Variable-speed exhaust fans
for meat chicken sheds

by Grant Brown
August 2018

AgriFutures™
Chicken Meat

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Foreword

On-farm energy consumption is a significant consideration for meat chicken growers in Australia. With rising energy prices, the need to invest in new technologies and methods to reduce power consumption is paramount.

Research has shown that one of the largest expenses for meat chicken growers is the electricity consumed by exhaust fans on mechanically ventilated sheds. Minimising power usage and reducing energy costs is a priority. One energy saving technology that has recently become available to the chicken meat industry is direct-drive, variable-speed fans. These operate at slower rotational speeds during times of low ventilation requirement, and at those times use less power than conventional belt-driven, single-speed fans.

This study investigates the potential energy savings that may be achieved with variable-speed fans. Combining fan performance data with real-world fan activity data revealed that fans only needed to be operated at maximum speed for a small fraction of the time, with the majority of the year being operated at reduced speeds. This results in substantial energy saving for sheds fitted with variable-speed fans. This research also demonstrated that there are benefits in having more variable-speed fans installed on a shed because it results in lower overall power consumption.

Variable-speed fans offer substantial advantages for meat chicken growers over traditional fixed speed fans, even though the initial purchase price may be dearer. Meat chicken growers who are considering purchasing fans for a new shed should consider installing variable-speed fans to achieve long-term energy and cost savings.

This project was funded from industry revenue, which was matched by funds provided by the Australian Government. This report is an addition to AgriFutures Australia's diverse range of over 2000 research publications and it forms part of our Chicken Meat RD&E program, which aims to stimulate and promote RD&E that will deliver a productive and sustainable Australian chicken meat industry that provides quality wholesome food to the nation.

Most of AgriFutures Australia's publications are available for viewing, free downloading or purchasing online at www.agrifutures.com.au.

John Harvey
Managing Director
AgriFutures Australia

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Abbreviations

kW	Kilowatt. A metric unit of power. 1kW = 1.34102 hp
kW.h	Kilowatt-hours. A unit commonly used as a billing unit for energy delivered to a consumer. Usually the energy delivered is at a constant rate over a period of time, i.e. kilowatt (energy) hours (time)
kVA	Kilovolt amperes. A unit commonly used to measure the apparent power of a system
kVAr	Kilovolt amperes-reactive. A unit used to represent the reactive power of an electrical system
m^3/h	Cubic metres per hour. A metric unit of airflow. Amount of air moved (m^3) in a given amount of time (h). 1 m^3/h = 0.588578 cfm
$m^3/h/watt$	Cubic metres per hour per watt. A unit of efficiency. Amount of air moved (m^3) in a given time (h) for a given amount of power (watts)
Pa	Pascals. A metric unit of pressure. 1 Pa = 0.00402 in.H_2O = 0.102 mm.H_2O
rpm	Revolutions per minute, a unit of rotational speed

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Executive Summary

What the report is about

Mechanically ventilated meat chicken sheds use electrically powered exhaust fans to control the in-shed environment. Studies have shown that one of the biggest on-farm expenses is the power consumed by the exhaust fans (McGahan et al., 2012). With power costs expected to continue rising, it is important to investigate methods and technologies that may reduce the power consumed by these fans. One emerging technology starting to be used by Australian meat chicken growers is direct-drive, variable-speed fans, which are fans that have the ability to operate at a range of different speeds. Variable-speed fans are expected to provide producers with substantial savings on power consumption.

This report builds on previous research funded by AgriFutures Australia into reducing costs from mechanically ventilated meat chicken sheds (Brown, 2015). It describes the underlying theory behind how variable-speed fans work and why they can lead to power savings when used in the correct manner. This report also uses data that was collected during a previous AgriFutures Australia project (Dunlop & Duperouzel, 2014) to estimate real-world costs and savings associated with using different models of variable-speed fans and how they compare with some currently available single-speed fans. This report also describes how the demand for airflow, and consequently power consumption, changes throughout a batch and how using variable-speed fans correctly can lead to considerable savings on energy costs year-round.

Who is the report targeted at?

This report is primarily aimed at meat chicken growers in Australia that operate mechanically ventilated sheds, or are considering converting to mechanical ventilation. The report contains information on:

- how variable-speed fans work
- how they differ to traditional single-speed fans
- how using variable-speed fans can provide energy savings for meat chicken growers
- how power consumption and airflow demand change throughout a typical grow-out cycle.

All of this information is of use to meat chicken growers in Australia who are considering using variable-speed fans.

Where are the relevant industries located in Australia?

The Australian chicken meat industry involves the participation of around 700 growers and 40,000 employees. Chicken meat production occurs in all Australian states, and typically in close proximity to major metropolitan centres. According to Australian Bureau of Agricultural and Resource Economics, chicken meat currently makes up 25% of meat production in Australia, and that is expected to rise to 28% by 2018–19.

Background

The biggest source of power consumption comes from using the exhaust fans to control the in-shed temperature. With rising electricity prices, it is important for Australian meat chicken growers to consider power saving technologies and methods. By switching to variable-speed fans, in-place of traditional single-speed fans, meat chicken growers may be able to reduce operating costs and become more resilient to rising energy prices.

Fan laws dictate that airflow is roughly proportional to a fan's rotational speed. Therefore reducing fan speed will reduce the airflow by roughly the same amount. However, reducing fan speed results in an exponential decrease in power consumption. Therefore a small drop in speed/airflow can result in a large drop in power consumption. It is this principle that enables variable-speed fans to provide energy savings when used on a meat chicken shed.

Aims/objectives

The overall objective of this project is to quantify the potential energy savings associated with direct-drive, variable-speed ventilation fans.

Methods used

Previously collected data on fan activity and internal shed static pressures (Dunlop & Duperouzel, 2014) was used to determine the airflow requirements of meat chicken sheds and fan operating hours. This data was combined with fan performance data from the manufacturer, and independent performance tests, to calculate power consumption by the fans during a grow-out cycle. This allowed different scenarios to be investigated and for various fan models to be compared with one another. Economic calculations were made using an estimate of $0.16/kW.h as a flat rate charge for electricity. This may not reflect power charges for individual farms, which are charged differently based on a number of factors. The economic estimations made in this report are for comparative purposes and are designed to show the difference between single-speed fans and variable-speed fans based on simplified electricity calculations.

Results/key findings

- Variable-speed fans, when used correctly, can substantially reduce energy costs on meat chicken farms.
- There can be as much as 7000 kW.h difference between the energy used per shed by a high-efficiency single-speed fan and the most efficient variable-speed fan.
- Approximately 25–30% of the power used by the fans occurs in the final 7 days of the grow-out cycle. We calculated that during a 56 day grow-out cycle, 30% of the power used is consumed between day 49 and day 56, and in a 49 day grow-out cycle, 25% of power is consumed between day 42 and 49.
- Power consumption is reduced by approximately 55% when a fans rotational speed is reduced by 30%.
- Fans are required to operate in 'full-tunnel' mode for less than 10% of the year. This means that for a shed with variable-speed fans installed, over 90% of the year the fans can be operated at reduced speed, and therefore reduced energy consumption.
- Minimum ventilation situations are the cause for the biggest difference in power consumption between single-speed fans and variable-speed fans.
- By installing more variable-speed fans on a shed, the power consumption is actually less than having fewer fans, which need to operate for longer at higher rotational speed.
- Calculations indicate variable speed fans can save more than $3000 per grow-out cycle if upgrading from poor performing fans.
- In terms of payback periods for installing variable speed fans, this is very shed specific and largely depends on what models of fan are currently installed.
- Example scenarios in this report suggest payback periods could be 2 to 7 years depending on currently installed fans.

Implications for relevant stakeholders

- Switching to variable speed exhaust fans could be a source of substantial energy savings for the chicken meat industry. The ability of these fans to operate at reduced speeds decreases the energy costs associated with cooling the birds in both winter and summer.
- Variable-speed fans are most likely the future direction for exhaust fans on meat chicken sheds, the high initial purchase cost is made up for in substantially lower running costs.
- With more farms being charged for kVA rather than kW, fan motors with a high power-factor (such as variable-speed fans) will be more appealing to growers being charged in this manner.

Recommendations

- Growers who are building new sheds should consider installing variable-speed fans as the running costs appear to be much lower than ‘high-efficiency’ single-speed fans.
- Growers should install sufficient fans to enable the fans to run at lower rotational speed in order to maximise the energy savings.
- We recommend future research to undertake monitoring of fan activity and power consumption on meat chicken sheds to confirm the findings of this desk-top study. Ideally, this monitoring would be conducted using identical sheds on the same farm, one with single-speed fans one with variable-speed fans.

Introduction

Mechanically ventilated meat chicken sheds rely on exhaust fans to control the in-shed environment. These fans operate year-round and are the main source of electricity consumption, and therefore the biggest expense, on meat chicken farms. With electricity prices forecasted to increase over the coming years, meat chicken farms will need to be more resilient to increasing production costs. One way to reduce production costs is to use the most efficient ventilation fans that are available, i.e. the fans that move the most amount of air, for the least amount of power. Some of the most efficient ventilation fans available are variable-speed fans (Czarick & Fairchild, 2017).

The relationship between fan rotational speed, airflow, and power consumption is governed by universal fan-laws (AMCA, 2016):

- The air moving capacity of a fan is roughly proportional to the rotational speed (rpm) at which the fan operates.
- The amount of energy a fan uses increases exponentially with increasing speed.

For example, by increasing a fans rotational speed by 10%, airflow would be expected to increase by about 10%, but the fan would use about 30% more power. The reverse of this is also true. By reducing a fans rotational speed by 10%, only a 10% reduction in airflow would be experienced, but the fan would use 30% less power.

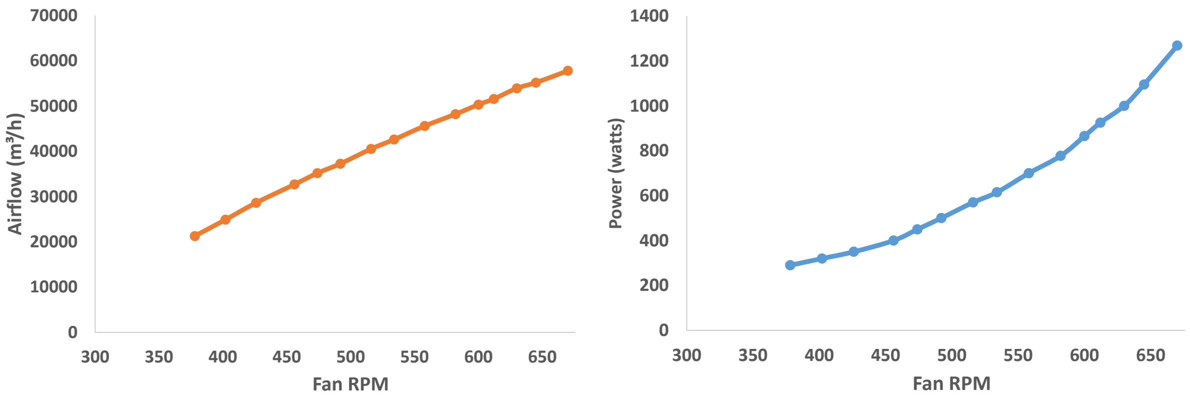

Figure 1: The linear relationship (left) between fan speed and airflow; and the exponential relationship (right) between fan speed and power usage.

This is why fans that have variable speed capabilities can be significantly more efficient than single-speed fans, at least when they are being operated at lower rpm. Variable-speed fans have the ability to reduce the speed of the fan blades, and therefore experience a small drop in the amount of air moved, but a larger reduction in the amount of power required.

An addition benefit of variable-speed fan technology is the very high 'power-factor' associated with variable-speed fans (ANSI, 2011). Power-factor is essentially a measure of the electrical efficiency in a motor, the higher the power-factor, the more effective the motor is at converting electrical power into motion (Brumbach, 2001). With more Australian meat chicken growers being charged for power in terms of kVA (kilovolt amperes) as opposed to kW (kilowatts), having higher power-factor motors on exhaust fans may lead to additional savings on power.

In simple terms, kVA is a measure of the apparent or total power of an electrical motor. Whereas kW, known as actual or active power, is the amount of power that is actually converted into useful motion. In a 100% efficient motor all of the apparent power is converted into motion i.e. kVA = kW. However, electrical motors and systems are never 100% efficient so not all of the power is converted into useful output. The efficiency of a motor to convert kVA into kW is known as its ‘power-factor’ and is labelled as a number between 0 and 1 with 1 being considered 100% efficient.

Figures 2 and 3 below explain how power-factor, in this case the angle of the triangle, affects the relationship between kVA and kW. The length of the sides of the triangle represent how much power is in each aspect, the closer the sides are to being equal in length, the closer they are to having the same amount of power.

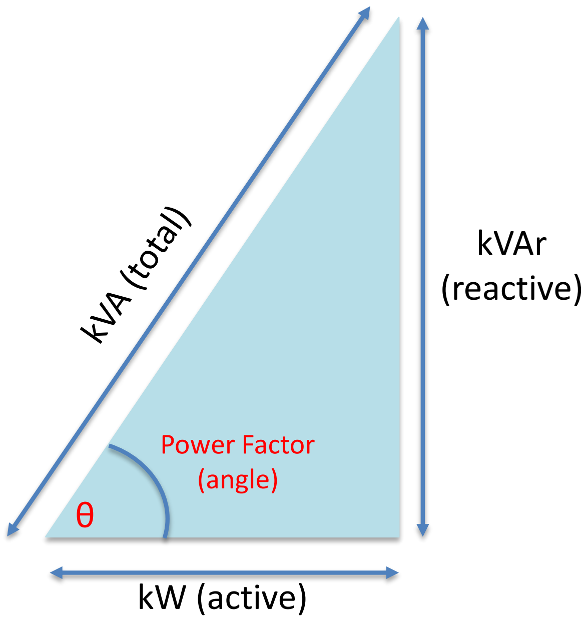

Figure 2: Power-factor relationship for single speed AC fans. The higher the angle (θ) the lower the power-factor. Note the difference in the length of the active power side compared to the total power side of the triangle.

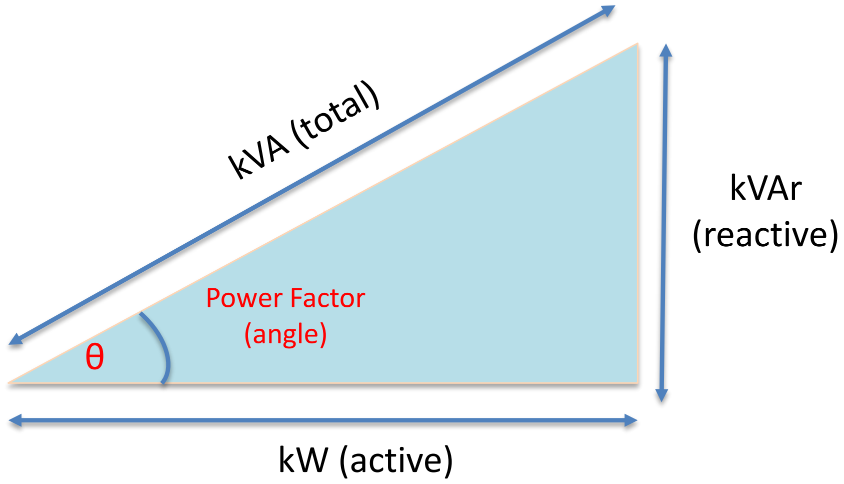

Figure 3 : Power-factor relationship for variable-speed fans. The lower angle (θ) translates to a higher power factor. This means that active power and total power on the triangle are much closer in length. Therefore a motor with a higher power-factor (lower angle) is more efficient.

With more Australian growers being charged for kVA, having high power-factor motors, such as those found on variable-speed fans, can lead to further savings on power bills.

Objectives

The overall objective of this project is to use fan performance test data and previously measured fan activity data to quantify the potential energy savings associated with direct-drive variable speed ventilation fans.

Methodology

Performance and efficiency data was compiled from a number of variable speed fan manufacturers and suppliers for the Australian market. The data was then combined with real-world fan activity data, which was collected in a previous AgriFutures project (Dunlop & Duperouzel, 2014), in order to assess the relative performance of variable speed fans for meat chicken sheds. The fan activity data was recorded over a 12 month period for 5 meat chicken sheds around Australia in 2006—located in south-eastern Queensland, central coast and New England Tableland New South Wales; and in southern Victoria. Having data from a number of states in Australia also allowed for comparison of variable speed fan viability in these states to determine if colder climates (such as in Victoria) favoured the performance of variable speed fans, over the warmer temperatures experienced in Queensland.
Data for these sheds was recorded every 15 minutes and included monitoring how many fans were active, the status of the mini-vents, the static pressure in the shed, and a number of other parameters. This data, along with the performance data of the installed fans, was then used to determine the airflow requirements for any time during the batch. Once this was calculated, the performance data for the installed fans could be substituted with the performance data of a variable speed fan to determine how the variable speed fan may have performed if it was installed on this shed. This formed the basis for the calculations used in this project.

Assessing performance of variable speed fans

Determining the performance of variable speed fans is not as straight forward as assessing traditional single speed fans, as each operational speed effectively needs to be treated as a separate fan. Once the performance for each speed is known, this needs to be combined together to give an overall performance curve for all the operational speeds of the fan. To achieve this for each fan type in this report, a general asymptotic regression model was fitted using GenStat (2016). Airflow was a nonlinear function of rpm and static pressure and is represented by the following equation.

Equation 1:

$$Airflow = (a + b \times RPM + c \times RPM^2) + (d + e \times RPM + f \times RPM^2) \times ((g + h \times RPM)^{Static\ Pressure})$$

Where 'a' through to 'h' are the empirically-fitted coefficients

This equation allows for the calculation of airflow from the variable speed fan at any rpm. See Appendix A for full equations.

It should also be noted that several assumptions about how the variable speed fans operate and how long each stage was active for needed to be made. These assumptions were based on monitored fan activity data, but as each shed is different, the specifics of how often each speed of the variable speed fan is operated will differ and actual real world performance may be better than the scenarios presented in this report. The overall idea of using variable speed fans is to operate as many fans as possible at the slowest speed to achieve airflow. This approach will ensure maximum efficiency from the variable speed fans.

Assessing the economics of variable speed fans using the spreadsheet

To assist in calculating the potential economic benefits associated with replacing ventilation fans, the use of an interactive spreadsheet was implemented. This spreadsheet is a modified version of a spreadsheet developed for a previous AgriFutures project (Brown, 2015) which allowed for the comparison of different fan models in Australia. This was based on a spreadsheet created by the University of Georgia (Czarick, 2008).

For the purposes of this project, the spreadsheet was further modified to allow for the comparison of variable speed fans. The focus of the spreadsheet is to estimate the costs associated with purchasing and running ventilation fans on meat chicken sheds in Australia. It allows for the comparison of performance and efficiency of single speed and variable speed fans available to the Australian market and helps determine which model may be the most economically viable for sheds of different dimensions and airflow requirements.

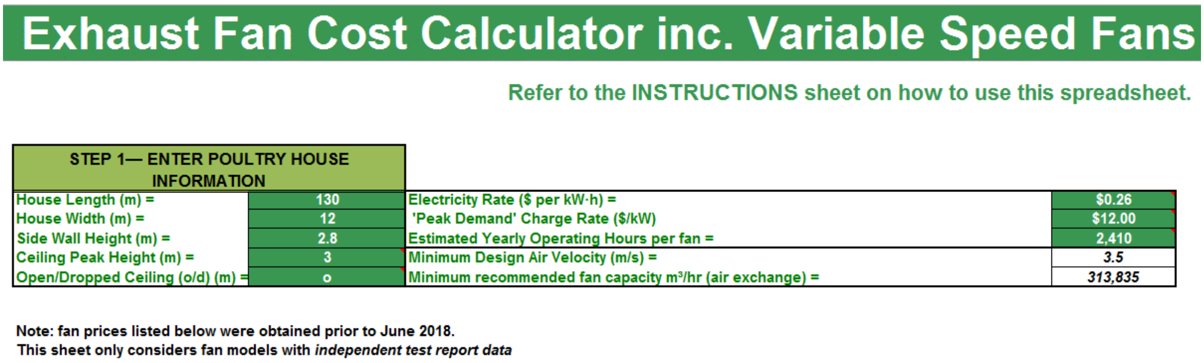

Figure 4: Screen shot from the exhaust fan cost calculator spreadsheet showing the various parameters that can be entered and their explanations.

Notes regarding the spreadsheet inputs

House length, house width and side wall height — length, width and wall height of the broiler shed to theoretically produce an airspeed of 3.0 m/s in the shed using the specified shed dimensions.

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 sheds but rarely seen in Australia. An open ceiling (i.e. roof is the ceiling) was selected.

Electricity rate — flat cost of electricity. This was an assumed value based on feedback from several poultry farms in south-eastern Queensland.

Peak demand charge rate — the network charge associated with the maximum amount of energy being drawn at any one time.

Estimated yearly operating hours per fan — as per the previous section; an average of 2,410 hours per year per fan was calculated based on previous research. This number can be modified to suit different situations.

Minimum design air velocity — this is the minimum tunnel ventilation airspeed required in the shed. Default value 3.0 m/s.

Minimum recommended fan capacity m³/hr (air exchange) — this value is calculated by the spreadsheet based on the shed cross-sectional area — 452,647 m³/h in this scenario is the total flow rate required to theoretically produce an airspeed of 3.0 m/s in the shed using the specified shed dimensions.

After entering the shed dimensions and electricity rates, the next step is to select a variable speed fan model from the list. At the time of publication, five variable speed fan models were available to Australian poultry growers. The spreadsheet calculates the minimum number of fans recommended to be installed, the estimated power consumption, yearly and ten-year cost associated with the selected fan models. Note that the number of fans recommended by the spreadsheet is a minimum value. More fans could be added (depending on wall space) and electricity costs would likely go down— more variable speed fans generally means less power used. In order to determine the optimal number of fans, the spreadsheet allows users to change the recommended number of fans and see how energy costs are affected.

Note: fan prices listed below were obtained prior to June 2018.
This sheet only considers fan models with *independent test report data*

STEP 2 — SELECT A VARIABLE SPEED FAN MODEL FROM THE LIST	Recommended Number of fans (based on shed dimensions)	Change number of recommended fans	Power Consumption of Fans kW	Total Fan Purchase Cost*	Yearly Fan Operating Cost	10 Year Running Cost: Electricity	10 Year Running Cost: Electricity + Fan Purchase cost
DACS MagFan 1.2 kW	8		8.5 kW	$24,000	$5,922	$59,217	$83,217
Skov BlueFan 1.2 kW							
DACS MagFan 1.2 kW							
Skov BlueFan 2.3 kW							
EBM-Pabst AgriCool 1.3 kW							
MultiFan Cone Vplus 2 kW							

STEP 3 — SELECT A SINGLE SPEED FAN MODEL FOR COMPARISON	Recommended number of fans (based on shed dimensions)	Change number of recommended fans	Power Consumption of Fans	Total Fan Purchase Cost*	Yearly Fan Operating Cost	10 Year Running Cost: Electricity	10 Year Running Cost: Electricity + Fan Purchase cost

Figure 5: Example of how the cost calculation spreadsheet recommends the number of fans to be installed based on shed dimensions then reports back estimates on how much power may cost on a yearly and 10-year basis.

After shed dimensions are entered and fan models are selected, the spreadsheet then allows for comparisons with traditional single speed fan models to help users see the potential differences in using variable speed fans or single speed fans.

Exhaust Fan Cost Calculator inc. Variable Speed Fans

Refer to the INSTRUCTIONS sheet on how to use this spreadsheet.
Enter values in GREEN sections (don't enter "$" or ","). Imperial to metric conversions on the following

STEP 1— ENTER POULTRY HOUSE INFORMATION			
House Length (m) =	130	Electricity Rate ($ per kW·h) =	$0.26
House Width (m) =	12	'Peak Demand' Charge Rate ($/kW)	$12.00
Side Wall Height (m) =	2.8	Estimated Yearly Operating Hours per fan =	2,410
Ceiling Peak Height (m) =	3	Minimum Design Air Velocity (m/s) =	3.5
Open/Dropped Ceiling (o/d) (m) =	o	Minimum recommended fan capacity m³/hr (air exchange) =	313,835

Note: fan prices listed below were obtained prior to June 2018.
This sheet only considers fan models with *independent test report data*

STEP 2 — SELECT A VARIABLE SPEED FAN MODEL FROM THE LIST	Recommended Number of fans (based on shed dimensions)	Change number of recommended fans	Power Consumption of Fans kW	Total Fan Purchase Cost*	Yearly Fan Operating Cost	10 Year Running Cost: Electricity	10 Year Running Cost: Electricity + Fan Purchase cost
DACS MagFan 1.2 kW	8		8.5 kW	$24,000	$5,922	$59,217	$83,217

STEP 3 — SELECT A SINGLE SPEED FAN MODEL FOR COMPARISON	Recommended number of fans (based on shed dimensions)	Change number of recommended fans	Power Consumption of Fans	Total Fan Purchase Cost*	Yearly Fan Operating Cost	10 Year Running Cost: Electricity	10 Year Running Cost: Electricity + Fan Purchase cost
Hired Hand 6603-8010 54" - CONE 1.5hp	12		12.4 kW	$23,448	$9,608	$96,084	$119,532

Estimated energy saving cost of the variable speed fan model over 10 years
$36,314.80

Figure 6: The spreadsheet also allows for the comparison of single speed fans and variable speed fans to give users an idea of how different models compare to each other.

Results and discussion

Fan models considered in this report

Table 1: List of fan models and performance data for the fans used in this project.

Fan Model	Rpm range	Airflow Range at 25 Pa (m³/h)	Energy Efficiency range at 25 Pa (m³/h/w)	BESS Test no.
DACS MagFan (1.2 kW)	378–670	21291–57807	45.7–73.4	14438, 14440 , 14439
SKOV BlueFan (2.3 kW)	464–650	39700–60900	33.4–51.3	16807, 16808, 16809
SKOV BlueFan (1.3 kW)	465–550	40000–49900	39.9–48.8	16815, 16816, 16817
EBM-Pabst AgriCool (1.3 kW)	300–600	12341–45615	25–54	EBM in-house testing
MultiFan Cone V-Plus (2 kW)	300–615	15700–59100	10.3–.45.5	16851
*Single Speed Fan**	515	43389	38	n/a

All data obtained prior to March 2018

*** Note— the *"Single-Speed Fan"* is the result of averaging the *American Coolair MNBCCE54L*, *Hired Hand 6603-7133* and the *Munters WD541V3CD-50* and represents the performance of high-efficiency single speed fans (Dunlop & Brown, 2015) for comparison against the variable speed fans in this report.**

Operating fans at reduced speed

The relationship between fan speed, airflow and power consumption is key to understanding how variable-speed fans can offer growers energy savings. Universal fan laws explain that airflow and rotational speed are roughly linearly related, whereas power and rotational speed are exponentially related. That is to say, by increasing a fan's rotational speed the expected airflow increase would be about the same, but the increase in power needed to achieve the increased rotational speed would be much greater. Figure 7 displays an example of the differences in airflow and power by reducing a variable-speed fan's (in this case a *DACS MagFan 1.2 kW*) rpm by approximately 25%. The effect on airflow is a drop of about 30% throughout the normal operating static pressure range, with the effect becoming more pronounced at higher pressures. However, the effect on power consumption is a reduction of about 55%. This means that by reducing the fan speed by just 25% a saving of 55% in power is achieved, with a reduction of only 30% in the airflow output.

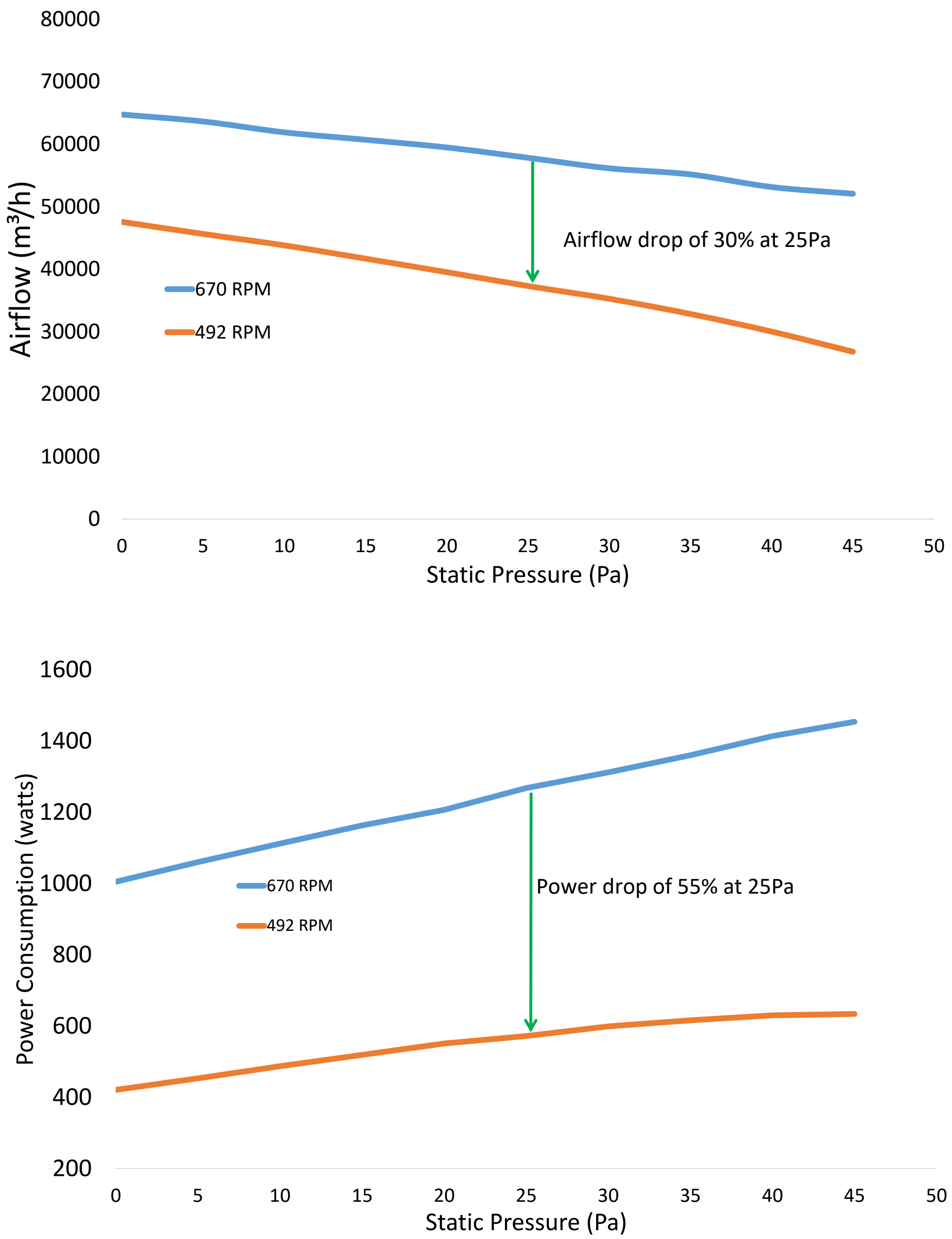

Figure 7: The effect on airflow (top) and power consumption (bottom) seen by reducing a variable-speed fan's rpm by 25% from 670 rpm to 492 rpm.

The effect of these changes in airflow and power consumption is an improvement in energy efficiency by approximately 80% simply by reducing the rotational speed, see Figure 8. The fan is therefore moving 80% more air for the same power input. Additional fans may need to operate to achieve the required shed airflow requirement, but the fans are moving more air for less electrical power consumption and the overall result is a substantial power saving.

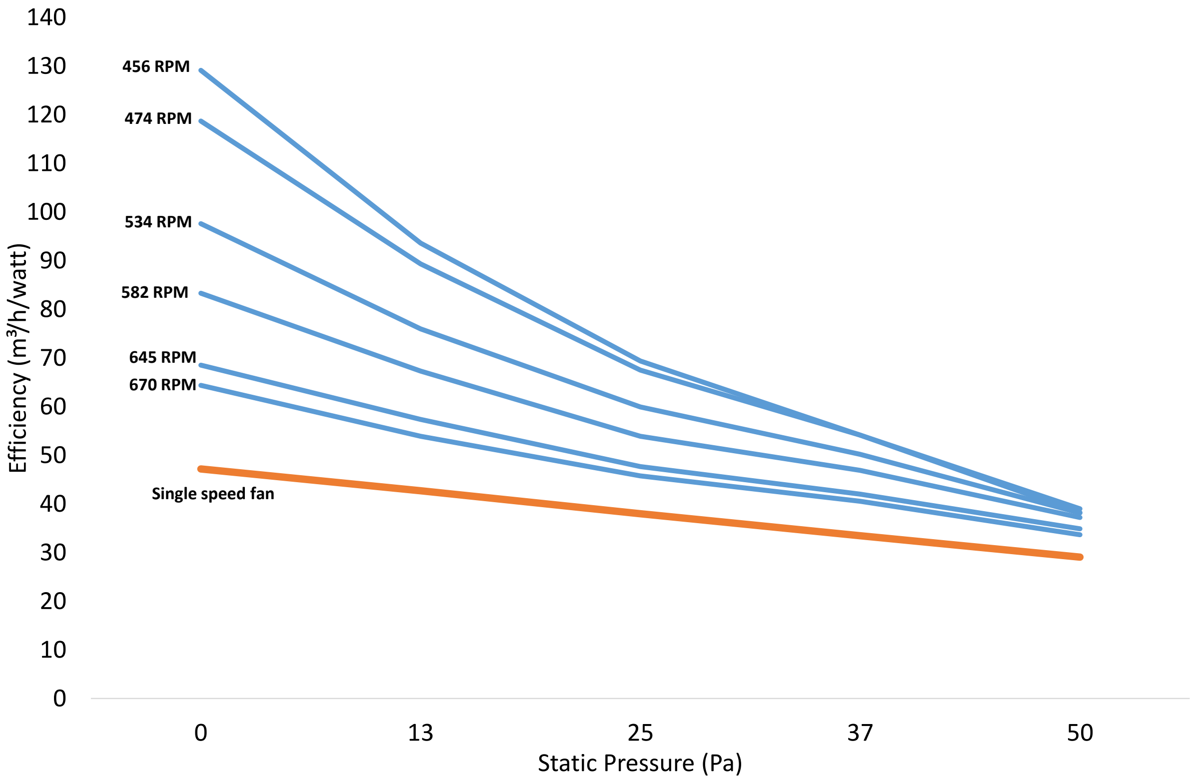

Figure 8: Example of how energy efficiency improves with reducing fan rotational speed. Blue lines represent different rotational speeds for the DACS MagFan; orange line represents the efficiency of the 'single speed fan'.

Figure 9 displays a further example of how reducing a fan's rotational speed can result in power savings, and how any loss of airflow can be compensated for by using more fans. It also shows that operating more fans can result in lower total power consumption.

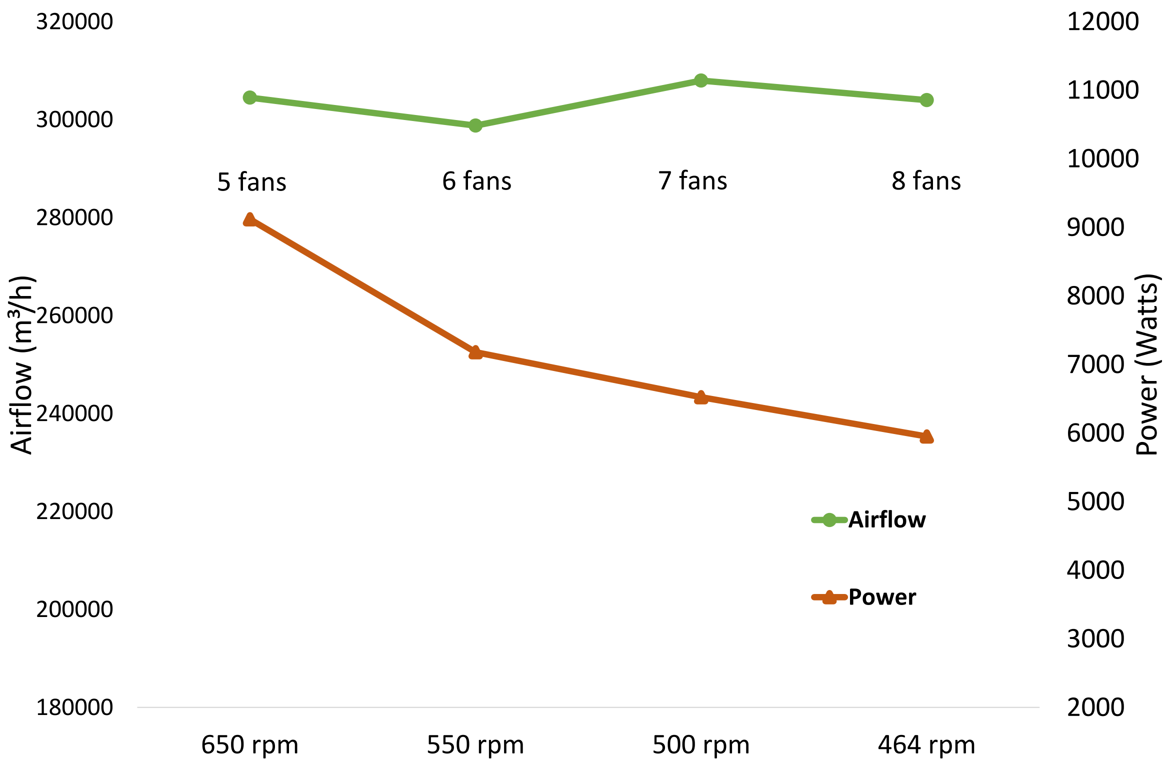

Figure 9: Example of how airflow and power change with rpm for a variable speed *DACS MagFan 1.2 kW*. Operating more fans at a reduced speed maintains airflow but reduces power consumption.

Figure 9 illustrates that when the variable-speed fan is set to 100% (650 rpm) 5 fans are needed to achieve the desired shed airspeed. When the speed is reduced to 70% of maximum (464 rpm) 8 fans are now required to achieve roughly the same airspeed. However, the total power consumption for all eight fans, at reduced speed, is less than five fans at maximum speed. By using more fans at reduced speed, the power needed to achieve similar airflow is actually now about 30% less.

One of the reasons why using variable-speed fans on meat chicken sheds results in power savings is that shed ventilation requirements throughout a batch don't require fans to operate at 100% speed all the time. By determining how much time the fans are required to operate at less than 100% speed, the value of having variable-speed fans can be better understood. Data previously collected (Dunlop & Duperouzel, 2014) was analysed to determine the number of fans active and the airflow requirements over the course of a number of grow-out cycles. This data was then used to calculate the number of variable-speed fans needed to achieve the airflow and the percentage of time they would operate at a defined rpm (Figure 10).

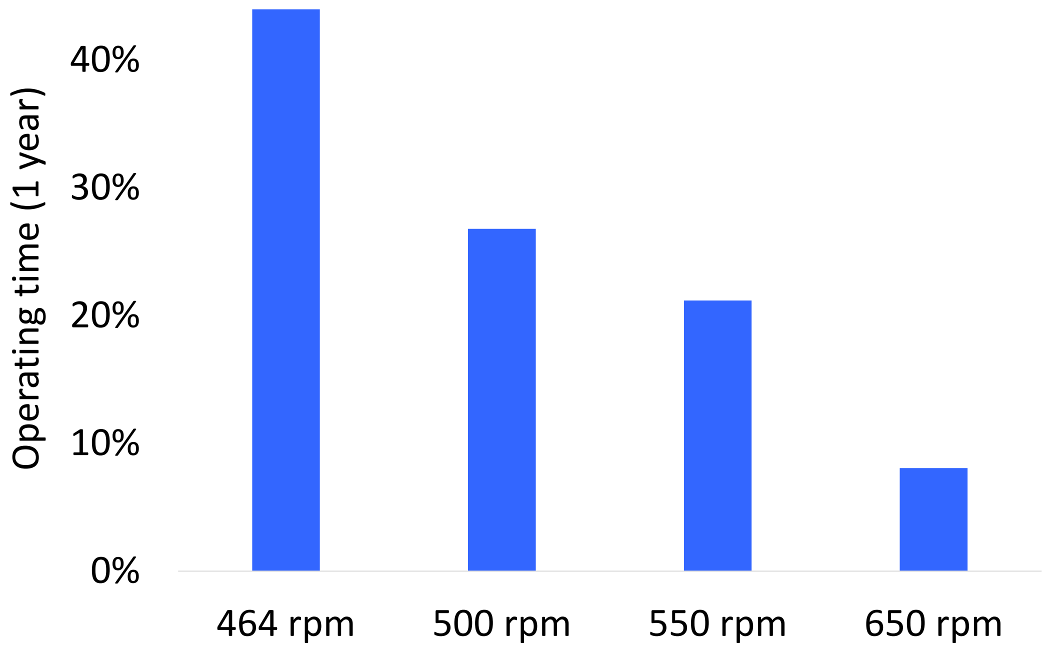

Figure 10: Percentage of time operating a different speeds over a 1 year monitoring period (combined data from 5 farms). For almost half the year the fans can be operated at their lowest speed (and lowest power). Less than 10% of the batch the fans are needed to operate at their maximum speed.

The data indicates that for over 90% of a year the fans can operate at reduced speed i.e. less than maximum rpm. As has been previously shown, any reduction in a fan's rotational speed can result in substantial power savings. In this example, the fans can operate at 70% rotational speed (450 rpm) for almost 45% of the year, which could result in large savings if switching from single-speed fans.

Operating fans at reduced speed also has the additional advantage of not requiring fans to constantly switch on and off to meet the airflow requirements during minimum ventilation. Fans constantly switching on and off increases wear on fan motors, belts and pulleys. It also requires vents to frequently adjust to match the airflow, which causes wear on those components and reduces the amount of time when in-shed conditions are stable and consistent. As Figure 10 suggests around 45% of the year the fans can be operated at their lowest speed, which is likely the period when fans switching on and off is highest.

Benefits of installing more than the minimum number of variable speed fans

By installing more than the minimum number of fans, the fans are able to run at lower rpm while still achieving the required airflow to maintain shed conditions. By virtue of the fan laws, this results in energy savings. The following example used real-world shed ventilation data to demonstrate the power savings that can be realised by installing more than the minimum number of fans. Calculations are based on the performance data of a direct-drive variable speed *Skov BlueFan* (2.3 kW). For this example (Figure 11), the variable-speed fan was 'locked' at its lowest speed (green) and then compared to when it was 'locked' at its maximum speed (orange).

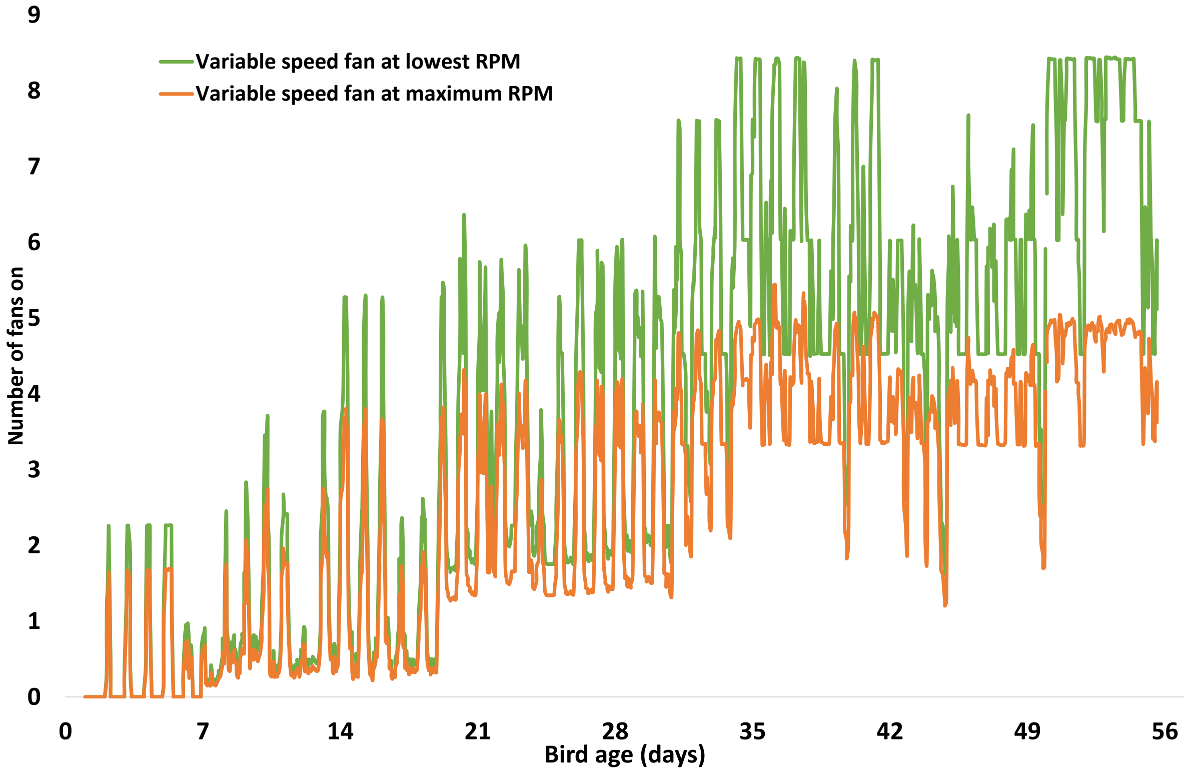

Figure 11: Example of the number of fans that would be active throughout the course of a summer batch when the fan is set at its highest and lowest rotational speed (based on collected hourly ventilation data).

Figure 11 shows the difference in the number of fans required to fulfil the airflow requirements throughout a batch. The difference in the number of fans needed isn't obvious early on in the batch, but as the batch goes on and the demand for airflow increases, the discrepancy in the number of fans needed becomes more pronounced. To meet the maximum airflow requirements late in the batch, nine fans at low speed are needed and only five fans are required at maximum speed. The result of this is the total power consumption is actually lower for the nine fans at minimum speed than for the five fans at maximum speed (Figure 12). The calculated power consumption at the end of the batch for the fans at maximum speed is 28,926 kW.h, compared to 20,638 kW.h for the minimum speed fans—a reduction of 28%. This example demonstrates that even though there are more fans active and more fans needed for airflow, the overall cumulative power consumption is less.

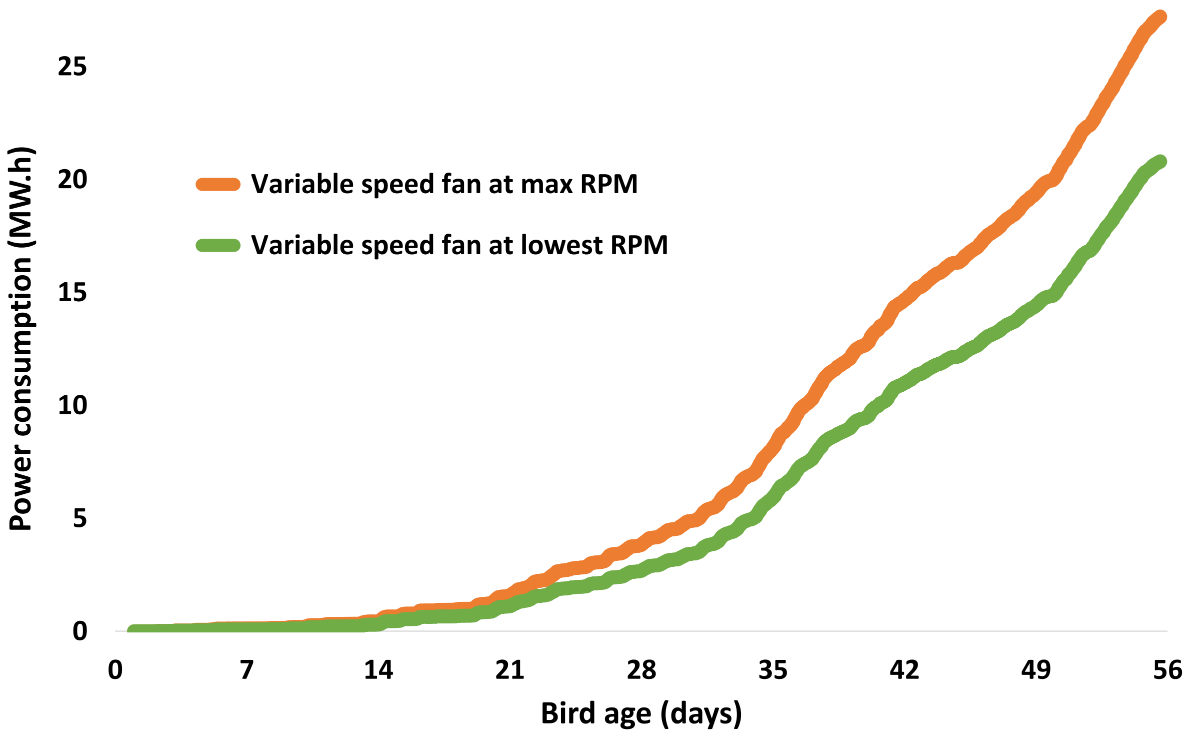

Figure 12: Calculated example of the difference between cumulative power consumption, over a summer batch, for a variable speed fan is set to maximum rpm compared to its lowest rpm. When at its lowest speed setting, the variable-speed fan needs more fans to achieve the airflow, it's actually consuming less power over the course of the batch than when less fans are operating at higher speed.

It should be noted, however, the initial purchase costs of variable-speed fans are often much higher than the purchase price of single-speed fans. This high purchase price may be a barrier for growers who do not have the extra initial capital to afford more expensive variable-speed fans. Therefore, while having more variable-speed fans installed reduces power consumption, it may not be cost effective due to the high initial costs.

Comparison of variable-speed fans and single-speed fans

Data for a number of variable-speed fans was used in the calculations for this project. For comparison, data for three of the highest efficiency single-speed fans (that were available at the time of undertaking the analysis) was also used. Figure 13 shows the calculated cumulative power consumption for all of the fans considered in this project over the same 56 day summer batch.

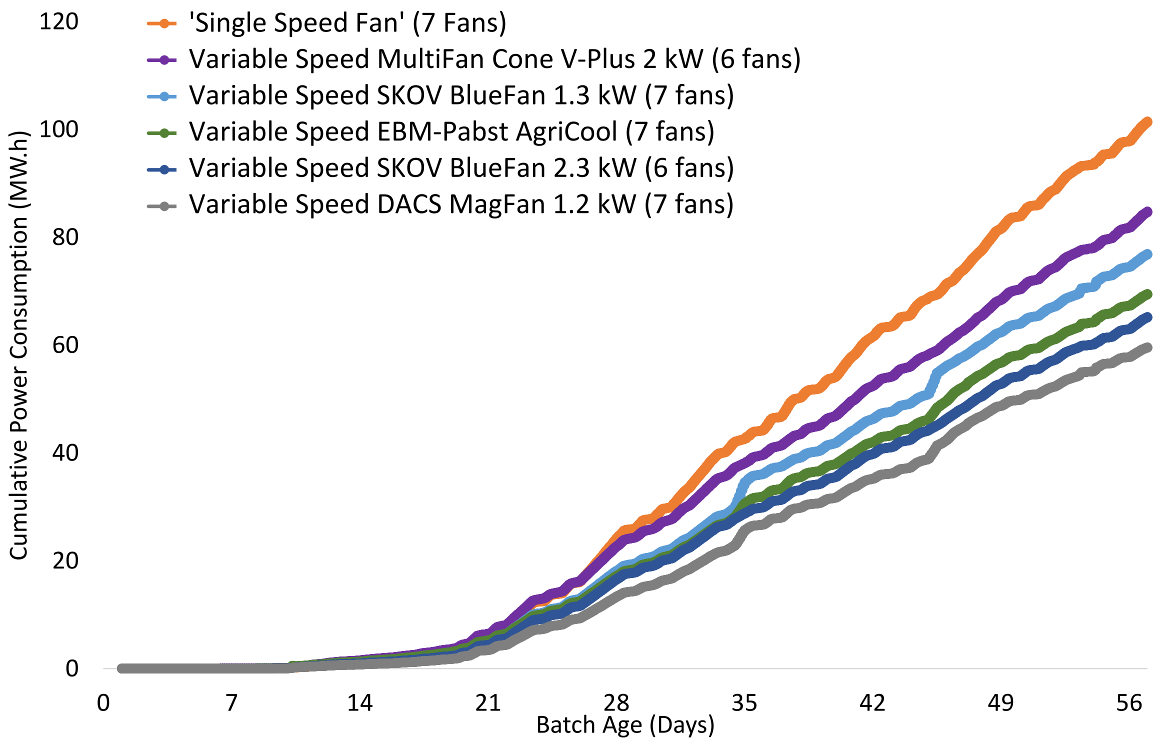

Figure 13: Calculated comparison of a single-speed fan and variable-speed fans in terms of their cumulative power consumption throughout a 56 day batch. Shown in brackets is the calculated number of fans that would be needed on the shed to achieve airflow at maximum demand.

Substantial differences in cumulative power consumption exists between fans, especially towards the end of the batch when demand for airflow increases. In this study, the fan with the highest cumulative power usage was the *single-speed fan*, and the fans with the lowest cumulative power consumption were the variable-speed fan models. For example the fan model with the highest calculated cumulative power consumption, the *single speed fan*, required seven fans to be installed to meet the airflow requirements. In comparison, the lowest cumulative power consumption was achieved with the variable speed *MagFan,* which also required seven fans to meet the airflow requirements. This is important to note, as it compares calculated data for two fans that are very similar in terms of output, but have very different power consumptions over a batch. The likely reason for this is the variable-speed fan's ability to operate at reduced speeds for a large majority of the batch. The longer the variable-speed fan can operate at less than 100% power, the more savings in terms of power consumption can be seen. Time operating at different rpms is explored further in the following section.

Also of note are the differences between variable-speed fans. The *SKOV BlueFan* has two models with different motor sizes; a 2.3 kW and a smaller 1.3 kW. In this example, a minimum of eight of the smaller capacity fans are needed to achieve the airflow needed in the shed, whereas only six of the larger capacity fans are required. This results in the smaller 1.2 kW model having a higher calculated cumulative power consumption over this batch than the larger capacity 2.3 kW model. The likely reason for this is that the smaller capacity model is required to operate at higher rpm's for longer periods of time to meet the minimum airflow requirements. This extended period of operating closer to the fan's maximum rotational speed reduces the fundamental benefits of operating the fan at low rotational speed.

Example of potential savings from variable speed fans

Using the previously collected fan activity and shed static pressure data, calculations were made to investigate the potential savings of using different types of fans on a shed over multiple grow-out cycles. Figure 14 shows the calculated relative power consumption for the variable speed fan models compared to the single speed fan over a one year period, using fan activity data from a shed in south-eastern Queensland and a shed in Victoria.

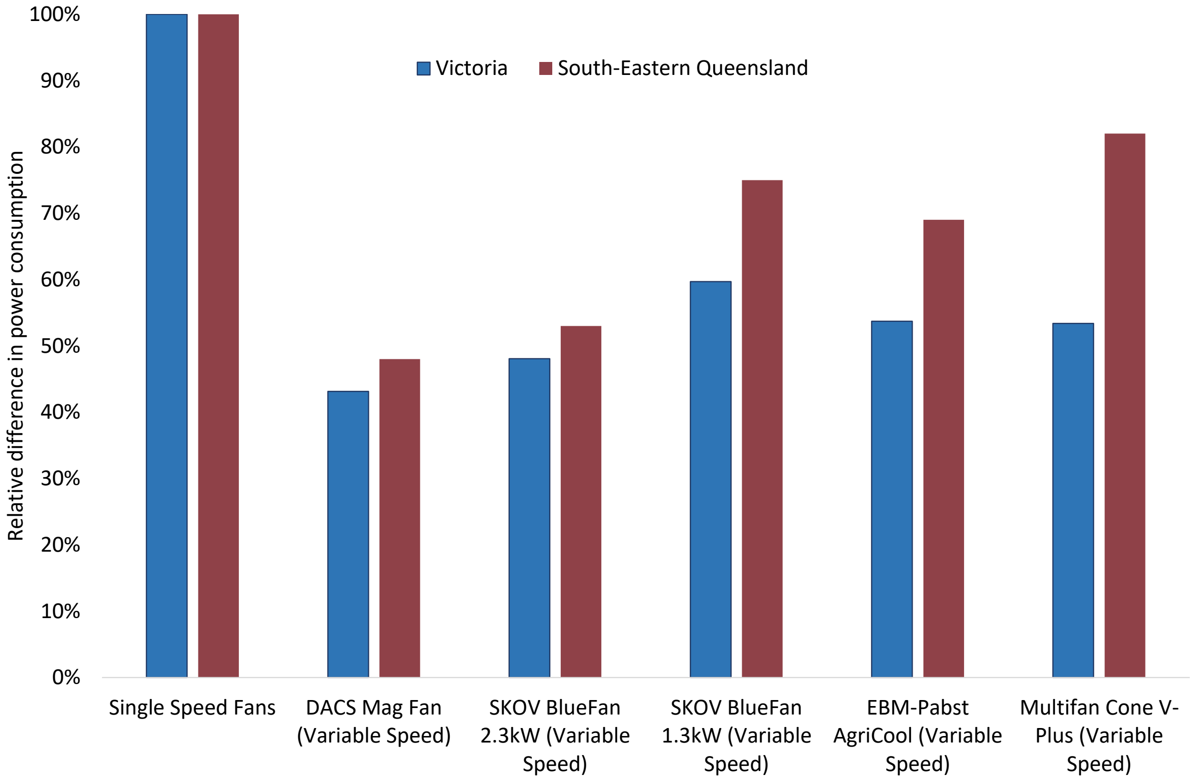

Figure 14: Calculated example showing the difference in power consumption for the variable speed fans relative to the single speed fans in Victoria and south-eastern Queensland.

In this example, the relative power difference is shown for the variable speed fans when compared to the single speed fans. The largest difference came from the Victorian example with the *DACS MagFan*, which was calculated to use 54% less power than the single speed fan over a year. The smallest difference came from the *MultiFan Cone V-Plus* in the south-eastern Queensland example, where this fan was calculated to use 18% less power than the single speed fan.

This example also shows the differences between the two states. The data for the south-eastern Queensland shed indicates variable speed fans will still save power over single speed fans, but the shed in Victoria shows an even greater saving. A possible explanation for this is that the shed in Victoria was required to be in full-tunnel ventilation less time than the south-eastern Queensland shed. This would mean the variable speed fans on the Victorian shed could spend more time at reduced rpm, and more time at reduced rpm means more savings over single speed fans.

Table 2 shows a practical example for how much savings are to be expected from this power difference based on the data for the south-eastern Queensland shed in the example above. This table translates the power consumption difference into overall power costs and payback periods for the various fan models.

Table 2: Example of calculated running costs over a 6 batch period for various fan models.

Fan Model	Calculated minimum number of fans needed	Estimated fan purchase price (total)*	Power consumed over 6 batches (MW.h)	Total power cost (assuming $0.16/kW.h)
'Single Speed Fan'	10	n/a	251.1	$40,187
DACS MagFan (Variable Speed)	9	$27,000	130.1	$20,820
SKOV BlueFan 2.3kW (Variable Speed)	9	$33,453	149.1	$23,860
SKOV BlueFan 1.3kW (Variable Speed)	10	$18,950	203.7	$32,603
EBM-Pabst AgriCool (Variable Speed)	10	$28,000	190.3	$30,451
Multifan Cone V-Plus (Variable Speed)	9	$27,000	206.6	$33,057

*Note: purchase prices obtained from Australia distributors for single fans only. Bulk purchases will likely result in prices less than shown

The calculations in Table 2 indicate quite substantial differences in power costs over a year period for the fan models.

In terms of payback periods for installing variable speed fans, this is very much shed specific and would largely depend on what models of fan are currently installed. Using the example above, if a shed was fitted with the '*single speed fans'* switching to any of the variable speed models would result in yearly power savings. This is a strong indication that using variable speed models should be considered over single speed fans. More specifically, using the most efficient variable speed fans in this example; the SKOV Blue Fan (2.3 kW), a minimum of nine fans would be needed to replace the ten '*single speed fans'* at an estimated cost of $33,453 (not including installation). The yearly power savings of the *SKOV Blue Fan (2.3 kW)* over the '*single speed fan*' would be $16,327, meaning that the fans could be paid off in just under 2 years. Using the less efficient *MultiFan Cone V-Plus*, nine of these fans would need to be purchased to replace the ten single speed fans at a cost of around $27,000 (not including installation). This combined with an estimated annual power saving of $7,130 the *MultiFan Cone V-Plus* fans could be paid back in around four years.

It should also be noted that these figures are based on using the minimum number of variable speed fans necessary to achieve airflow for this example shed. Installing more variable speed fans than the minimum will likely reduce yearly running costs.

Power consumption towards the end of a grow-out cycle

In comparing the cumulative power consumption for different fan models over the course of a batch, a general observation could be made that a large percentage of the overall power consumed by the fans comes in the final stages of the batch. This is where more fans are required to operate more frequently or for longer periods of time meaning more power consumption. This is also true for variable speed fans, as the end stages of a batch are where the fans are most likely required to operate at maximum speed, and therefore lowest efficiency. In the example below (Figure 15) the cumulative power consumption for a single speed fan and a variable speed fan is shown for a 56 day summer batch in south-eastern Queensland.

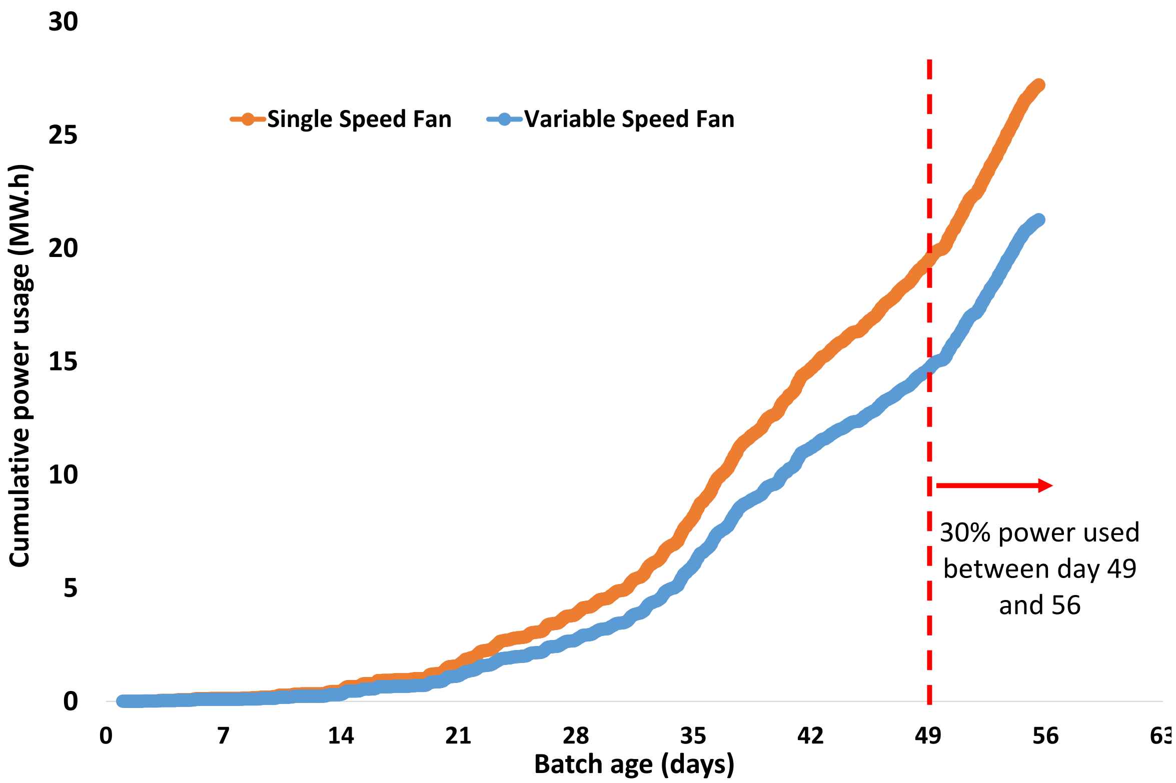

Figure 15: 70% of the power used throughout the batch is consumed prior to day 50. The final week of the grow-out requires 30% of the total power used for the entire batch.

By day 49 of the batch, the shed with the single speed fans has consumed 19.0 MW.h of power and by the end of the batch, on day 56, has consumed 27.2 MW.h. Comparatively, the shed with variable speed fans installed has consumed 15.1 MW.h by day 49 and 21.3 MW.h. by day 56. Regardless of the fan type installed on the shed, the final week of a grow-out requires about 30% of the total power used over the entire batch. This is due to the increased airflow requirements as bird density increases and more fans are required to operate for longer periods of time or, in the case of variable speed fans, at higher rpm. While growers may not have control over how long a batch goes for, shorting a batch by just one week would lead to considerable power savings.

Using variable speed fans has the most benefits when the fans can be run at the lowest speed and highest efficiency; this means that the most of the benefits of using variable speed fans can be seen early in a batch. Figure 16 shows that very little power is consumed by the variable speed fan up until around day 28. The gap between the variable speed fan and the single speed fan is maintained from day 28 to around day 48. From this point on, the variable speed fan appears to consume more power than the single speed fan. This is due to the variable speed fan operating at maximum speed, where its efficiency is lower than the single speed fan in this example.

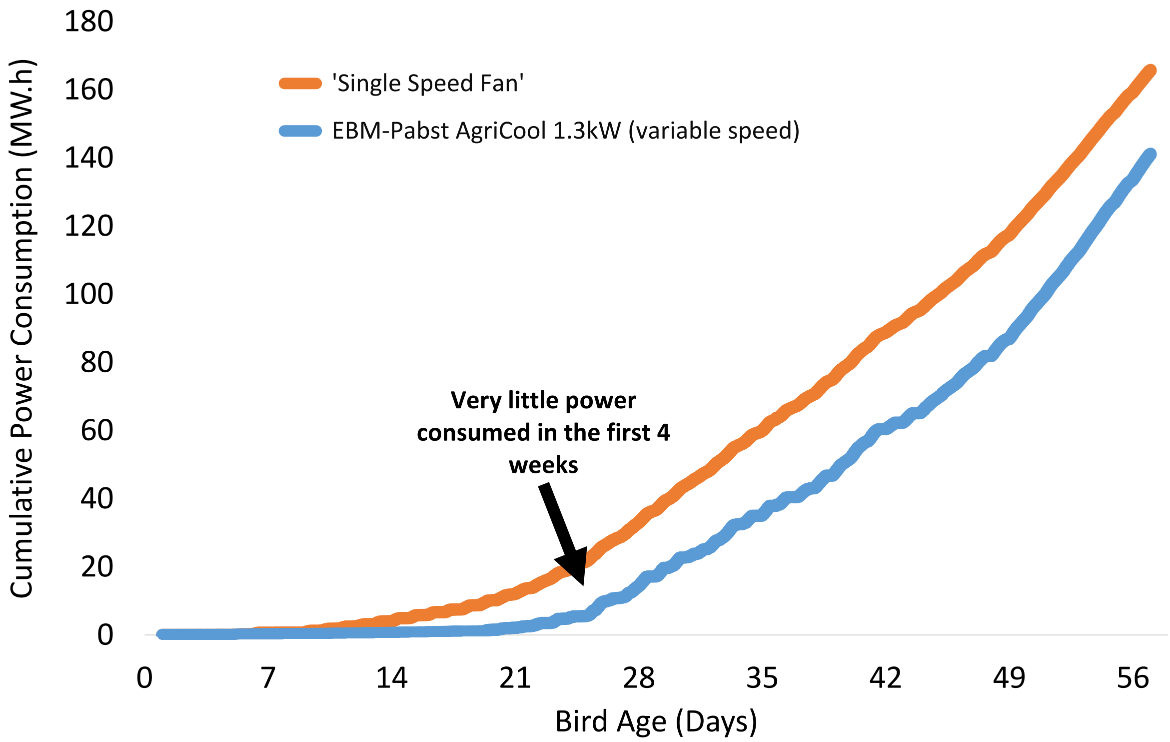

Figure 16: Calculated example of a shed with variable speed fans (blue) and a shed with single speed fans (orange). The shed with the variable speed fans consumes less power early on and maintains this gap until around day 48.

Conclusions

- Variable speed fans achieve much higher energy efficiency than single speed fans when they are operated at low rotational speed (rpm).
- Variable speed fans are more energy efficient, and use less power, over the course of a batch than single speed fans.
- When variable speed fans are running at maximum rpm they may have about the same, or slightly worse, energy efficiency than high efficiency single speed fans (this comparison is fan model dependent).
- Most of the time (about 90% of a batch) fans can be operated at less than maximum power, which results in large savings.
- Minimum ventilation situations are the cause for the biggest difference in power consumption between single-speed fans and variable-speed fans. Variable speed fans consume much less power than single speed fans in the first 4 weeks of a batch.
- Payback periods for purchase costs of variable speed fans are very shed specific and depend on a number of factors— shed age, installation costs, ease of replacement, currently installed fans.
- Example scenarios used in this report indicate a payback period of 2 to 4 years, depending on fan type.
- Roughly 25–30% of the total power used in a batch, is consumed in the final week of a grow-out. This was true regardless of fan type installed.
- An interactive spreadsheet '*Exhaust Fan Cost Calculator'* has been developed in conjunction with this report to assist growers to estimate operating costs of variable speed fans.

Interactive spreadsheet for estimating running costs of variable speed fans

Installing variable speed fans on meat chicken sheds in Australia will likely reduce yearly running costs. Savings for particular fan types and sheds can be estimated using the '*Exhaust Fan Cost Calculator'* spreadsheet developed in conjunction with this report. The spreadsheet allows for shed dimensions and electricity rates to be entered, and for the user to select variable speed and single speed fans for comparison in terms of the yearly and 10-year running costs. This spreadsheet tool can assist growers in estimating the payback periods and costs associated with variable speed fans to help growers find a solution that suits their needs.

Implications

- Using variable speed fans may help reduce electricity costs associated with running mechanical ventilation fans on Australian meat chicken farms.
- Variable speed fans at lower speeds to maximise power savings.
- There are limits on how slow they can go to maintain negative pressure in the shed and not stall.
- High power-factor electric motors on most variable speed fans provide additional electricity savings, especially for farms being charged for kVA rather than kW.
- Replacing older fans with variable speed fans will save on running costs.
- There may be some difficulties in achieving maximum efficiencies using variable speed fans with older controllers
- The interactive spreadsheet developed for this project may assist growers in determining what is best for their set-up.
- Variable-speed fans are most likely the future direction for exhaust fans on meat chicken sheds, the high initial purchase cost is made up for in lower running costs.

Recommendations

- Growers who are building new sheds should consider installing variable-speed fans as the running costs are lower than even the ‘high-efficiency’ single-speed fans.
- Growers should install sufficient fans to enable the fans to run at lower rotational speed in order to maximise the energy savings.
- Future research to undertake monitoring of fan activity and power consumption on meat chicken sheds to confirm the findings of this desk-top study. Ideally, this monitoring would be conducted using identical sheds on the same farm, one with single-speed fans, and one with variable-speed fans.

Glossary

Active power (kW)	Sometimes called real power, is the amount of power that is actually converted into useful motion.
Reactive power (kVAr)	Sometimes called “imaginary” power, represents the power drawn by inductive loads. The motors that drive AC fans draw reactive power out of phase with the voltage. Reactive power does not do any work (and may be viewed as *wasted* power), which is why it is referred to as imaginary power.
Apparent power (kVA)	The combination of reactive and active power. It is the product of voltage and current. Where a reactive component is present, such as in fan motors, apparent power is always greater than active power as current and voltage are not in phase.
Power factor (PF)	Power factor is a measure of the ratio of the 'apparent power' (kVA) that is demanded by a motor and the 'active power' (kW) that is used by the motor. The higher the power factor (i.e. the closer it is to 1) the less losses are experience by the motor. DC motors, like the ones on variable speed fans, have very high power-factors.

Appendix A

Table 3: Non-linear regression equations for calculation of airflow for the fans used in this project

Fan Model	Airflow (y) Equation	R^2
SKOV Blue Fan 2.3 kW	$y = (284991 + (-1003) \times RPM + 1.107 \times RPM^2) + (-258156 + 1004 \times RPM + (-1.019 \times RPM^2) \times ((1.05 + (-0.00007) \times RPM^{Static\ Pressure})$	0.991
SKOV Blue Fan 1.3 kW	$y = (4741706 + (-19692) \times RPM + 20.69 \times RPM^2) + (-4655671 + 19446 \times RPM + (-20.35 \times RPM^2) \times ((1.0957 + (-0.00017) \times RPM^{Static\ Pressure})$	0.962
EBM-Pabst AgriCool	$y = (55456 + (-122) \times RPM + 0.218 \times RPM^2) + (-56012 + 201 \times RPM + (-0.213 \times RPM^2) \times ((1.0353 + (-0.0000376) \times RPM^{Static\ Pressure})$	0.997
MultiFan Cone V-Plus	$y = (51264 + (-130) \times RPM + 0.128 \times RPM^2) + (-52021 + 185 \times RPM + (-0.198 \times RPM^2) \times ((1.0957 + (-0.0000452) \times RPM^{Static\ Pressure})$	0.985
DACS MagFan	$y = (69285 + (-52.4) \times RPM + 0.1235 \times RPM^2) + (-74821 + 169.4 \times RPM + (-0.1423 \times RPM^2) \times ((1.02473 + (-0.00002375) \times RPM^{Static\ Pressure})$	0.999

Appendix B

Exhaust Fan Cost Calculator inc. Variable Speed Fans

Refer to the INSTRUCTIONS sheet on how to use this spreadsheet.
Enter values in **BLUE** sections (don't enter "$" or ","). Imperial to metric conversions on the following worksheets

STEP 1— ENTER POULTRY HOUSE INFORMATION			
House Length (m) =	130	Electricity Rate ($ per kW·h) =	$0.26
House Width (m) =	12	'Peak Demand' Charge Rate ($/kW)	$12.00
Side Wall Height (m) =	2.8	Estimated Yearly Operating Hours per fan =	2,410
Ceiling Peak Height (m) =	3	Minimum Design Air Velocity (m/s) =	3.5

Note: fan prices listed below were obtained prior to June 2018.

STEP 2 — SELECT A VARIABLE SPEED FAN MODEL FROM THE LIST	Recommended Number of fans (based on shed dimensions)	Power Consumption of Fans kW	Total Fan Purchase Cost*	Yearly Fan Operating Cost	10 Year Running Cost: Electricity	10 Year Running Cost: Electricity + Fan Purchase cost
Skov Blue Fan 2.3 kW	8	10.9 kW	$29,736	$7,558	$75,584	$105,320

Skov Blue Fan 1.2 kW
DACS MagFan 2.2 kW
Skov Blue Fan 2.3 kW
EBM-Pabst AgriCool 1.3 kW
MultiFan Cone Vplus 2 kW

STEP 3 — SELECT A SINGLE SPEED FAN MODEL FOR COMPARISON	Recommended number of fans (based on shed dimensions)	Power Consumption of Fans	Total Fan Purchase Cost*	Yearly Fan Operating Cost	10 Year Running Cost: Electricity	10 Year Running Cost: Electricity + Fan Purchase cost

Exhaust Fan Cost Calculator inc. Variable Speed Fans

Refer to the INSTRUCTIONS sheet on how to use this spreadsheet.
Enter values in **BLUE** sections (don't enter "$" or ","). Imperial to metric conversions on the following worksheets

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Skov Blue Fan 2.3 kW	8	10.9 kW	$29,736	$7,558	$75,584	$105,320

STEP 3 — SELECT A SINGLE SPEED FAN MODEL FOR COMPARISON	Recommended number of fans (based on shed dimensions)	Power Consumption of Fans	Total Fan Purchase Cost*	Yearly Fan Operating Cost	10 Year Running Cost: Electricity	10 Year Running Cost: Electricity + Fan Purchase cost
Hired Hand 6603-8010 54" - CONE 1.5hp	12	12.4 kW	$23,448	$9,608	$96,084	$119,532

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Chicken Meat

Variable-speed exhaust fans for meat chicken sheds

by Grant Brown
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