for 20–45 minutes and the static pressure across the fans was set at 25 Pa. The median rotational speeds for all of the fans are shown in Table 12.

Table 12. Rotational speed measurement—the number of fans assessed and median RPM

Shed	Fan Type	Number of fans assessed	Median rotational speed at 25 Pa (rpm)
A	American Coolair NBFA54L 54” 1.0 hp	9	333
B	American Coolair NBFA54L 54” 1.0 hp	9	331
C	American Coolair NBFA54M 54” 1.5 hp	8	387
D	Skov 1400 (similar to Munters Euroemme EM50, 1.0 hp)	14	372
E	Munters Euroemme EM50, 1.0 hp	10	390
F	Munters Euroemme EM48, 1.0 hp	10	375
F*	Munters Euroemme EM48 1.0 hp (*New belts and sheaves fitted 1 batch before testing)	4 – with new parts [5 – existing parts]	378 [375]
G	Hired Hand 6603-7403 52”, 1 hp with Cone)	6	620
H	Hired Hand 6603-7403 52”, 1 hp with Cone)	10	591
I	Titan 1220/1.5 kW/6B (48”, 2.0 hp)	8	512
J	Titan 1220/1.5 kW/6B (48”, 2.0 hp)	5	534
K	Titan 1372/2.2 kW/8B (54”, 3.0 hp)	8	512
L	Cumberland 50” 1.5 hp	11	412

Rotational speed values on their own are of limited value, but when compared to manufacturer’s test data (if available); the other fans in the shed or previous measurements, relative values can be used as an indicator of fan wear and likely airflow performance. Figure 17 is a box plot showing the percentage variation in fan rotational speed from the mean values provided in Table 12. It can be seen that in some of the sheds, there were fans that were spinning 5–24% slower than the other fans in the shed and in one shed there was a fan spinning 16% faster than the median value. These slower and faster fans should be inspected for drive belt/sheave wear and adjustment. While this once-off measurement in a shed may have identified one or two fans with maintenance/wear issues, additional data from manufacturer’s testing or previous measurements would be required to assess whether or not all of the fans in the shed were underperforming.

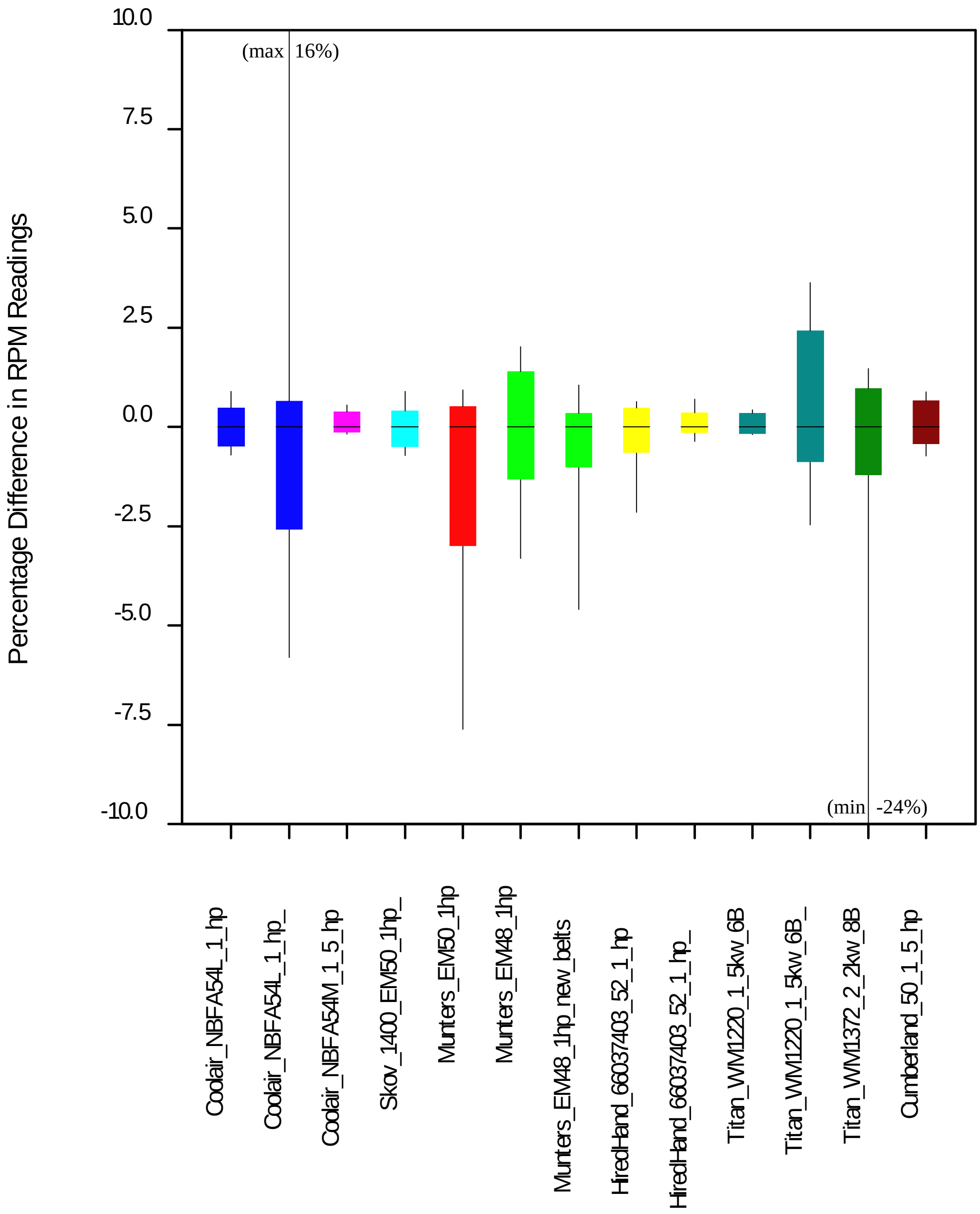


Figure 17. Percentage variation between individual fan rpm and the median rpm of all fans in each shed

Note for interpreting box-plot in Figure 17: The line inside the box is the median value (in this case the median rpm provided in Table 12). The box shows the middle 50% of data around the median value. The thin lines or 'whiskers' represent the bottom 25% of values and the top 25% of values. The extent of the whiskers shows the full extent of the data values. The written values show the maximum or minimum when this was beyond the axis limits (for improved presentation of the graph).

Air flow rate measurement, air flow ratio and energy efficiency

Air flow rate was measured through four fans in each of the sheds listed in Table 8. Air flow rate was measured at 12.5 Pa, 25 Pa and 50 Pa static pressure (except shed G, where 50 Pa was unable to be achieved to due to a mechanical fault with the mini-vents). Air flow rate data is presented in Appendix 5. Airflow rate at 37.5 Pa was interpolated from the other measurements using polynomial regression. Figure 18 graphically presents the air flow rates and Figure 19 presents the air flow ratio and energy efficiency values that were measured for each set of fans (categorised by shed).

Air speed measurements required approximately 15–20 minutes per fan including time to install the temporary duct. Fans were ‘warmed-up’ by operated them for at least 20–45 minutes prior to testing.

Table 13 shows a summary of the air flow capacities measured at 25 Pa, the energy efficiency values at 25 Pa and the air flow ratio calculated for the fans.

Table 13. Summary of air flow, efficiency and air flow ratio statistics

	Minimum	Maximum	Median
Air flow at 25 Pa – m^3/h	22,526	43,673	33,088
Energy efficiency at 25 Pa – $m^3/h/W$	22.0	43.3	31.0
Air flow ratio	0.45	0.86	0.71

Where the same model of fan was re-assessed in different sheds (primarily with an age difference), measured performance in terms of airflow was reasonably similar. There were two exceptions:

1. Shed F, Euroemme EM48 with/without new belts and pulleys fitted—Air flow was noticeably lower on these fans after the belts and sheaves were replaced, despite higher rotational speed. At Shed F, the safety grill on the inlet side of the fan made it difficult to seal the temporary cowling on each fan and it is possible that this was the cause of the inconsistent airflow measurement.

2. Shed J, Titan WM1220/1.5/6B—Air flow was noticeably lower for the fans in Shed J compared with the same model of fan in Shed I and also compared to manufacturer’s data (44,222 m^3/h at 25 Pa). This is despite the mean rotational speed being higher. It is suspected that the fan blade angle may have been different on the fans in Shed J. Air flow ratio and energy efficiency in Shed J were better than Shed I and similar to manufacturer’s test data.

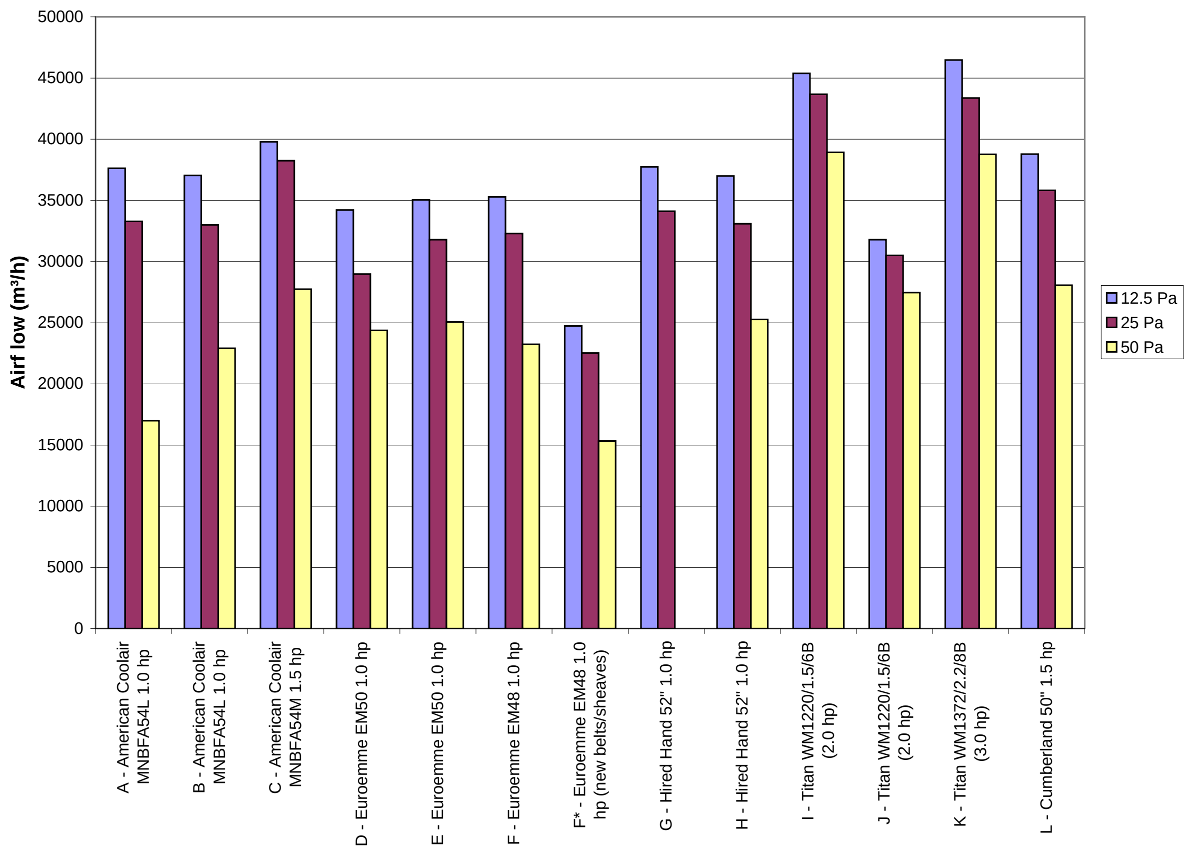


Figure 18. Air flow rates measured on-farm

Air flow ratio and energy efficiency values presented in Figure 19 shows substantial variability between the different types of fans. Some of the fans were nearly twice as efficient as others. Variability in air flow ratio shows that while the airflow rate through some fans only reduced by about 15% as static pressure increased from 12.5 Pa to 50 Pa, the airflow rate through other fans reduced by 55%. Farmers with the fans with low air flow ratio (45% to 62%) should ensure they are aware of this and minimise static pressure as much as possible in order to maintain ventilation rate in their shed.

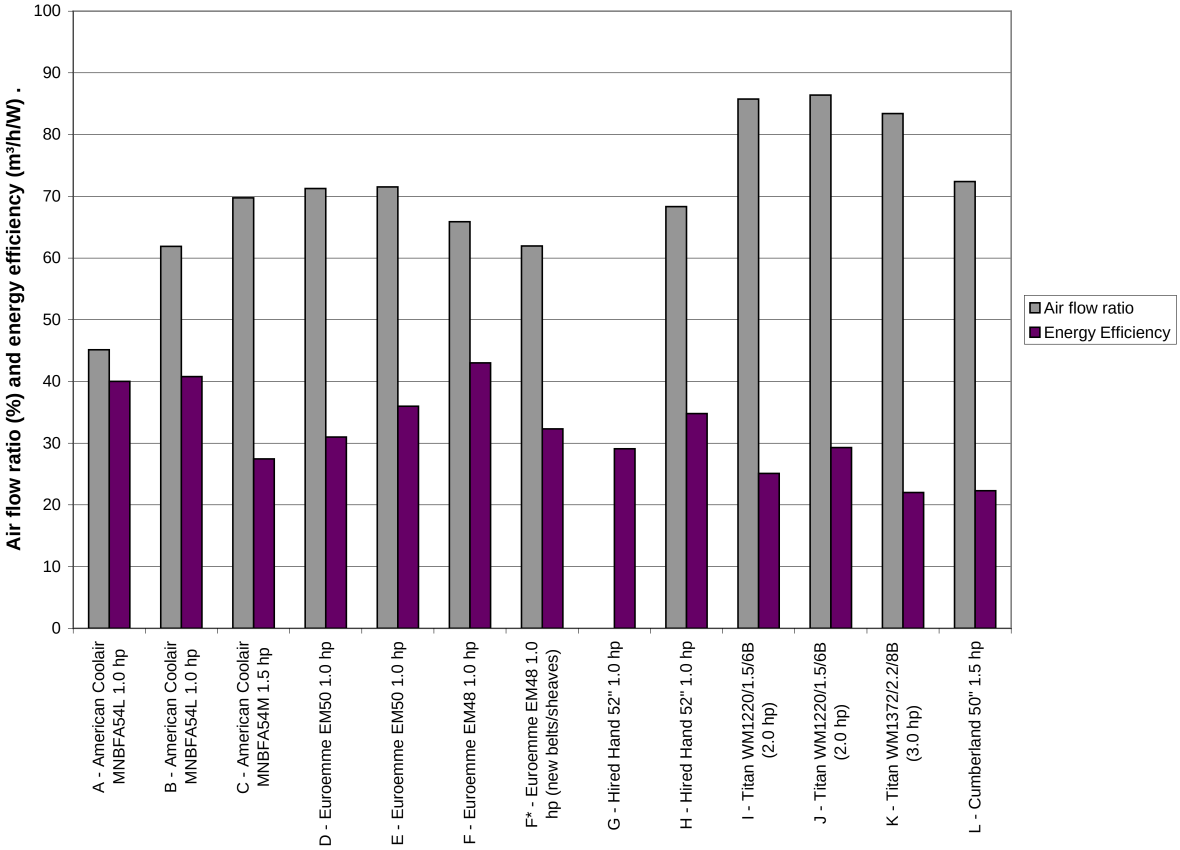


Figure 19. Air flow ratio and energy efficiency measured on-farm

The relative consistency of measurements for similar fans is an indication that the methods used are appropriate for the purpose of checking the ongoing performance and efficiency of fans installed in meat chicken sheds. However, the precision and repeatability of the in-shed methods are in no way comparable to the exacting requirements of test laboratory methods.

The majority of the fans assessed in-shed were 8–14 years old but their performance and efficiency were similar to new fan models still available for purchase. Despite their age and thousands of hours of use, and based on limited data, there did not seem to be a substantial and systematic reduction of air flow capacity or energy efficiency when compared to the performance test data for the new fans. Some fans had maintenance issues or worn components that demonstrated sub-standard performance that could be improved with appropriate servicing. Overall, the performance of these older fans is a good demonstration that fans do not perform worse with age and it is unlikely that fans will require replacement at some specified age due to a trend of decreasing performance.

Implications

Compiling fan energy efficiency and performance data

Challenges obtaining relevant, accurate and trustworthy fan performance and efficiency data from multiple fan suppliers may make it too difficult for Australian meat chicken producers to make informed decisions about which fan will be the most suitable and cost effective for their situation.

If meat chicken producers were able to more easily select the most efficient and cost effective fans for their situation, farm electricity costs and industry wide energy usage would be reduced.

Energy efficiency of fans available on the Australian market

The majority of ventilation fans available in Australia for meat chicken farms have an energy efficiency rated as 'poor' using the rating system described in this report—61% of fans had energy efficiency less than 32.3 $m^3/h/W$. Approximately 18% of fans had 'excellent' energy efficiency (i.e. greater than 35.7 $m^3/h/W$). This means that meat chicken producers who are looking to purchase new fans have the opportunity to select a fan that may be substantially more efficient than others.

The selection of one of the most energy efficient fans could potentially save up to $30,000 per shed in electricity costs in the first 10 years of operation (based on the scenario used in this report). Specific cost savings for a particular fan type and situation can be estimated using the '*Tunnel Ventilation Fan Comparison Spreadsheet*' available from the RIRDC website.

The cost of replacing inefficient fans will, in general, outweigh the potential electricity cost savings associated with more energy efficient fans. Producers have one opportunity to select the most energy and cost effective fan for their situation, so they need to get it right the first time.

On-farm measurement of fan air flow and energy efficiency

Measuring fan airflow requires the purchase of an air speed meter and approximately 15–20 minutes per fan (following a warm-up period and establishing appropriate test conditions, e.g. setting static pressure to 25 Pa). To measure the air flow rate through all fans in a shed may take 2–6 hours depending on the number of fans in the shed. The benefits of routinely measuring air flow rate are questionable. Fans that have the shutters and grills regularly cleaned and drive belts regularly maintained are likely to perform in a similar way to when they were new. Drive belt and sheave wear (or adjustment issues) can readily be detected with a tachometer used to measure blade rotational speed—this test takes only 10–30 seconds per fan. One thing to consider regarding belt wear is that using worn belts/sheaves may make a fan more energy efficient (Czarick, 2010; Lawrence Berkeley National Laboratory and Resource Dynamics Corporation, 2003); however fan air flow rate and ability to move air at higher pressure will be reduced potentially leading to inadequate shed ventilation capacity.

Measurement of air flow rate and energy efficiency may be a useful activity for chicken meat farms considering installing a new type of poultry fan and have no information about the performance or efficiency of the fans already in their shed. For this purpose, investing in the purchase of a static pressure meter (~$200), anemometer (air speed meter, ~$200–300), thee phase power meter (~$350) and a few hours of an electrician's time may be considered reasonable. After measuring fan performance, the data can be inputted into the '*Tunnel Ventilation Fan Comparison Spreadsheet*' available from the RIRDC website, and compared against the expected performance of new fan models.

Recommendations

Database for current fan performance data

Fan performance and efficiency data included in this report will become outdated as new fan models are developed and current fan models are improved. A central database would simplify the process for meat chicken growers to collate data for multiple fans from different suppliers. Fan suppliers should be encouraged to present their fan data in an appropriate format to import into the '*Tunnel Ventilation Fan Comparison Spreadsheet*' available from the RIRDC website, and supply actual test reports to inform customers of the fan configuration and test conditions underlying their data.

Selecting efficient poultry fans

Meat chicken growers have only one opportunity to select the most efficient and cost effective fan that is suitable for their situation. Selecting an inefficient fan will cost many thousands of dollars in extra electrical power over the life of the fan.

Growers should pick the most energy efficient fan that suits their situation. This does not necessarily mean picking the most energy efficient fan on the market because it may not suit their particular situation. Factors such as construction quality; warranty; local dealer reputation; after sales parts and support; and previous experiences need to be considered. **A more energy efficient fan may cost more to purchase; however, it is likely that savings in electrical power will more than pay back the original investment.**

From an industry view point, growers should be encouraged to install energy efficient fans in new sheds to reduce the chicken meat industry's total power usage and associated carbon footprint.

Measuring fan performance and efficiency in meat chicken sheds

Meat chicken growers should be encouraged to measure fan air flow and power consumption (using a licensed electrician) if they need that data for a specific purpose. In which case, the methods described in this report should be followed:

- Attachment of a temporary inlet cowling;
- Measure the static pressure across the fans;
- Use a 36 point sampling array on the inlet side of the fan;
- Measure air speed with an anemometer;
- Use a three phase power meter.

To check the ongoing operation of fans, a tachometer (purchase cost $25–100) should be used to measure fan rotational speed (RPM). This test should be repeated regularly using the same conditions, especially shed static pressure, and the values should be recorded as a reference for future measurements. Without a historical record of fan RPM, it may be difficult to identify if a fan's performance has decreased over time. These methods have been described in detail in a complementary report: '*How to' guide for measuring fan performance and efficiency in meat chicken sheds*, which is available from the RIRDC website (RIRDC publication no. 15/035).

Recommendations for further work

A guide should be published to assist meat chicken growers to identify the design features or operating practices in their sheds that increase static pressure and subsequently reduce the performance and efficiency of their ventilation fans. With this extra information, growers will have a single reference on how to identify and measure the airflow and ventilation dynamics within their sheds.

Glossary and Abbreviations

air flow rate	The volume of air that a fan moves in a given time period. Units commonly used are cubic metres per hour (m^3/h); or cubic feet per minute (CFM) if using imperial units.
air flow ratio	This is a value that helps to define how well a fan's performance is maintained as the static pressure increases. The air flow ratio is calculated by dividing the air flow rate at 50 Pa by the air flow rate at 12.5 Pa static pressure.
Anemometer	An instrument used to measure air speed.
cfm	Cubic feet per minute – volumetric air flow rate through a fan. This is the number of cubic feet of air a fan will move in a minute. 1 cfm = 1.699 m^3/h
fan efficiency	The air flow rate (m^3/h) that a fan will move with one watt of electrical power. Alternatively, it is the total volume of air that is moved by one unit of electrical energy (W·h for m^3/h or W·minute for cfm). Units of efficiency are cubic metres per hour per watt ($m^3/h/W$) or cubic feet per minute per watt (cfm/W) if using imperial units).
fan performance	General term referring to *air flow rate*, *energy efficiency* and *air flow ratio* of a fan at specified operating conditions (especially static pressure)
FANS	Fans Assessment Numeration System – a specialised anemometer array used to measure air flow through large diameter axial fans in-situ. It is commonly used by researchers in the United States.
m^3/h	Cubic metres per hour – volumetric air flow rate through a fan. This is the number of cubic metres of air a fan will move in an hour time period. 1 m^3/h = 0.5886 cfm
Pa	Pascals – this is the unit of pressure. 1Pa = 0.0040 inches H_2O = 0.01 mBar 249.2 Pa = 1 inch H_2O 1 mBar = 100 Pa 12.5 Pa ≈ 0.05" H_2O 25 Pa ≈ 0.10" H_2O 37.5 Pa ≈ 0.15" H_2O 50 Pa ≈ 0.20" H_2O
rpm	Revolutions per minute. This is the rotational speed of the fan or motor.
static pressure	This is the term used to describe the pressure differential between the inlet and the outlet of the fan. Units are Pascals (Pa)
watt	The unit of electrical power. Power is the rate at which electrical energy is consumed.
watt hour	Is the total quantity of electrical energy used by a fan in one hour. This is the unit used by power meters (units W·h)

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Appendix 1. Air flow, efficiency and purchase cost for ventilation fans

Fan Model	Air flow rate (m³/h)				Energy efficiency m³/h/W @ 25 Pa	Purchase price ($ excl. GST)
	12.5 Pa	25 Pa	37.5 Pa	50 Pa		
Hired Hand 6603-7403 52" 1 hp (60hz)	46,553	43,665	40,946	37,548	35.0	$1,133
Hired Hand 6603-6527 52.5" - 1 hp Butterfly damper (60 Hz)	46,720	43,665	39,925	35,850	32.8	$1,198
Hired Hand 6603-3000 52.5" - 1.5 hp	43,665	40,605	37,038	32,790	33.0	$1,542
Hired Hand 6603-8010 54" - 1.5 hp	45,363	42,645	39,417	35,509	41.1	$1,464
Munters Euroemme EM50 - 1hp	32,978	30,786	27,713	24,365	26.5	$908
Munters Euroemme EM50 - 1.5hp	40,042	38,272	36,028	33,717	21.8	$931
Munters Euroemme EC-50 1hp (60Hz, 1 phase)	38,590	35,870	32,640	28,560	33.7	$1,101
Munters Euroemme EC-50 1.5hp	44,401	42,526	40,451	38,018	26.7	$1,121
American Coolair MNBF60M (60Hz)	49,470	46,070	41,310	34,340	31.2	$2,189
American Coolair MNBFC60M (60Hz)	54,400	50,320	44,880	36,890	33.8	$2,445
American Coolair MNBFA54L (60Hz) (1Hp)	40,236	37,655	34,690	29,998	32.6	$1,758
American Coolair MNBFA54M (60Hz) (1.5 Hp)	45,042	42,720	40,294	37,303	26.3	$1,830
American Coolair MNBFA54N (60Hz) (2Hp)	48,875	46,711	44,529	42,090	20.1	$1,892
American Coolair MNBFA48L (60Hz) (1Hp)	31,387	29,053	26,651	23,774	31.3	$1,458
American Coolair MNCFC52L (60Hz)	41,310	37,570	33,150	26,350	30.4	$1,708
American Coolair MNBCCE54L (60 Hz)	43,494	40,266	36,019	30,752	46.2	$1,888
American Coolair MNCFE52L (60Hz)	35,530	32,300	28,050	21,590	33.5	$1,470
Titan WM1000/1.1/5B (1.5 hp)	26,215	25,254	24,289	23,169	38.3	$1,200
Titan WM1000/1.5/6B (2 hp)	31,273	30,258	29,224	27,979	28.3	$1,250
Titan WM1220/0.75/5B (1 hp)	31,431	29,851	28,036	25,225	53.3	$1,350
Titan WM1220/1.1/5B (1.5 hp)	39,013	36,738	34,459	31,820	39.1	$1,410
Titan WM1220/1.5/6B (2 hp)	45,835	44,222	42,206	39,661	31.1	$1,460
Titan WM1220/2.2/8B (3 hp)	53,269	52,135	50,612	48,657	24.7	$1,540
Titan WM1372/1.5/8B (2 hp)	52,207	49,636	46,800	42,894	34.2	$1,870
Titan WM1372/2.2/8B (3 hp)	58,600	57,495	56,350	54,478	27.4	$1,950
Multifan MF130 0.75kW (50.5", 1.0hp, 3 blade)	35,400	32,100	27,200	22,500	27.3	$720
Multifan MF130 1.12 kW (50.5", 1.5 hp, 3 blade)	40,200	37,800	34,600	30,600	25.4	$720
Multifan MF130 0.75 kW (50.5", 1.0 hp, 3 blade) with CONE	38,800	35,800	32,400	28,200	30.6	$890
Multifan MF130 1.12 kW (50.5", 1.5 hp, 3 blade) with CONE	44,100	41,700	38,900	36,100	28.5	$890
Skov DB1400 1hp (60hz, 1 Phase)	33,100	30,658	28,200	24,400	26.5	$750
Skov 1400 Cone 1.5hp (3ph air flow, 1ph effic)	44,401	42,526	40,451	38,018	26.7	$900
Eurofan 36" axial fan 0.4kW - 0.75 hp (9FJ9.1)	17,556	16,735	15,113	NA	29.7	$530
Eurofan 50" axial fan 1.1kW- 1.5 hp (9FJ12.7)	41,897	40,759	39,547	36,764	25.9	$833
Eurofan 50" butterfly fan with cone 0.75kW - 1.0 hp (9FJ12.7T-4)	40,234	37,849	30,611	NA	40.6	$1,053
Eurofan 50" butterfly fan with cone 1.1 kW - 1.5 hp (9FJ12.7T-3)	48,353	46,829	45,126	42,919	27.9	$1,053
Gigola and Riccardi ES-140 R/S 1.0 hp	35,344	32,808	30,272	NA	38.6	NA
Gigola and Riccardi ES-140 R/S 1.5 hp	38,580	36,208	33,836	NA	30.2	NA
Gigola and Riccardi ES-120 R/S 1.0 hp	25,579	24,040	22,502	NA	28.3	NA

Appendix 2. Data source for the air flow and efficiency data in Appendix 1

Fan Model	Data Source
Hired Hand 6603-7403 52" 1 hp (60hz)	BESS test 02466
Hired Hand 6603-6527 52.5" - 1 hp, butterfly damper (60 Hz)	BESS test 05334
Hired Hand 6603-3000 52.5" - 1.5 hp	BESS test 07090
Hired Hand 6603-8010 54" - 1.5 hp	BESS test 08257a
Munters Euroemme EM50 - 1hp	Munters test 01078
Munters Euroemme EM50 - 1.5hp	Munters test 3031
Munters Euroemme EC-50 1hp (60Hz, 1 phase)	Munters brochure (2005)
Munters Euroemme EC-50 1.5hp	Munters test (150704)
American Coolair MNBF60M (60Hz)	BESS test 09248
American Coolair MNBFC60M (60Hz)	BESS test 09257
American Coolair MNBFA54L (60Hz) (1Hp)	American Coolair brochure (Jan 2010)
American Coolair MNBFA54M (60Hz) (1.5 Hp)	American Coolair brochure (Jan 2010)
American Coolair MNBFA54N (60Hz) (2hp)	American Coolair brochure (Jan 2010)
American Coolair MNBFA48L (60Hz) (1hp)	American Coolair brochure (Jan 2010)
American Coolair MNCFC52L (60Hz)	American Coolair brochure (Oct 2007)
American Coolair MNBCCE54L (60 Hz)	American Coolair brochure (Nov 2010)
American Coolair MNCFE52L (60Hz)	BESS test 99160
Titan WM1000/1.1/5B (1.5 hp)	Titan-direct communication
Titan WM1000/1.5/6B (2 hp)	Titan-direct communication
Titan WM1220/0.75/5B (1 hp)	Titan-direct communication
Titan WM1220/1.1/5B (1.5 hp)	Titan-direct communication
Titan WM1220/1.5/6B (2 hp)	Titan-direct communication
Titan WM1220/2.2/8B (3 hp)	Titan-direct communication
Titan WM1372/1.5/8B (2 hp)	Titan-direct communication
Titan WM1372/2.2/8B (3 hp)	Titan-direct communication
Multifan MF130 0.75kW (50.5", 1.0hp, 3 blade)	BESS test 12123
Multifan MF130 1.12 kW (50.5", 1.5 hp, 3 blade)	BESS test 12126
Multifan MF130 0.75 kW (50.5", 1.0 hp, 3 blade) with CONE	BESS test 12136
Multifan MF130 1.12 kW (50.5", 1.5 hp, 3 blade) with CONE	BESS test 12138
Skov DB1400 1hp (60hz, 1 Phase)	Munters test 01078
Skov 1400 Cone 1.5hp (3ph air flow, 1ph effic)	Munters test 150704
Eurofan 36" axial fan 0.4kW - 0.75 hp (9FJ9.1)	KEY Laboratory, China Ag. University test (tested up to 34 Pa only)
Eurofan 50" axial fan 1.1kW- 1.5 hp (9FJ12.7)	KEY Laboratory, China Ag. University test (1/12/2008) (tested up to 44 Pa only)
Eurofan 50" butterfly fan with cone 0.75kW - 1.0 hp (9FJ12.7T-4)	KEY Laboratory, China Ag. University test (30/6/2009) (tested up to 30 Pa only)
Eurofan 50" butterfly fan with cone 1.1 kW - 1.5 hp (9FJ12.7T-3)	KEY Laboratory, China Ag. University test (30/6/2009) (tested up to 44 Pa only)
Gigola and Riccardi ES-140 R/S 1.0 hp	Gigola Elostar Brochure (unknown if grills/shutters fitted or if 3 phase 50 Hz)
Gigola and Riccardi ES-140 R/S 1.5 hp	Gigola Elostar Brochure (unknown if grills/shutters fitted or if 3 phase 50 Hz)
Gigola and Riccardi ES-120 R/S 1.0 hp	Gigola Elostar Brochure (unknown if grills/shutters fitted or if 3 phase 50 Hz)

Appendix 3. Output from the ‘Tunnel Ventilation Fan Comparison Spreadsheet’

Air flow ratio and energy efficiency ratings, 10 year operating costs and fan rankings (comparing fans to each other) (colour code provided in Table 7).

Fan Model	Air Flow Ratio	Air Flow Ratio Rating	Energy Efficiency @ 25 Pa ($m^3/h/W$)	Energy Efficiency Rating	Operating costs over 10 years			Fan comparison rankings		
					Purchase $	Electrical $	Total $	Air Flow Ratio	Energy Efficiency	10 Yr Total Cost
Hired Hand 6603-7403 52" 1 hp (60hz)	0.81	Excellent	35.0	Good	12,463	41,200	53,663	16	8	3
Hired Hand 6603-6527 52.5" - 1 hp Butterfly damper (60 Hz)	0.77	Good	32.8	Min acceptable	13,181	43,900	57,082	19	14	6
Hired Hand 6603-3000 52.5" - 1.5 hp	0.75	Good	33.0	Min acceptable	18,505	44,400	62,905	22	13	15
Hired Hand 6603-8010 54" - 1.5 hp	0.78	Excellent	41.1	Outstanding	16,104	34,200	50,304	18	3	2
Munters Euroemme EM50 - 1hp	0.74	Good	26.5	Poor	14,528	55,800	70,328	24	31	28
Munters Euroemme EM50 - 1.5hp	0.84	Outstanding	21.8	Poor	11,175	63,300	74,475	11	37	34
Munters Euroemme EC-50 1hp (60Hz, 1 phase)	0.74	Good	33.7	Min acceptable	15,414	44,800	60,214	24	11	9
Munters Euroemme EC-50 1.5hp	0.86	Outstanding	26.7	Poor	12,331	52,500	64,831	8	29	19
American Coolair MNBF60M (60Hz)	0.69	Poor	31.2	Poor	24,079	48,700	72,779	29	17	32
American Coolair MNBFC60M (60Hz)	0.68	Poor	33.8	Min acceptable	24,450	44,700	69,150	30	10	26
American Coolair MNBFA54L (60Hz) (1Hp)	0.75	Good	32.6	Min acceptable	22,854	45,000	67,854	22	15	24
American Coolair MNBFA54M (60Hz) (1.5 Hp)	0.83	Outstanding	26.3	Poor	20,130	53,500	73,630	12	33	33
American Coolair MNBFA54N (60Hz) (2Hp)	0.86	Outstanding	20.1	Poor	18,920	69,700	88,620	8	38	35
American Coolair MNBFA48L (60Hz) (1Hp)	0.76	Good	31.3	Poor	24,786	47,300	72,086	20	16	31
American Coolair MNCFC52L (60Hz)	0.64	Poor	30.4	Poor	22,204	48,200	70,404	31	20	29
American Coolair MNBCCE54L (60 Hz)	0.71	Min acceptable	46.2	Outstanding	22,656	31,400	54,056	28	2	4
American Coolair MNCFE52L (60Hz)	0.61	Poor	33.5	Min acceptable	23,520	46,300	69,820	33	12	27
Titan WM1000/1.1/5B (1.5 hp)	0.88	Outstanding	38.3	Outstanding	21,600	35,600	57,200	5	7	7
Titan WM1000/1.5/6B (2 hp)	0.89	Outstanding	28.3	Poor	18,750	48,100	66,850	3	25	21
Titan WM1220/0.75/5B (1 hp)	0.8	Excellent	53.3	Outstanding	21,600	26,900	48,500	17	1	1
Titan WM1220/1.1/5B (1.5 hp)	0.82	Excellent	39.1	Outstanding	18,330	36,700	55,030	13	5	5
Titan WM1220/1.5/6B (2 hp)	0.87	Outstanding	31.1	Poor	16,060	46,900	62,960	7	18	16
Titan WM1220/2.2/8B (3 hp)	0.91	Outstanding	24.7	Poor	13,860	57,000	70,860	2	35	30
Titan WM1372/1.5/8B (2 hp)	0.82	Excellent	34.2	Good	18,700	43,500	62,200	13	9	13
Titan WM1372/2.2/8B (3 hp)	0.93	Outstanding	27.4	Poor	15,600	50,400	66,000	1	27	20
Multifan MF130 0.75kW (50.5", 1.0hp, 3 blade)	0.64	Poor	27.3	Poor	11,520	56,400	67,920	31	28	25
Multifan MF130 1.12 kW (50.5", 1.5 hp, 3 blade)	0.76	Good	25.4	Poor	9,360	58,000	67,360	20	35	22
Multifan MF130 0.75 kW (50.5", 1.0 hp, 3 blade) with cone	0.73	Good	30.6	Poor	10,080	49,100	59,180	27	19	12
Multifan MF130 1.12 kW (50".5, 1.5 hp, 3 blade) with cone	0.82	Excellent	28.5	Poor	8,640	52,700	61,340	13	23	17
Skov DB1400 1hp (60hz, 1 Phase)	0.74	Good	26.5	Poor	12,000	55,500	67,500	24	31	23
Skov 1400 Cone 1.5hp (3ph airflow, 1ph effic)	0.86	Outstanding	26.7	Poor	9,900	52,500	62,400	8	29	14
Eurofan 36" axial fan 0.4kW - 0.75hp 6 blade (9FJ9.1)	NA	NA	29.7	Poor	15,370	49,100	64,470	NA	22	18
Eurofan 50" axial fan 1.1kW - 1.5 hp, 6 blades (9FJ12.7)	0.88	Outstanding	25.9	Poor	9,163	51,900	61,063	5	34	11
Eurofan 50" butterfly fan - cone 0.75kW - 1.0 hp, 3 bl (9FJ12.7T-4)	NA	NA	40.6	Outstanding	15,795	42,000	57,795	NA	4	8
Eurofan 50" butterfly fan - cone 1.1 kW - 1.5 hp, 6 bl (9FJ12.7T-3)	0.89	Outstanding	27.9	Poor	10,530	50,300	60,830	3	26	10
Gigola and Riccardi ES-140 R/S 1.0 hp	NA	NA	38.6	Outstanding	NA	38,200	NA	NA	6	NA
Gigola and Riccardi ES-140 R/S 1.5 hp	NA	NA	30.2	Poor	NA	46,800	NA	NA	21	NA
Gigola and Riccardi ES-120 R/S 1.0 hp	NA	NA	28.3	Poor	NA	51,000	NA	NA	24	NA

NA=Not available

Appendix 4. Process calculations from the ‘Tunnel Ventilation Fan Comparison Spreadsheet’

Calculated required number of fans for the scenario described in Table 2 and resulting ventilation rate, fan running costs and shed airspeed

Fan Model	Design Static Pressure	Fan Performance (m³/h)	Number of Fans Required	Total ventilation rate (m³/h)	Fan running cost ($ per annum)	Average shed air speed (m/s)
Hired Hand 6603-7403 52" 1 hp (60hz)	37.5	40,946	11	450,400	4120	3.15
Hired Hand 6603-6527 52.5" - 1 hp Butterfly damper (60 Hz)	37.5	39,925	11	439,200	4390	3.07
Hired Hand 6603-3000 52.5" - 1.5 hp	37.5	37,038	12	444,500	4440	3.10
Hired Hand 6603-8010 54" - 1.5 hp	37.5	39,417	11	433,600	3420	3.03
Munters Euroemme EM50 - 1hp	37.5	27,713	16	443,400	5580	3.10
Munters Euroemme EM50 - 1.5hp	37.5	36,028	12	432,300	6330	3.02
Munters Euroemme EC-50 1hp (60Hz, 1 phase)	37.5	32,640	14	457,000	4480	3.19
Munters Euroemme EC-50 1.5hp	37.5	40,451	11	445,000	5250	3.11
American Coolair MNBF60M (60Hz)	37.5	41,310	11	454,400	4870	3.17
American Coolair MNBFC60M (60Hz)	37.5	44,880	10	448,800	4470	3.13
American Coolair MNBFA54L (60Hz) (1Hp)	37.5	34,690	13	451,000	4500	3.15
American Coolair MNBFA54M (60Hz) (1.5 Hp)	37.5	40,294	11	443,200	5350	3.09
American Coolair MNBFA54N (60Hz) (2Hp)	37.5	44,529	10	445,300	6970	3.11
American Coolair MNBFA48L (60Hz) (1Hp)	37.5	26,651	17	453,100	4730	3.16
American Coolair MNCFC52L (60Hz)	37.5	33,150	13	431,000	4820	3.01
American Coolair MNBCCE54L (60 Hz)	37.5	36,019	12	432,200	3140	3.02
American Coolair MNCFE52L (60Hz)	37.5	28,050	16	448,800	4630	3.13
Titan WM1000/1.1/5B (1.5 hp)	37.5	24,289	18	437,200	3560	3.05
Titan WM1000/1.5/6B (2 hp)	37.5	29,224	15	438,400	4810	3.06
Titan WM1220/0.75/5B (1 hp)	37.5	28,036	16	448,600	2690	3.13
Titan WM1220/1.1/5B (1.5 hp)	37.5	34,459	13	448,000	3670	3.13
Titan WM1220/1.5/6B (2 hp)	37.5	42,206	11	464,300	4690	3.24
Titan WM1220/2.2/8B (3 hp)	37.5	50,612	9	455,500	5700	3.18
Titan WM1372/1.5/8B (2 hp)	37.5	46,800	10	468,000	4350	3.27
Titan WM1372/2.2/8B (3 hp)	37.5	56,350	8	450,800	5040	3.15
Multifan MF130 0.75kW (50.5", 1.0hp, 3 blade)	37.5	27,200	16	435,200	5640	3.04
Multifan MF130 1.12 kW (50.5", 1.5 hp, 3 blade)	37.5	34,600	13	449,800	5800	3.14
Multifan MF130 0.75 kW (50.5", 1.0 hp, 3 blade) with CONE	37.5	32,400	14	453,600	4910	3.17
Multifan MF130 1.12 kW (50.5", 1.5 hp, 3 blade) with CONE	37.5	38,900	12	466,800	5270	3.26
Skov DB1400 1hp (60hz, 1 Phase)	37.5	28,200	16	451,200	5550	3.15
Skov 1400 Cone 1.5hp (3ph airflow, 1ph effic)	37.5	40,451	11	445,000	5250	3.11
Eurofan 36" axial fan 0.4kW - 0.75hp 6 blade (9FJ9.1)	37.5	15,113	29	438,300	4910	3.06
Eurofan 50" axial fan 1.1kW - 1.5 hp, 6 blades (9FJ12.7)	37.5	39,547	11	435,000	5190	3.04
Eurofan 50" butterfly fan with cone 0.75kW - 1.0 hp, 3 blade (9FJ12.7T-4)	37.5	30,611	15	459,200	4200	3.21
Eurofan 50" butterfly fan with cone 1.1 kW - 1.5 hp, 6 blades (9FJ12.7T-3)	37.5	45,126	10	451,300	5030	3.15
Gigola and Riccardi ES-140 R/S 1.0 hp	37.5	30,272	15	454,100	3820	3.17
Gigola and Riccardi ES-140 R/S 1.5 hp	37.5	33,836	13	439,900	4680	3.07
Gigola and Riccardi ES-120 R/S 1.0 hp	37.5	22,502	20	450,000	5100	3.14

Appendix 5. On-farm measurement of air flow and energy efficiency for fans

Fan Model	Air flow rate (m³/h)				Energy Efficiency at 25 Pa m³/h per watt
	12.5 Pa	25 Pa	37.5 Pa	50 Pa	
American Coolair MNBFA54L 1.0 hp	37619	33281	26403	16984	40.0
American Coolair MNBFA54L 1.0 hp	37039	32999	28292	22918	40.8
American Coolair MNBFA54M 1.5 hp	39785	38239	34226	27745	27.5
Euroemme EM50 1.0 hp	34212	28970	25692	24379	31.0
Euroemme EM50 1.0 hp	35040	31794	28468	25062	36.0
Euroemme EM48 1.0 hp	35279	32286	28274	23242	43.0
Euroemme EM48 1.0 hp (new belts and pulleys fitted)	24735	22526	19390	15326	32.3
Hired Hand 52" 1.0 hp	37747	34120	30493	26866	29.1
Hired Hand 52" 1.0 hp	36988	33088	29183	25272	34.8
Titan WM1220/1.5/6B (2.0 hp)	45376	43673	41521	38921	25.1
Titan WM1220/1.5/6B (2.0 hp)	31789	30502	29063	27471	29.3
Titan WM1372/2.2/8B (3.0 hp)	46479	43363	40792	38765	22.0

Note: Airflow values in shaded cells were derived from polynomial regressions

Appendix 6. Output from the '*Tunnel Ventilation Fan Comparison Spreadsheet*' (on-farm measurements)

Air flow ratio and energy efficiency ratings, 10 year operating costs and fan rankings (comparing fans to each other) (colour code provided in Table 7).

Fan Model	Air Flow Ratio	Air Flow Ratio Rating	Energy Efficiency @ 25 Pa ($m^3/h/W$)	Energy Efficiency Rating	Operating costs over 10 years			Fan comparison rankings		
					Purchase $	Electrical $	Total $	Air Flow Ratio	Energy Efficiency	10 Yr Total Cost
American Coolair MNBFA54L 1.0 hp	0.45	Poor	40	Outstanding	29886	42400	72286	13	3	7
American Coolair MNBFA54L 1.0 hp	0.62	Poor	40.8	Outstanding	28128	38800	66928	11	2	4
American Coolair MNBFA54M 1.5 hp	0.7	Min acceptable	27.5	Poor	24544	54300	78844	8	10	9
Euroemme EM50 1.0 hp	0.71	Min acceptable	31	Poor	15436	47700	63136	6	7	3
Euroemme EM50 1.0 hp	0.72	Min acceptable	36	Excellent	14528	42400	56928	4	4	1
Euroemme EM48 1.0 hp	0.66	Poor	43	Outstanding		36000		10	1	
Euroemme EM48 1.0 hp (new belts and pulleys fitted)	0.62	Poor	32.3	Min acceptable		48100		11	6	
Hired Hand 52" 1.0 hp	0.71	Min acceptable	29.1	Poor	16995	52800	69795	6	9	6
Hired Hand 52" 1.0 hp	0.68	Poor	34.8	Good	16995	42800	59795	9	5	2
Titan WM1220/1.5/6B (2.0 hp)	0.86	Outstanding	25.1	Poor	16060	57400	73460	1	11	8
Titan WM1220/1.5/6B (2.0 hp)	0.86	Outstanding	29.3	Poor	21900	46800	68700	1	8	5
Titan WM1372/2.2/8B (3.0 hp)	0.83	Outstanding	22	Poor	21450	65000	86450	3	13	10
Cumberland 50" 1.5 hp	0.72	Min acceptable	22.3	Poor		67500		4	12	

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By Mark Dunlop and Grant Brown

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RURAL INDUSTRIES
Research & Development Corporation

Phone: 02 6271 4100

Fax: 02 6271 4199

Bookshop: 1300 634 313

Email: rirdc@rirdc.gov.au

Postal Address: PO Box 4776,
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