Evaluation of Energy Usage and Ventilation Performance of Tunnel Ventilated Layer Sheds

Final Project Report

A report for the Australian Egg Corporation Limited

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Foreword

To comply with stringent animal welfare requirements, caged egg producers have invested in new sheds or retrofitted older sheds that are fully environmentally controlled. These sheds are fitted with ventilation fans at one end of the shed, with air inlets along the length of the shed and cooling pads at the opposite end of the shed, to provide optimal environmental conditions for the hens. These sheds are more energy intensive than natural ventilated sheds. With rising energy prices, energy efficiency is an important focus area for the Australian egg industry. Electricity consumption dominates energy usage for environmentally controlled sheds. Electricity is required for running fans and lighting, and for running feed and water lines.

Additionally, technology within environmentally controlled sheds has generally been imported from overseas (particularly Europe), with different climatic conditions. There is limited data on the energy efficiency and ventilation performance of environmentally controlled sheds operating under Australian conditions.

This study provides factual data on energy use of a representative Australian caged egg farm and energy use and ventilation performance of an environmentally controlled shed at that farm.

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

This report is an addition to AECL's range of peer reviewed research publications and an output of our R&D program, which aims to support improved efficiency, sustainability, product quality, education and technology transfer in the Australian egg industry.

Most of our publications are available for viewing or downloading through our website http://aecl.org/r-and-d/.

Printed copies of this report are available for a nominal postage and handling fee and can be requested by phoning (02) 9409 6999 or emailing research@aecl.org.

Dr Angus Crossan
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About the Authors

The authors of this report were a multidisciplinary team of enginners and scientists from FSA Consulting. FSA Consulting is a specialist environmental and agricultural engineering consultancy based in Toowoomba (Queensland) and has been in operation since 1994. The FSA Consulting multi-disciplinary team includes highly qualified agricultural and environmental engineers and agricultural and environmental scientists with diverse experience. FSA Consulting has extensive experience in research, extension and service delivery to the poultry industries.

The lead author (Mr Eugene McGahan) has 20 years years experience in providing advice and conducting research in the intensive livestock industries.

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Abbreviations

^{o}C	Degrees celcius
CEC	Condamine Electrical Company
CFM	Cubic feet of air per minute
CT	Current Transformer
e.g.	For example
kW	Kilowatt (1000 watts)
kWh	Kilowatt hour
kWh/day	Kilowatt hour used over a period of 24 hours
kWh/week	Kilowatt hour used over a period of seven days
LED	Light-emitting Diode
LPG	Liquid Petroleum Gas
m	Metre
MJ	Mega joule
PV	Photovoltaic
RMS	Root mean square
RPM	Revolutions per minute
R&D	Research and Development
T	Tonne
VFD	Variable frequency drive

Executive Summary

The Australian egg industry faces a number of key challenges including increasing competition, pressures on operating margins and profitability, increasing costs of business inputsand higher expectations by consumers and the community in general (particularly in the areas of environmental management and animal welfare). To remain competitive and meet the demand for eggs, the industry recognises the need for it to continue to make significant gains in areas of technical and cost efficiency. Whilst agriculture is excluded from the carbon tax, egg producers will still likely experience increased input costs (energy and transport) via those sectors included in it. Increasing the efficiency and profitability of egg production systems and ensuring hen welfare are key outcomes for the Australian Egg Corporation Limited (AECL).

Cage egg production represents about 55% of egg production in Australia (AECL 2012). This is currently the most cost-effective system and most consumers purchase their eggs based on price. Modern cage systems produce superior bird performance and reduce overall labour requirements compared to the older high-rise caged systems. However, they require a higher capital investment cost per bird.

Layer sheds fitted with welfare compliant cages are thermal, environmentally controlled facilities that require ventilation systems to exchange air and maintain acceptable indoor thermal conditions all year round. Tunnel ventilation systems are typically designed to achieve a specific minimum air velocity at maximum ventilation.

Caged egg producers have invested in new sheds or retrofitted older sheds to operate in tunnel ventilation mode. Shed design and tunnel ventilation technologies have been imported from overseas manufacturers and adapted to Australian conditions. There is limited data available on the performance of these tunnel ventilated sheds in Australia.

Energy usage is a key input to egg production that is under increasing cost pressure. Energy cost pressure and increasing regulation affects feed production efficiency, breeding, rearing, egg production, grading and transportation – all having the effect of increasing production costs and seriously impacting upon the economic sustainability of the industry.

Electricity consumption dominates energy usage for environmentally controlled sheds. Life Cycle Assessment studies by the authors showed total farm energy usage varied by 66%. This suggests that there may be scope for improvements in electricity energy efficiency.

This study investigated the energy usage and ventilation performance of a modern tunnel ventilated layer production system. Short-term energy monitoring was conducted on key farm activities, including feed preparation, individual sheds and the total farm energy use. Long term energy use was recorded for the total farm, an individual shed and key components within an individual shed (ventilation fans, manure belts, lighting and cooling system). The performance of the ventilation under cold (minimum ventilation conditions) and hot (maximum ventilation conditions) was assessed.

At the start of the study, the selected farm operated with five tunnel ventilated egg production (layer) sheds, feedmill, one tunnel ventilated rearing shed, water supply and treatment facility, egg processing and grading complex and office. During the course of the study, an additional rearing shed was constructed at the site. Key characteristics of the selected farm are Hyline Brown genetics; 160,000 layers birds in five tunnel ventilated sheds; two tunnel ventilated rearer sheds housing 80,000 rearer birds; and on-farm feed preparation.

Total farm electrical energy use ranged from an average of 1500 kWh/d in winter to 2500 kWh/d in summer. Peak loads of between 140 and 185 kW were recorded during warmer periods of the day. The electricity energy consumption of a single tunnel ventilated shed varied between averages of 280 kWh/d in winter to 350 kWh/d in summer. This represented approximately 15% of the total farm electrical energy use.

The electrical energy usage was expressed per kilogram of eggs produced and per bird place basis. The electrical energy efficiency of the single layer shed was on average 0.15 kWh per kg of total eggs produced. When rearing and grading activities are included, the energy usage increased to 0.25 kWh per kg of total eggs produced. This increase is a result of the grading floor and rearing shed, which require electrical energy, but do not produce eggs. Feedmill energy use was not included in total farm energy use.

The total farm energy usage was higher for both egg weight produced and per bird when compared against data from tunnel ventilated layer farms collected in Australian LCA studies. High temperatures during the summer monitoring period may have contributed to a high demand in electrical energy use to operate the ventilation system. Direct comparison over the same time periods would be required to provide any definitive comparison of energy efficiency between different farms.

Ventilation performance of one layer shed was assessed under minimum ventilation (cold) and maximum ventilation (hot) conditions. During the minimum ventilation assessment, the shed was functioning with a single fan and mini-vents. During the maximum ventilation assessment all fans and cool pads were functioning. In both assessments temperatures increased towards the fan end of the shed due to the fans drawing the warm air generated by the heat of the birds. There was also a variation in temperature at different heights in the shed. The bottom of the shed was several degrees cooler than the top, likely due to warm air rising and becoming trapped by the roof.

Shed temperature in winter fell below the minimum recommended set point for optimum layer production of 21°C. This only occurred at the inlet end of the shed. Reducing air leaks at this point of the shed would be the first step in improving bird comfort and productivity before additional heating (via gas heaters) is considered. On a hot summer day (ambient temp 40°C) the shed apparent temperature (ambient shed temperature with wind chill effect) reached approximately 30°C, this is several degrees above the fan contoller set point of 26.5°C but still within the recommended temperature for healthy bird conditions provided exposure is not sustained. Ensuring the cooling pads and fans are operating efficiently may improve shed cooling under extreme summer conditions.

The apparent temperature was also calculated for the shed under maximum (tunnel) ventilation conditions. Wind chill effects reduced the temperature felt by the birds by approximately 2-3°C and keep them well within the recommended climate conditionsfor optimum layer production.

Total shed ventilation performance under maximum ventilation conditions (tunnel ventilation) was assessed and was found to be below manufacturer’s specifications and requiring maintenance. However, more detailed monitoring of individual fan performance would be required to obtain accurate perfiormance variability between the fans. The test method used could be improved by taking more spot measurements at designated points over the cross sectional area of the individual fans.

Overall Conclusions

Electrical energy monitoring at the selected farm showed that electrical energy use ranged from an average of 1500 kWh/d in winter to 2500 kWh/d in summer. Peak loads of between 140 and 185 kW were recorded during warmer periods of the day. A single tunnel ventilated layer shed (Shed 5) was assessed; electrical use was 280 kWh/d in winter and 350kWh/d in summer. Operating ventilation fans required 60-70% of the total energy while lighting required 17%.

Intensive energy monitoring on the farm for two weeks revealed an acceptable power factor of 0.8 for both the whole farm and the test layer shed averaged. During the intense monitoring period, the feedmill power factor dropped to an undesirable ratio of 0.2. This may be a result of the motors being over-specified or if they are running with no load.

The electrical energy efficiency of egg production was analysed by calculating energy use (kWh) per kilogram of egg produced and by the energy used per bird. The test shed alone had an average energy efficiency of 0.15 kWh per kg of eggs produced. Average energy use for the total farm was 0.25 kWh per kg of eggs produced. The total farm result is skewed as the electricity consumpltion monitored also includes external components such as the grading floor and rearing shed. As expected, electrical efficiency in winter was better due to lower cooling requirements.

The energy use per production unit was higher than other tunnel-ventilated farms in other research. This may be due to electrical monitoring for the study farm including all facets of the site. The study site was also located in a warm sub-tropical climate which requires greater cooling during summer. A direct comparison of farms during the same time period is recommended to compare energy efficiency between different production systems.

The ventilation performance of a single layer shed was during minimum ventilation (cold) and maximum tunnel ventilation (hot). Results from both maximum and minimum ventilation trials showed that the temperature increased by several degrees towards the exhaust fan end of the shed. There was also a few degrees temperature difference at different heights in the shed, with the bottom cooler than the top. These results are due to poor air flow patterns. This is a problem for the design of the ventilation system, especially during summer conditions. Air mixing can be improved by rectifying inlet placement, opening sizes and airspeed at the inlet to achieve adequate mixing of cold and warm air.

During both trials the sheds ventilation control system was responding to a single temperature sensor within the shed. The differences in temperature throughout the shed highlight the difficulties and error created when this occurs. It is highly recommended that the shed control system be programmed to operate on the average of several sensors located throughout the shed.

The layer shed temperature in winter fell below the minimum recommended level for optimum layer production of 21°C at the shed inlet. Reducing air leaks will improve bird comfort and productivity, if results are not achieved, additional heating (via gas heaters) should be considered. During hot conditions (ambient temperature 40°C), shed temperature reached 30°C, this is several degrees above the controller set point of 26.5°C but still within the recommended bird health temperature limits.

The apparent temperature (wind chill effect) was calculated for the shed under maximum (tunnel) ventilation conditions. Wind chill effects reduced the temperature felt by the birds by approximately 2-3°C and to within the recommended temperatures and climate conditions for optimum layer production of between 21 and 26.5°C.

Total shed ventilation performance (air-flow volume) under maximum tunnel ventilation conditions was assessed and found to perform below the manufacturer's specifications. It is recommended to service and maintain the fans to improve ventilation rate.

1 Introduction

1.1 Background on the Industry

The Australian Egg Corporation estimated that over the past five years, the demand for eggs has increased by 20 per cent. These eggs are produced mainly in cage housing systems with barn laid (cage free) and free range systems making up the balance. In order to meet more stringent animal welfare requirements, egg farmers have had to undertake extensive capital reinvestments in larger cage sizes and subsequently new sheds. This has led to a reduction in the number of egg producers.

Sheds fitted with modern environmental cages have computerised climate control with tunnel ventilation. Most of these sheds also have automated feeding systems and many are fitted with manure belts under the cages that collect the manure and automatically remove it. These belts are also often fitted with a drying system that removes moisture from the manure to optimise the shed environment and hence improve production. Cages are designed to allow eggs to roll clear of the hens for daily collection. Collection is generally done automatically via conveyor belts. The modern cages produce superior bird performance and reduce overall labour requirements, compared to the older cage systems.

Free range systems comprise weatherproof buildings where hens can roost, lay, drink and eat. Adjoining the shed is an open-aired outdoor range. The sheds protect the birds from the elements and predators while the free-range area allows them access to open space and vegetation. Barn laid systems generally comprise an automated nesting system, with the hens group-housed in weatherproof sheds with litter and perches. Increasingly, free range and barn laid systems have automated nesting, feeding and watering systems.

To remain competitive and meet the demand for eggs, the industry recognises the need for it to continue to make significant gains in areas of technical and cost efficiency. Whilst agriculture is excluded from the carbon tax, egg producers will still experience increased input costs (energy and transport) via those sectors included in it. Increasing the efficiency and maintaining profitability of egg production systems and ensuring bird welfare are key outcomes for the Australian Egg Corporation Limited.

The key components of an egg production farm are the layer sheds and packing shed. A farm may also include a feedmill, grading floor, office, workshop and rearing sheds.

Cage egg production represent about 55% of eggs sold in the retail market in Australia (AECL 2012), as this is currently the most cost-effective system and most consumers purchase their eggs based on price. Cages represent 69% of the laying facility (G. Runge, pers. comms. 2013). Cages are designed to allow eggs to roll clear of the hens for daily collection. Egg collection is either manually or automatically via conveyor belts. Modern cages produce superior bird performance and reduce overall labour requirements. However, they require a higher capital investment cost per bird.

The Model Code of Practice for the Welfare of Animals – Domestic Poultry 4th Edition (2001) was introduced in 2001. It included new requirements for cage dimensions and stocking densities. During the next nine years, the egg industry invested in new cage facilities that met the new requirements.

84% percent of cage layer sheds fitted with welfare compliant cages are thermal, environmentally controlled facilities that require ventilating systems to exchange air and maintain acceptable indoor thermal conditions all year round (G. Runge, pers. comms., 2013). The remainder are naturally ventilated. Tunnel ventilated sheds draw air through evaporative cooling pads at one end of the shed and exhausted by large capacity fans at the opposite end during hot weather. Tunnel ventilated houses also have a minimum ventilation system for supplying ventilation during cold weather. One or more fans draw air through small inlets mounted in the sidewalls. All sheds have automated feeding and manure removal systems. Manure belts under each deck of cages collect the manure and remove it from the sheds on a regular basis. In locations that experience cold wet winters the cages above each belt are fitted with a drying system that removes moisture from the manure to optimise the shed environment and hence improve production. Six percent of the cage facility capacity in the southern states are cross flow ventilated rather than tunnel ventilated (G. Runge, pers. comms. 2013).

There is 1.3 million hens capacity (7.9% of total capacity) from alternative production system housed in tunnel ventilated sheds (G. Runge, pers. comms., 2013).

Tunnel ventilation systems are typically designed to achieve a specific minimum air velocity down the shed at maximum ventilation. Exhaust fans are the key component of mechanical ventilation systems. Exhaust fans are used to create both airflow and air exchange. The fresh air conveyed by the fans supplies oxygen to the animals and removes heat, moisture, and aerial contaminants from the shed. Exhaust fans are usually selected by a designer based on a fan performance characteristic. Proper environmental control relies on the fan capacity to supply the required volume of air as well as properly configured and operated inlets for fresh air.

Egg producers have invested in new sheds or retrofitted older sheds to operate in tunnel ventilation mode. Shed design and tunnel ventilation technologies have been imported from overseas manufacturers and adapted to Australian conditions. There is limited data available on the on-farm performance of tunnel ventilated sheds.

Energy is a key input to egg production that is under increasing price pressure. Energy cost pressure and increasing food safety and environmental regulation affects feed production efficiency, breeding, rearing, egg production and packing and grading; all having the effect of increasing production costs and influencing upon the sustainability of the industry.

Electricity consumption dominates energy usage for environmentally controlled sheds. Electricity is required for running fans and lighting, and for running feed and water lines. Average electricity usage for the tunnel ventilated farms investigated by Wiedemann & McGahan (2011) as part of a Life Cycle Assessment project for the Australian egg industry is shown in Table 1-1. Energy usage varied by 66% between the highest and lowest user. The range suggests that there may be scope for improvements in electricity efficiency.

Table 1-1 - Average electricity usage across three environmentally controlled egg production operations

Production system	Units	Farm A	Farm B	Farm C
Caged layer hens	kwh / hen / yr	2.19	3.00	1.69
Caged layer hens	kwh / kg eggs	0.109	0.154	0.093

To address these issues, a study has begun to increase the knowledge base of the egg production sector on how energy usage affects their enterprise and the performance efficiency of tunnel ventilated sheds. This will provide producers with information that will enable them to achieve new ways of improving energy use and ventilation efficiency leading to direct economic savings.

1.2 Project Description

The Australian egg industry faces a number of key challenges including increasing competition; pressures on operating margins and profitability; increasing costs of business inputs; and higher expectations by consumers and the community in general (particularly in the areas of environmental management and animal welfare).

All sectors of the Australian egg industry are reliant on a sustainable business environment to ensure their future. Many factors impinge on this sustainability, with a key factor being the environmental impact of their business. Optimising resource usage (energy) is one method of improving both the economic and environmental sustainability of an egg business. This will provide the general public and the consumers with additional confidence that the egg industry is proactively addressing sustainability issues.

Energy usage is a key input to egg production that is under increasing price pressure. Energy cost pressure and increasing regulation would affect feed production efficiency, breeding, rearing, egg production, packaging, grading and transportation – all having the effect of increasing production costs and seriously impacting upon the economic sustainability of the industry. The key economic benefits of this study will be an increase in the knowledge base of the egg production sector on how energy usage affects their enterprise and the performance efficiency of tunnel ventilated sheds. This will provide growers with information that will enable them to achieve new ways of improving energy use and ventilation efficiency leading to direct economic savings.

Explicit economic benefits include:

- Optimisation of layer shed ventilation performance and energy efficiency
- Determine the feasibility/design of alternative on-farm energy systems
- Optimise whole system performance
- Identify the most cost effective options for shed environment management

Increased knowledge at the producer level on how resource use impacts on their enterprise will provide producers with information that will enable them to achieve improvements in resource use, leading to direct economic savings.

The community and market place demand that the egg industry demonstrates sustainable natural resource management. To ensure the long-term sustainability of the industry and of individual farms, the management of environmental issues has and continues to be, a high priority. Hence, it is imperative that the egg industry be prepared for future questions about its environmental sustainability in terms of resource efficiency.

Quantifying energy usage and developing cost-effective shedding that incorporate environmental management and design strategies will enable egg producers to demonstrate the sustainable management of resources from which energy is derived. The shed environment and animal welfare will not be compromised to achieve energy reductions; the two aspects will be implemented in tandem to achieve positive production and economic outcomes. Therefore, the industry can demonstrate to the consumer the production of high quality ‘clean and green’ products in an efficient and sustainable production system. Ultimately, this will affect local consumption for Australian egg products.

1.3 Project Description

The objectives of the project are to:

- Quantify energy use and energy use profile for an egg production farm, including the different layer-shed components and the variation in energy use over one year (all seasons)
- Assess tunnel ventilated layer-shed design from a ventilation and energy efficiency perspective and to compare performance data with manufacturer specifications
- Provide actual segregated energy use data

The outcomes of the project include:

- Quantified resource usage (energy) of egg farms and standardised (e.g. per bird, per weight of eggs)
- Information to assist egg producers to reduce their energy usage.
- Identification of 'hot spots' where high levels of energy usage occur on farm and within layer sheds
- Proposed management / R&D options to reduce energy usage in a targeted, efficient way
- Evaluation of ventilation efficiency and fan performance in tunnel ventilated layer sheds
- Proposed management / R&D options to improve tunnel ventilation efficiency and fan performance in a targeted, efficient way
- Comparison of energy usage, ventilation efficiency and fan performance from Australian egg production with international research for egg production in the published literature
- Dissemination of results to the Egg Industry by conducting two workshops

The outcomes of this project will allow the Australian Egg Industry and individual producers to develop a better understanding of the annual on-farm energy usage, and the relative contributions that various on-farm components have on annual energy usage.

Characterising energy usage profiles within layer sheds will be used to improve shed efficiency and operation. Evaluation of ventilation efficiency and fan performance in tunnel ventilated layer sheds will provide an independent assessment against which producers can compare design data. Evaluation of tunnel shed ventilation system performance will provide the Australian Egg Industry with some rules of thumb for on-farm ventilation efficiency, fan performance and peak energy demand.

2 Systems design and literature review

2.1 Total energy use

Energy is fundamental to an egg production farm, with a reliable energy supply required to operate a range of equipment. Despite this, there has been little research into energy use by egg production farms. Rather, the energy requirements of egg production farms have been estimated from several studies undertaken in North America in the 1970's and 1980's. In a 2012 study investigating the Life Cycle Assessment of Australian egg production, Wiedemann & McGahan (2011) collected some data on total energy usage of Australian egg production farms. They found that whilst total energy supply data was available it was difficult to separate usage into activities.

Egg production farms use energy to operate machinery and equipment, to heat or cool buildings, lighting and office equipment and indirectly through incoming birds and eggs and commodity delivery. Energy use is primarily electricity used in shed lighting and ventilation, egg grading and processing equipment, feed preparation, cooling in offices and staff amenities and water supply. Natural gas or Liquid Petroleum Gas (LPG) is also used for shed heating (particularly rearing). Diesel is used to operate vehicles, trucks, tractors and other mobile machinery for feed delivery, waste management, back-up generators, administration and water supply.

Indirect energy is consumed off the farm for transport of chickens, spent hens, and eggs and in the delivery of feed and commodities.

2.2 Energy use in individual activities

2.2.1 Feed management

Feed management involves diet preparation and quality control, nutrient balancing, mixing and delivery to the birds. Diet preparation includes unloading, movement, storage and processing of grains and additives. The delivery component includes transport of the diet from the on-site preparation area to the birds.

As with other intensive livestock production, layer and rearer birds require a diet that meets both production and economic performance demands. Typical diets generally contain a high proportion of cereal grains on a dry matter basis and hence, infrastructure associated with grain processing is a predominant component of the feed preparation facility.

The feed preparation facility consists of a composite of simple components and processes. The major components may include grain storage structures, handling equipment, grain processing and feed mixing operations. Whilst many of the components are interactive, component design, selection, maintenance and operation can influence the overall energy efficiency of the feed preparation facility. Electricity is the predominant energy source. It is utilised in the operation of electric motors in grain handling and processing activities. Gas and diesel may also be used in boilers for heat/steam generation if pelleted feed are being generated. Photograph1 illustrates a typical grain storage and distribution system.

Photograph 1 – Typical grain storage and distribution system

In caged egg production systems, feed is generally delivered to a storage silo at each shed. A conveyor system transfers feed from the silo to the birds via an automatic conveyor system running along the front of the cages.

2.2.2 Water supply

Water is considered an essential nutrient for birds. It is important for a variety of bodily functions that include but are not limited to nutrient transportation, body temperature regulation, lubrication of joints and organs, enzymatic/chemical processes including those related to feed digestion. A large number of factors can influence water usage in the bird's body and include environmental temperature, relative humidity, health status of the bird (especially intestinal health), diet formulation, presence or absence of feed, and even genetics (Czarick & Fairchild 2006).

Drinking water is generally reticulated through the cages by a water system delivering water at controlled pressure to the nipples. Therefore, the birds drink from a clean nipple rather than from an open water surface. The drinking water is supplied through lines of nipple drinkers that are positioned above the birds' heads to conserve water and leaking (Houldcroft et al. 2008). A drinking water delivery system at a cage layer shed in shown in Photograph 2.

Photograph 2 - Drinking water delivery

2.2.3 Egg collection and grading

Modern caged layer production sheds have egg collection belts on each row of cages that bring eggs to the main collection conveyor. The main egg collection conveyor then connects each layer shed to a grading/packaging shed complex by running across the front of each row of cages in each layer shed and between each layer shed to the grading shed complex.

From the main egg collection conveyor, eggs are delivered to the grading/packaging shed complex from the layer sheds. Alternatively, the eggs are packed onto flats for delivery to a contract grading and packaging facility. This type of facility includes a cool room. Grading and processing generally involves accumulating the eggs, egg washing, candling, grading/sorting and packaging. After packaging eggs are stored in a cold room before dispatch and distribution.

Egg collection, sorting and processing involves the use of electric motors to operate the various equipment. Photograph 3 shows eggs being delivered from the cage egg collection belt to the main conveyor that transports them to the packaging or grading floor.

Photograph 3 - Egg collection belts

2.2.4 Shed energy use

2.2.4.1 Waste Management

In modern environmentally controlled sheds, manure is collected on belts that run directly under each cage tier, similar to that shown in Photograph 4. These manure belts are driven by electric motors and often fitted with dryers above to dry the manure before it leaves the shed. Manure belts are generally operated one to three times per week, where the manure is transferred to a cross conveyor at the fan end of the shed, where it is further transferred to a collection vehicle or storage bay.

Photograph 4 - Manure collection belts (left) and manure belt motor (right)

2.2.4.2 Lighting

Artificial lighting is required in total enclosed tunnel ventilated sheds to provide a constant day length and at a uniform luminance or intensity to ensure their comfort and optimum performance. Lighting is also required for workers performing management activities.

Lighting needs vary with production type and task. The amount and length of time light is required by the birds is different from what the worker requirements. The luminance or intensity of lighting is controlled by a dimming system. Clarke & Ward (2006) provide a lighting guide for poultry production for light levels and photoperiod requirements directly associated with production. They note that a properly designed, energy efficient light system enhances productivity, and saves on maintenance and electrical operating costs.

While lighting costs vary across farms depending on the number of lights and type of lighting system used, lighting can account for a significant proportion of electrical energy use (DERM 2010). Farms have changed from high wattage incandescent lights as their main light source to more energy efficient fluorescent lighting. Further savings may be possible by implementing light-emitting diode (LED) lighting systems.

Modern electronic dimmers reduce light output by electronically reducing the voltage going to the light bulbs. As the dimmer is turned down, the voltage going to the bulbs is reduced, which in turn reduces both light intensity and power usage (Czarick & Lacy 1997). Dimmer switches are now also available with LED lights.

2.2.4.3 Ventilation System

Layer sheds fitted with welfare compliant cages are thermal, environmentally controlled facilities that require ventilating systems to exchange air and maintain acceptable indoor thermal conditions all year. During hot weather conditions, sheds operate in tunnel ventilation mode, in which air is drawn through evaporative cooling pads at one end of the shed and exhausted by large capacity exhaust fans at the opposite end, as displayed in Photograph 5.

Tunnel ventilation systems are typically designed to achieve a specific minimum air velocity at maximum ventilation. Exhaust fans are the key component of mechanical ventilation systems. Exhaust fans are used to create both airflow and air exchange. The fresh air conveyed by the fans supplies oxygen to the birds and removes heat, moisture, and aerial contaminants from the shed. Exhaust fan selection is based on the fan performance characteristic. Proper environmental control relies on the fan capacity to supply the required volume of air as well as properly configured and operated inlets for fresh air. The operation of the exhaust fans represents the single largest energy use in tunnel-ventilated sheds. A small number of sheds in the southern states are cross-flow ventilated, rather than tunnel ventilated.

Photograph 5 - Tunnel ventilated shed - exhaust fans

2.3 Ventilation systems

Exhaust fans are key components of mechanical ventilation systems in confined animal housing facilities for pigs and poultry (Casey et al. 2008). Properly operating exhaust fans create an air pressure difference between the inside and outside. This air pressure difference, known as static pressure, causes the airflow that produces the required air exchange in facilities housing egg producing birds.

Depending on the type of ventilation system, there may be negative, positive or neutral pressure inside the shed compared with the outside. The most common system is a negative pressure or vacuum system. With this system, the exhaust fan(s) create a slight negative pressure, which causes air to enter the shed through designed inlet structures.

Positive pressure systems do the opposite, where fans blow air into the shed to create a positive pressure and air escapes through designed outlets. This system is not used in poultry sheds as there is little control over air movement patterns in the shed and it often causes building materials including insulation to deteriorate because of moisture ingress into the building cladding.

Mechanical ventilation systems in environmentally controlled layer sheds in Australia consist of three major components: fans, openings and controls. Fans and openings control the amount of air exchange and impact on the air distribution and mixing. Controls are needed to adjust the ventilation system as weather and bird numbers change (Dunlop 2011).

Runge (1999) describes the three modes of ventilation used in tunnel ventilated poultry housing (i.e tunnel or hot weather ventilation, good weather ventilation and minimum or cold weather ventilation):

> *Tunnel ventilation is the use of more than half the available fans to ventilate the house. It is used when the outside temperature is greater than that required by hens, usually at least 1-2^oC above. It uses wind chill effect to cool the hens. If house temperature rises above 28^oC - 30^oC additional evaporative cooling is required.*

Good weather ventilation is used when the ambient or outside temperature is similar to that required by the hens. Either natural or fan ventilation is used. With natural ventilation, curtains are fitted in both sidewalls and the amount of opening is controlled by a controller attached to winching devices or by manual adjustment of the winches. The shed is operated in good weather mode when the outside temperature is 1 – 3°C below or 1-2°C above that required for the hens.

If fans are used instead of natural ventilation the sidewalls can be solid with the house relying entirely on fans for ventilation. Up to two thirds of the tunnel ventilation fans are on and air is pulled in through the tunnel ventilation inlets. The number of fans on is dependent on the heat load in the house. This is related to density of hens.

Minimum or cold weather ventilation is used to maintain house air quality when the temperature outside is 1–2°C less than that required by the hens. The temperature difference between inside and outside is dependent on the heat produced by the hens. The ventilation rate must be sufficient to remove moisture, gases such as ammonia and carbon dioxide, maintain oxygen levels and yet keep enough of the hen body heat in to maintain house temperature. Up to half of the tunnel ventilation fans are used. The air is drawn in through special minimum ventilation inlets to ensure the cold air is mixed with warm shed air before coming in contact with the hens.

2.3.1 Tunnel ventilation

Research carried out over 40 years ago by Drury and Siegel (1966) lead to the better application of stirring fans in a meat chicken shed with two rows. Further advancements lead to the development of tunnel ventilation that provided better fan insulation efficiency, improving the performance of meat chickens in summer. The foundation for understanding wind chill effect was also provided in this study. Researchers observed that body temperatures did not stay elevated after a thermal stress for as long at high air velocities, when compared with lower velocities.

Tunnel ventilation was originally developed for birds on litter, meat chickens and breeders, before later being adapted for multi-tiered caged sheds. In a tunnel-ventilated shed, exhaust fans are located in one end of the building and two large openings are installed in the opposite end. Air is drawn through these openings and then down the long axis of the shed through the fans. The air can be cooled by drawing it through evaporative cooling pads, or by the use of misting nozzles located throughout the shed (Czarick and Tyson 1990).

The most significant difference between tunnel ventilated and conventional housing is the uniformity of air movement. In conventional curtain sided housing, a significant level of air movement only exists in limited areas around each circulation or stirring fan. In tunnel ventilated sheds for birds housed on litter, air velocity at bird level remains relatively constant from the inlet end to the fan end of the shed (Czarick & Tyson 1990).

The air velocity in a tunnel ventilated shed is greater than that in a conventional cross-ventilated arrangement with similar rates of air exchange (Lott et al. 1998). The amount of air exchange required depends on animal size, stocking density, type, and incoming air temperature (Casey et al. 2008).

2.3.2 Exhaust fans

Exhaust fans are used in mechanical ventilating systems to supply the energy needed to exchange the amount of air required in the shed.

The amount of air an exhaust fan moves depends on the blade diameter, blade shape, rotational speed, and other associated attachments like shrouds or louvers. Fan capacity is measured in cubic feet of air per minute (CFM), or in SI units, cubic meters of air per hour, at specific static pressure levels.

Fan staging is an effective ventilation management tool. This involves a controller managing the number of fans running. A greater ventilation rate occurs when more fans are on in response to ambient temperature and the birds' requirements. Single-speed fans can be staged to regulate ventilation airflow from minimum to maximum rates as required. One or more fans can be used to provide the minimum required rate for winter moisture and ammonia control. As the outside temperature rise, more fans are needed for both air exchange and temperature control. Minimum ventilation would be considered stage one, the next fan(s) turned on would be stage two, the third fan(s) stage three, and so on.

Three major decisions are needed in order to stage a set of fans: 1) the number of stages needed; 2) the set point temperatures that will activate each stage; and 3) the magnitude of airflow needed at each stage (University of Kentucky 2010).

2.3.3 Shed openings

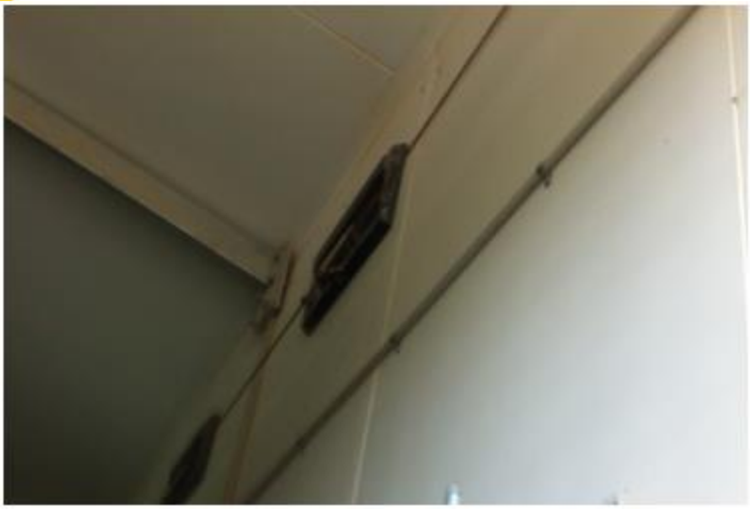
Inlets are needed to allow air into a negative pressure system to control direction of airflow and maintain sufficient inlet air velocity to ensure mixing the cold air before it comes in contact with the birds. The ventilation requirements change based on the number of birds and time of year.

There are various types of inlet designs for negative-pressure systems. A typical inlet design is shown in Photograph 6. In this design, a moveable bottom-hinged baffle can be adjusted to control the size of the opening as conditions change (University of Kentucky 2010).

Unplanned inlets need to be minimised to provide control over the ventilation system. Unplanned inlets include openings such as cracks around door, openings around manure handling or for feed and egg conveyors. Minimising unplanned inlets allow the ventilation system to bring in air through the designed inlets for more control over ventilation air distribution (University of Kentucky 2010).

Tunnel inlet openings are placed on the opposite end of the building from the exhaust fans. Due to construction practices, they are often positioned in both sidewalls, rather than the end wall (University of Kentucky 2010). In cooling pad systems, the shed's air inlet is through the cooling pad as shown in Photograph 7.

With good ventilation system design and management, including inlet design and control, conditions in the shed can be maintained within the bird's comfort zone (University of Kentucky 2010).



Photograph 6 - Inlet vents alongside of layer shed

Photograph 7 - Cooling pads from outside of layer shed

2.3.4 Controlling and monitoring ventilation

Proper ventilation is essential to maintain suitable conditions in the shed buildings, which have a direct effect on animal welfare and productivity. Environmental parameters such as temperature, relative humidity, air velocity and air quality inside the shed are controlled automatically by ventilation, heating, and cooling equipment. Mechanical ventilation equipment consists of inlets and exhaust fans.

Ventilation rate influences heat, moisture and gas balance, and thus it affects the indoor temperature, relative humidity and gas concentration (Blanes & Pedersen 2005).

Ventilation control is achieved by adjusting the air inlet opening and the airflow (by switching fans on or off, or by adjusting fan speed).

Airflow from exhaust fans varies significantly with the static pressure that a fan works against (Casey et al. 2002). Static pressure is the parameter most commonly used to adjust the opening of inlets in mechanically ventilated sheds (Blanes-Vidal et al. 2007).

2.3.5 Air velocity

Tunnel ventilated sheds with inadequate ventilation systems can suffer high mortality rates when the air inside the building is hot, humid and nearly still in the microenvironment close to the birds.

To maintain the optimum environmental conditions in layer sheds in summer time in Australia most environmentally controlled layer sheds today are being designed to obtain an air speed of between 2.5 and 3.0 m/s. Czarick (2004a, b, c) note that for litter based sheds, the design air speed is the average air speed and air speed will vary significantly across the cross-section of a shed. Air speeds will tend to be higher in the centre of the shed compared to the side walls and higher at the ceiling than near the floor. The reason for the variation is that air will tend to take the path of least resistance. This uneven air speed will likely be exacerbated in layer sheds, where the infrastructure causes the air to channel down the alley-ways between the tiers of cages.

2.3.6 Ventilation effiency and performance

A study by Webster and Czarick (2000) on ventilation performance in a tunnel ventilated, high rise, commercial layer shed during winter and summer found differences in average daily temperature occurred amongst different areas of the layer house. In winter, the centre was coolest while intermediate sites tended to be warmest. During summer, the centre was again coolest, with end sites being warmest. Furthermore, egg sizes in different areas of the shed followed seasonal variations in temperature. The centre sites had the largest eggs during the winter and summer months. The intermediate sites tended to have the smallest eggs from January to March. Correlation calculations indicated that in all months of the study smaller eggs were laid in areas of the house that had higher temperatures. The authors suggested that egg size variation amongst different house areas might be reduced in winter by covering the outside of the tunnel inlet, and in summer by using only the temperature probes nearest the fans as a basis for controlling fan operation at night when in tunnel ventilation mode.

Tunnel ventilation systems are typically designed to achieve a high velocity of 2.5 to 3.0 m/s over the average cross sectional area of the house. In tunnel ventilation mode, the fans operate against 2.5 to 30 Pa of static pressure, and it is generally recommended to keep static pressure low to maximise airflow rate and velocity (Casey et al. 2008). Exhaust fans are fitted with safety guards, shutters, or other accessories, such as discharge cones. Guards and shutters reduce the airflow and fan efficiency, whereas discharge cones increase airflow (Casey et al. 2008).

A study by Calvet et al. (2010) on ventilation rates in mechanically ventilated commercial poultry buildings found that the flow reduction in relation to the manufacturer values varied between fans from 1% to 19% in large fans and from 3% to 24% in small fans. The differences between measured and theoretical (manufacturer) flows were within the range of those reported by Simmons and Lott (1998), who found a 10.9% reduction by shutters alone and 24% in old, dirty fans. However, this reduction was lower than the results from Casey et al. (2002), who found an average 28% reduction in a broiler house. (Janni et al. 2005), found reductions between 10% and 75% in pig housing exhaust fans because of a combination of factors including belt slippage, dust and dirt accumulation on the guard and shutters, and corroded shutter linkages that limited the function of the shutters. Casey et al. (2008) also found a higher variability between fans (24%), which was attributed to accumulated dirt and corrosion, differences in the resistance to flow imposed by the shutters, and differences in motor and bearing wear due to run time and aging.

These studies highlight that actual ventilation rates from in-situ exhaust fans are lower than manufacturer's theoretical values, due to ageing, dust and the presence of shutters. A reduction in the actual ventilation rate could impair the indoor thermal and air quality, and also can result in a reduced energy efficiency (Casey et al. 2008).

In an earlier study on exhaust fan performance, (Casey et al. 2008) found that mechanical condition and degree of maintenance can significantly affect actual fan capacity.

2.4 Ventilation measurement techniques

Ventilation rates are often evaluated by measuring air velocity, temperature and relative humidity and using direct measurement tools (Boon & Battams 1988, Lee et al. 2003, Wheeler et al. 2003a, Wheeler et al. 2003b).

However, there are three main negative aspects associated with direct measurement of air velocities:

- The number of points that can be measured is limited, making it difficult to obtain a comprehensive knowledge of indoor air velocity patterns;
- Direct measurement requires a measurement agent, which unavoidably interferes with the air velocity and therefore distorts the measurement output.

A summary of ventilation measurement techniques is provided in Table 2-1.

Table 2-1 - Comparison of ventilation monitoring methods

Project Aim	Type of Ventilation System	Method	Parameters Measured	Auth
Measure airflow in a mechanically ventilated building	Mechanically ventilated commercial poultry building	Air velocity sensors & air temperature sensors were placed in pairs on a mobile mast. These were positioned at 3 different heights & the mast moved to different locations. Measurements were taken simultaneously from all sensors every 0.5s. Data taken at each location was averaged over the whole measurement period. The anemometer was used to manually take measurements outside of the building and the mean air velocity at each air inlet and at specific coordinates of the outlets. Air velocity was measured at the end of the fan duct. Wall temperatures at internal solid surfaces were measured 3 times with the infrared thermometer. 15 locations per surface; roof at fan side, roof at inlet side, wall where fans and inlets were located	Air and Wall temperature Air velocities Differential pressure	Blanes Vidal e (2008)

Effect of VFD control system on energy consumption	Tunnel ventilated poultry houses, equipped with heating units	Temperature and humidity were measured at four locations along each house at the bird's height. Electricity meters were used to monitor electricity consumption of the fans. The temperature and humidity sensors at the centre & with output of contactors indicated time of operation	Temperature, humidity, electricity consumption and run-time of each fan	Teitel e al. (200
Study AFRs in a naturally ventilated buildings	Naturally ventilated cowsheds	Measurements of temperature and relative humidity were carried every minute out using sensors/loggers positioned at four locations inside the building and two locations outside. Ambient wind conditions were measured by means of a weather station. The measurements of ventilation rates were carried out using three methods; heat balance (temperature), tracer gas tech. (impulse) and CO^2 balance (gas concentration) The trace gas under consideration was Krypton-85, where the decay of radioactive isotope 85Kr was implemented. The tracer gas was distributed four to five times each summer and winter season	Temperature, humidity and wind conditions	Samer al. (201
Develop a system to measure ventilation	Mechanically-ventilated commercial broiler farm	The flows exhausted by each fan were determined at different levels of pressure drop in order to obtain individual performance curves. Ventilation rates were calculated from the average air velocity at the exhaust. The time of operation of each fan and the relation between ventilation rate and pressure drop was measured for each fan section and the surface exhaust area	Air velocities Differential pressure	Calvet al. (201
On-farm ventilation fan performance evaluation	In-field measurement of fan performance at broiler houses	The measurement of the supply voltage, current draw and power consumption of the fan was made using a power analyser. The static pressure was monitored using a digital manometer, the output from a differential pressure transducer was also recorded by a data logger once per second Fan speed was measured using a non-contact digital tachometer The ventilation control system at the site used individual thermostats on each fan and a logger recorded run time	Temperature Run-time of each fan Fan Speed Static pressure Power consumption	Casey al (200
Dew point as a control parameter for ventilation	Mediterranean poultry house, equipped with conventional cross-ventilation by	A computerized velocity, temperature and pressure variation sensing system measured air velocity. Air velocity sensors were RTD's. Air velocity was estimated by means of constant T hot	Air velocity Differential pressure	Blanes Vidal e (2007)

	negative pressure.	wire anemometry. Differential pressure was measured with the differential pressure sensor. For indoor measurements air velocity sensors were placed in pairs, on a mobile post at three heights		
Heat balance for two commercial broiler barns with solar preheated ventilation air	Commercial broiler barns, solar preheated vent air Thermocouples control the ventilation system	The inside air temperature and humidity was measured at a floor height temperature of the incoming fresh air was measured at two locations inside the air inlets. Heat production was monitored on one heater per floor, and running time was logged. The ventilation rate was monitored by recording the rotational speed of one fan per floor. The air flow rate was computed from a correlation obtained using a Balometer, during which the volumetric air displacement of all 400mm fans was measured at a rpm varying from 55 to 100%. A Hobo data logger recorded all readings every 5 min. a weather station that recorded the ambient climatic conditions, namely wind velocity and direction, ambient air temperature and relative humidity To verify the performance of the ventilation system infra-red images were taken inside building	Temperature CO_2, Humidity Thermal Imaging	Cordea & Barring (2010)
		Inside and outside air temperature and relative humidity measured by temperature and humidity sensors. Measurements were generally made at 15 min intervals changing among the poultry houses from time to time & avg. calculated for 2 hourly periods in 24 hr. The outside air temp & relative humidity was measured through shielded weather stations. Then calculated averages of data were used for the calculations	Humidity Temperature	Mutaf e al. (200
Use and efficiency of air mixing fans in a broiler building	Commercial broiler building	Temperature was measured at 120 points throughout the building. The sensors were encapsulated thermistors (5k resistance at 20C). A grid of 10 of 5 thermistors was installed 0.15m from the floor paving; there being one row in each bay and one row adjacent to an end wall. Alternate rows were supplemented by a further 14 thermistors, installed in a vertical plane, which were suspended from straining wires running the length of the building 200 channel data logger was used with the data recorded on magnetic tape for	Temperature Wind Speed	Boon & Battam (1988)

		subsequent transmission to either a mainframe of micro-computer. Air speeds within the building were measured with a flow analyser with six measuring heads to check that the speeds were not above the recommended maxima for young birds		
Fan performance and minimum distance required between fans	Tunnel ventilated shed	The volumetric flow rate of the stationary fan was measured with an anemometer array especially constructed to perform equal area traverses on large ventilation fans. A mechanical drawing of the device is shown in Fig 3-2. Five propeller driven anemometers were mounted on a horizontal bar, which was suspended at either end on a linear bearing system. This provided smooth and accurate motion along a track but restricted movement of the support bar to vertical travel always locked into a level position. The support bar was raised and lowered with machined lead screws, which were turned in unison with a length of no. 25 roller (bicycle type) chain and rotated with a small gear motor.	Wind speed Air Flow	Simmo et al. (1998)

3 Materials and methods

3.1 Overview of experimental work

The study was conducted in a number of steps. These included:

1. Select an egg layer farm that is; representative of a tunnel ventilated chicken egg production system in Australia; and has both current design and older style tunnel ventilated sheds.
2. Review the electrical supply and distribution system at the site.
3. Determine suitability of electrical installation to enable cost effective data collection.
4. Design a data collection system for the farm to meet the overall project budget.
5. Set up one shed with intensive data collection to determine loads of individual groups of equipment.
6. Undertake data collection over a 12-month period.
7. Analyse, review and report the data.

3.2 Farm selection

A number of layer farms were reviewed as to their suitability for inclusion in the study. The criteria for farm selection included:

- To provide a representative example of a typical poultry egg facility incorporating on-site feed processing, recently constructed tunnel ventilated sheds (<5 years), egg grading, processing and storage, rearing shed/s and office.
- Tunnel ventilated (not a naturally ventilated shed retrofitted with tunnel ventilation fans).
- Industry standard management practices - no additional procedures undertaken that are not part of typical day-to-day management.
- Within workable distance to the FSA Consulting office in Toowoomba for conducting monitoring.

A farm was selected on the Darling Downs, QLD. FSA Consulting and CEC Electrical (a company based in Dalby that specialises in industrial and agricultural power installations and control systems), undertook a site inspection of the selected farm. During the site inspection at the farm, the existing mains power meter was located and an electrical circuit survey of the farm was completed. From this, a gap analysis was undertaken to determine the quantity and type of power measurement instrumentation required to allow direct or indirect measurement of the major electrical energy processes.

3.3 Farm description

At the start of the study, the selected farm operated five tunnel ventilated egg production (layer) sheds, feedmill, one tunnel ventilated rearing shed, water supply and treatment facility, egg processing and grading complex and office. During the course of the study, an additional tunnel ventilated rearing shed was constructed at the site. The farm uses electricity, diesel, petrol and LPG as energy sources. Table 3-1 summarises the key characteristics of the selected farm. To maintain confidentiality, the farm is not identified by name and will be referred to as Farm A.

Table 3-1 - Local climatic conditions at closest meterological site

Farm Capacity and Design	
Farm Capacity	190,000 birds
Bird Breed	Hyline Brown
No. of Layer Sheds	4 x 30,0000 birds, 1 x 40,000 birds
No. of Rearing Sheds*	1 x 30,000 birds
Ventilation System	Tunnel Ventilated
Tunnel Fans	Multifan 50” (1270 mm) 3 Blade
Grain Processing Method	On-Farm Feedmill - Disc milled
Energy Sources	Electricity, LPG, Diesel

The summer conditions have a mean maximum temperature of 29.6°C and a relative humidity of 64.7% (measured at 9 am). The location of the farm is also characterised by moderate to cool dry winters. The winter conditions have a mean minimum temperature of 5.7°C, mean maximum temperature of 17.5°C and relative humidity averaging approximately 69% (measured at 9 am). The historical average monthly temperature and humidity at the closest weather station are displayed in Figure 3-1.

During hot summer conditions, the shed ventilation and cooling system works at maximum capacity to ensure optimum environmental conditions are maintained and maximum production performance is achieved. The animal welfare code and planning approval scheme require any mechanically ventilated poultry shed (controlled environment) have a standby generator and alarm system. Hence, the farm has installed a back-up power generation system, which automatically starts-up if an interruption to the main electricity supply occurs. The system includes a primary back-up generator that automatically starts to run the whole farm. An additional back-up generator is provided that is used to power the sheds ventilation system (fans) should the primary back-up generator fail.

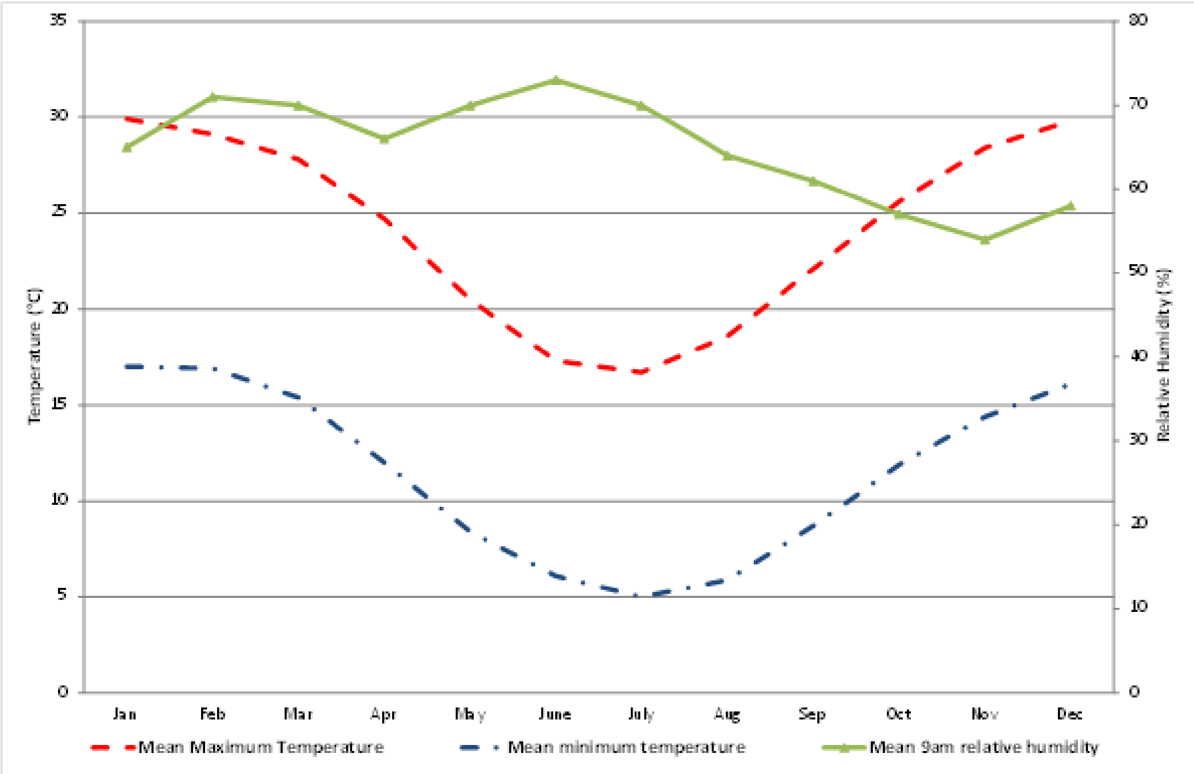


Figure 3-1 - Average monthly temperature and humidity for site

3.3.1 Shed design and ventilation system

The layer sheds are purpose built tunnel ventilated sheds with the same basic arrangement, but with varying dimensions. These sheds are controlled environment sheds with computerised microclimate control and are fully insulated with Bandorpanel® sandwich panel. The walls are 50 mm thick with and R value 1.32 m^2K/W of and the roof is 75mm with an R value of 1.92 m^2K/W. Each shed is fitted with between 10 and 14 (depending on the shed size), 1270mm diameter (50”) 3 blade Multifan exhaust fans at one end of each shed and evaporative cooling pads on each side at the opposite end of the shed to the fans. The cooling pads are 26.7m long and 1.8m high, giving a total area of 48 m^2 along each side of the shed. They start at 4m from the shed inlet end, and finish around 30m along the shed. During full tunnel ventilation mode water is continuously supplied to the cooling pads. The cooling pads are a plastic honeycomb design as shown in Photograph 8. The study shed contained 14 ventilation fans. The fans draw air through the shed and during tunnel ventilation operation, evaporatively cooled air is drawn through the shed via the cooling pads. The rearing sheds are nearly identical to the layer sheds, except smaller dimensions, rearing cage fittings, heat exchanges for brooding and no egg collection belts.

Photograph 8 - Shed 5 cooling pads

All sheds are orientated with their long axis in an east-west direction with the exhaust fans at the western end of the shed. Each shed has an evaporative cooling pad system located at the east end of the shed and a dedicated feed silo. Water is supplied to the sheds from a common supply pump, which delivers bore water at constant pressure through a modern variable speed drive control system.

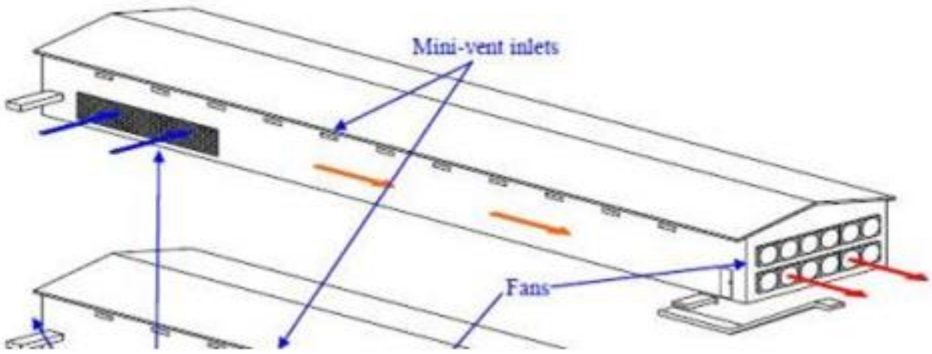


Figure 3-2 - Components of the layer shed ventilation system (Dunlop et al. 2011)

The layer shed, which is the focus of the study, is 110m long by 11.3m wide. The internal side wall height is 4.35m and the gable height is 1.5m. The shed design is cool room sandwich panel walls and roof with metal cladding. The shed has a capacity of 40,000 laying birds. The laying birds are housed in cages set out in four rows with each row containing five tiers of cages.

Drinking water is reticulated through the cages by a water system using lubing layer nipples. Feed is delivered to the laying birds via an automatic conveyor robotic system running along the front of the cages. Manure is collected on belts that run directly under each tier of cages and transferred onto a cross conveyor at the fan end of the shed. A series of cross-conveyors transfer the manure straight into a tip truck. They are manually operated once or twice each week to remove the manure from the shed. In addition to regularly removing manure from the shed, settled dust and feathers are regularly swept or blown out of the shed.

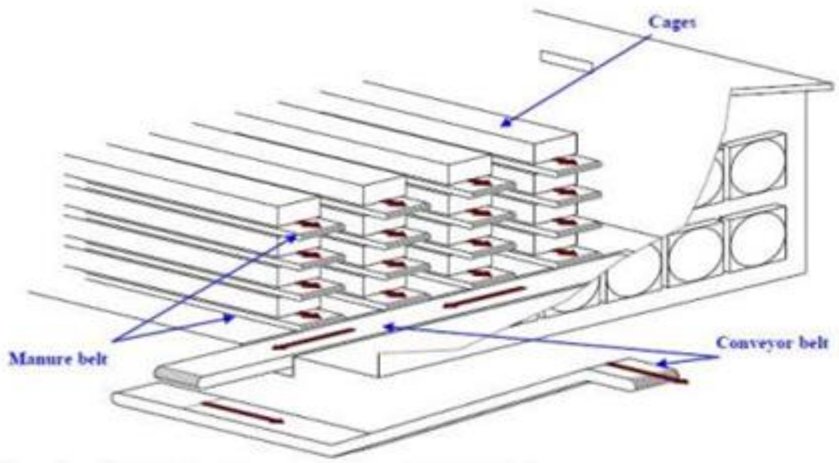


Figure 3-3 - Manure belt system to remove manure from the layer shed (Dunlop et al. 2011)

Eggs are collected automatically via an egg collection belt on each tier that delivers the eggs to the main collection conveyor at the shed inlet end. The main egg collection conveyor connects each layer shed to the grading shed complex.

Upon arrival at the grading shed complex, the eggs pass through the accumulator to the in-line washer where they are washed. From the washer they pass through the handler where they are graded and sized and sorted. Once graded and sorted they are packaged in trays or cartons. The packaged eggs are placed in a cool room ready for transport to market. Reject eggs are packaged, stored in the cool room and then transferred to an egg pulping plant.

Photograph 9 - Egg grading and packaging

The majority of the waste associated with the operation is through manure produced by the laying hens. Manure is collected on belts that run directly under the cages and into a cross conveyor at the fan end of the shed. A series of cross-conveyors transfer the manure straight into a tip truck.

This is removed from the sheds two to three times per week and transported to a stockpile on-site, as shown in Photograph 10. The manure is then composted and either sold off-site or used on farm as a fertiliser for crops and pastures.

Photograph 10 - On-site manure composting

3.3.2 Tunnel ventilated layer shed energy use components

The tunnel ventilated layer test shed at Farm A has various energy use components, which contribute to overall electricity use and cost. Each of the components motor size (power rating) and approximate weekly running time are shown below in Table 5. From this data, a calculation of theoretical power usage from the shed was estimated at about 1250kWh/week excluding fans. (Note: The water pump only runs during warmer months, as it only supplies the evaporative cooling pads).

Table 3-2 - Tunnel ventilated shed energy use components

Component	Motor Size (kW)	Number of Motors	Approx. Weekly Run Time (hrs)	Theoretical Power Use (kWh/week)
Manure Belt (Tiers)	0.37	20	2	14.8
Manure Crossbelt	2.2	1	2	4.4
Egg Elevator Belt	2.2	1	2	4.4
Egg Collection Belt	0.37	4	24	35.5
Egg conveyor (Anaconda)	0.75	2	24	36
Water (Cooling) Pump	1	2	63	126
Feeder Motor	0.3	4	52.5	63
Feeder Cross Auger	2.2	1	24.5	53.9
Fan Motor	1.1	14	Depends on ventilation requirements	
Lights	0.036	226	112	910

3.4 Energy assessment

3.4.1 Energy supply network

As part of the farm selection process, the energy supply network at the farm was reviewed and an electrical distribution flow chart prepared. Electrical energy usage for the total farm, the tunnel ventilated test shed and the processes within the shed (exhaust fans, feed augers, egg collection belts, manure belts, lights and cooling pumps) needed to be measured.

Energy sources include electrical energy, diesel to operate farm machinery and backup generators, petrol and diesel to operate farm machinery, and gas for heating (LPG – propane). LPG gas usage was available from the farm records and invoices paid, however petrol and diesel usage for the farm could not be differentiated from other activities at the site.

The electrical power supply to the farm is from an overhead high voltage power line to a transformer providing low voltage power to the farms main switchboard. The main switchboard distributes power to the various farm activities through separate sub mains. Each tunnel ventilated layer shed is supplied with a separate sub main from the main switchboard. Total farm electrical energy usage is monitored by the power authorities meter located inside the main switchboard. Therefore, total power consumption for the farm can be monitored by taking readings from the main switchboard. Typically, the main power usage includes power consumption to the layer and rearing sheds, the grading shed and the cooler room. To assess the electrical energy usage of an individual shed, activities or components within activities, the installation of additional monitoring equipment is required at a shed level.

Figure 3-4 and Figure 3-5 show the power supply and circuitry of the egg collection system and ventilation system for an individual tunnel ventilated layer shed on Farm A.

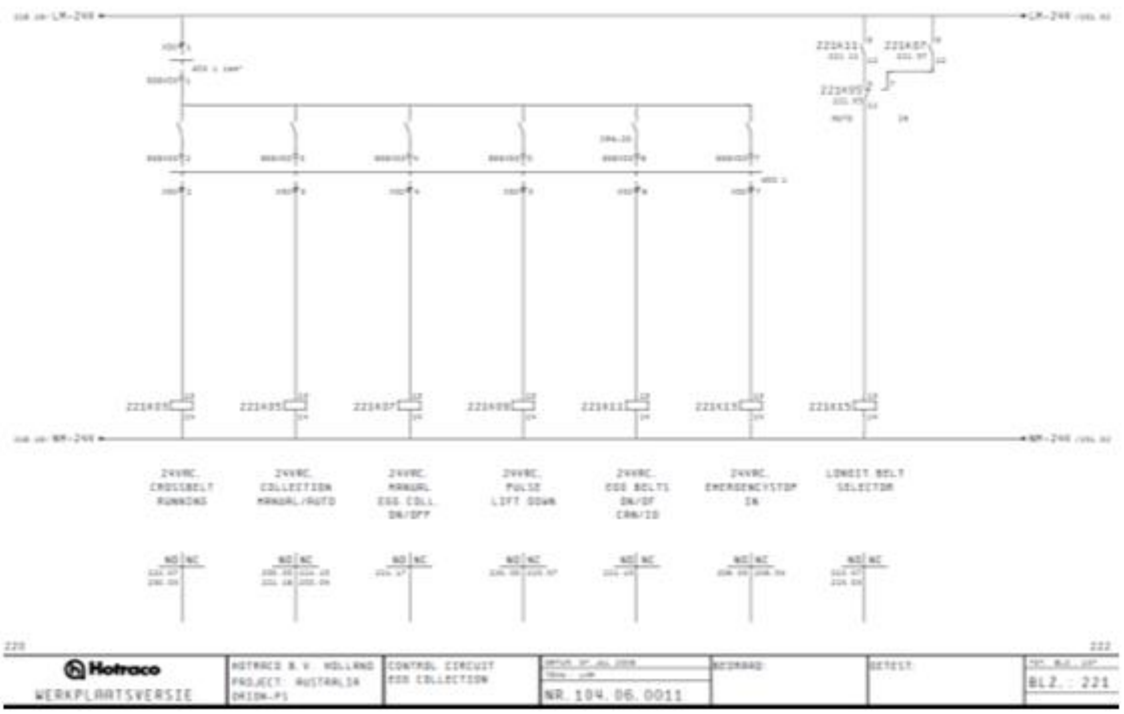


Figure 3-4 - Eletrical circuit for exhaust fans within selected tunnel ventilated shed

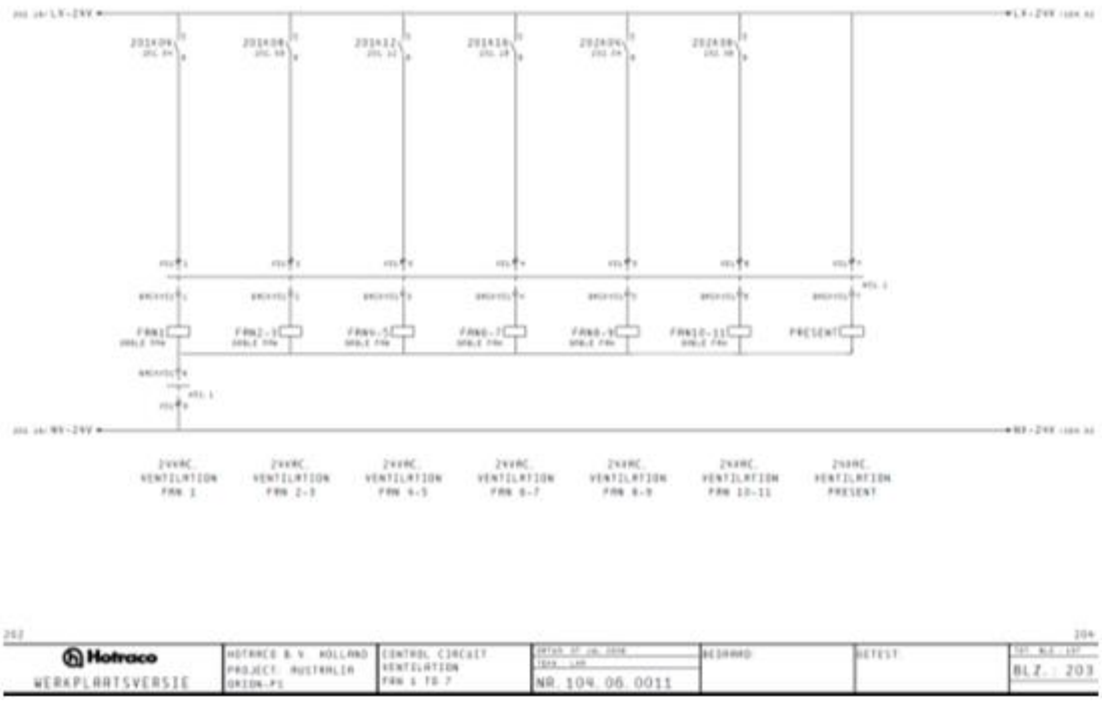


Figure 3-5 - Electrical circuit for egg collection within tunnel ventilated shed

3.4.2 Energy usage instrumentation

Condamine Electrical Company (CEC), in consultation with FSA Consulting selected and supplied and installed an appropriate power metering system. The selection parameters included the cable size, the electrical capacity of the sub-main (amperage), current transformer (CT) size, type and quantity, and mounting requirements. Power meters and the associated switchgear were selected that best suited the individual installation. A description of these for Farm A is described below.

A Powermonic portable three-phase power quality and disturbance analyser was used to monitor the feedmill, mains and total shed power at the farm over a three week period in late April / early May 2012. Total shed power and power factor was recorded by the Powermonic portable power analyser on a one minute basis.

> *Power factor is defined as the ratio of the real power flowing to the load to the apparent power in the circuit, and is a dimensionless number between 0 and 1. Real power is the capacity of the circuit for performing work in a particular time. Apparent power is the product of the current and voltage of the circuit. Due to energy stored in the load and returned to the source, or due to a non-linear load that distorts the wave shape of the current drawn from the source, the apparent power will be greater than the real power.*
>
> *In an electric power system, a load with a low power factor (<0.85) draws more current than a load with a high power factor (>0.85) for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, power authorities will usually charge a higher cost to customers where there is a low power factor. Hence, a power factor close to unity (1) is the aim.*

Three digital meters and logging devices were installed in the tunnel ventilated test layer shed to monitor total shed energy usage, exhaust fans energy usage and the farm mains energy usage over a nine month period from June 2012 to March 2013. The meters chosen were a Nemo 72-L. The power meters incorporate a pulse output, which allows total power use to be logged. The power meter output was connected to a Campbell Scientific PC200 logger to record power usage every three minutes. The loggers were downloaded manually every three months using a laptop computer.

The power meters were installed in a weatherproof cabinet along with a circuit breaker to enable the power supply to the meters to be turned off without effecting the operation of the electrical system in the shed.

3.4.2.1 Nemo 72-L Power Meter

The Nemo 72-L is a programmable power meter that can monitor three phase (500V) networks. The unit is provided in a self-contained polycarbonate enclosure and is flush mounted on the cabinet panel. All of the quantities of three phase a network are monitored including voltage (phase and linked), current (phase and linked), power (phase and three phase active), power factor, frequency and working hours and minutes. These measurement quantities are displayed on different key activated pages on the backlit LCD. The unit has a reading accuracy of voltage (v), current (a), power (kWh) of ± 0.5%, power factor ± 2% and frequency ± 0.2 Hz. The unit is connected with three CT's to monitor power in each phase of the power supply. Photograph 11 illustrates the installed power metering system.

Photograph 11 - Nemo 72-L Power Meter and Logger

3.4.2.2 Powermonic Power Meter

Intensive, short-term power monitoring of total farm power usage and the feedmill was performed using the Powermonic Power Meter. The Powermonic portable three-phase power quality and disturbance analyser incorporates three-phase, three-channel voltage logging and three phase, four-channel current logging of RMS volts, current, Power, harmonic voltages and currents, interharmonic voltages and currents, and power factor for each phase. The unit can also capture high resolution snapshots of fluctuations including motor starts, spikes and transients based on voltage and current limit settings.

3.5 Ventilation assessment

The environmental control performance of the tunnel-ventilated test shed was assessed under different climatic conditions (both summer and winter). Temperature, relative humidity, air velocity inside the shed along with the differential pressure and fan activity was monitored. Visual assessments of temperature variations within the shed were also performed using an infra-red camera (FLIR i5).

3.5.1 Fan performance

Ventilation performance was assessed by logging fan activity and correlating it with environmental measurements inside the shed. Mercury tilt switches were attached to the fan back-draft shutters to monitor fan activity. The use of tilt switches was selected due to low cost, availability of components, reliability (when compared to more complex systems) and ease of installation. Mercury tilt switches were fitted onto an angled aluminium plate, which was then riveted onto the external backdraft shutters of every exhaust fan on the shed (see Photograph 12). To ensure the tilt switch would always activate, the mounting plate was angled so that the tilt switch passed beyond the horizontal position, whenever the louvers opened.

Photograph 12 - Mercury tilt switch (left) and shed exhaust fans (right)

The tilt switches were connected to a Campbell Scientific data logger (CR10x) (Photograph 13) which was programmed to monitor and record the output of each mercury tilt sensor at 30 second intervals.

Photograph 13 - Fan activity data logging equipment

3.5.2 Temperature, relative humidity and airflow monitoring

The temperature, relative humidity and air velocity inside the shed were monitored using a Kestrel 4200 Pocket Air Flow Tracker as shown in Photograph 14.

Photograph 14 - Kestrel 4200 Weather Meter

The Kestrel 4200 is a pocket weather meter capable of measuring temperature, relative humidity, air flow and barometric pressure. The Kestrel 4200 specifications are listed in Table 3-3.

Table 3-3 - Kestrel 4200 Specifications

Measurement	Description	Unit	Accuracy
Temperature	The ambient air temperature	ºC	±1.0 ºC Range: -45 to 125 ºC
Relative humidity	The amount of water vapour actually in the air divided by the max. amount of water vapour the air could hold at that temperature	%	± 3% rh Range: 0.0 to 100% rh
Air flow	The volume of air passing through an area for a given period of time	m/s	± 3% of reading Range: 0.4 to 60 m/s
Barometic Pressure	The air pressure of your location reduced to sea level	hPa	± 1.5 hPa Range: 10.0 to 1100 hPa

Nine Kestrel 4200 devices were mounted on brackets attached to the travelling feed delivery hopper system (robotic).

The feed delivery system is programmed to distribute feed at set intervals throughout the day and in both directions. Feed is dispensed at 5, 6, 7, 8, 9, 10 am and 12, 2, 4, 5, 7, 8:15 pm. Hence, this allowed the monitoring of environmental conditions at each end of the shed and along the shed at the time when feed is distributed.

The Kestrel 4200 was positioned approximately 300 mm from the cage front. The mounting position allows unrestricted airflow to the Kestrel 4200. The Kestrel 4200 mounting arrangement is shown in Photograph 15. Across the shed, the Kestrel 4200's were located on row 1 (between row 1 and row 2 – southern side of shed), row 2 (between row 2 and row 3) and row 4 (between row 3 and row 4 – northern side of shed) as shown in Figure 3-6. On each row, the Kestrels were located at three different heights on: i) tier 1 - the bottom row of cages approximately 0.8m from the ground, ii) tier 3 - the middle tier of cages approximately 2.2m from the ground, and iii) the tier 5, the top row of cages approximately 3.5m from the ground.

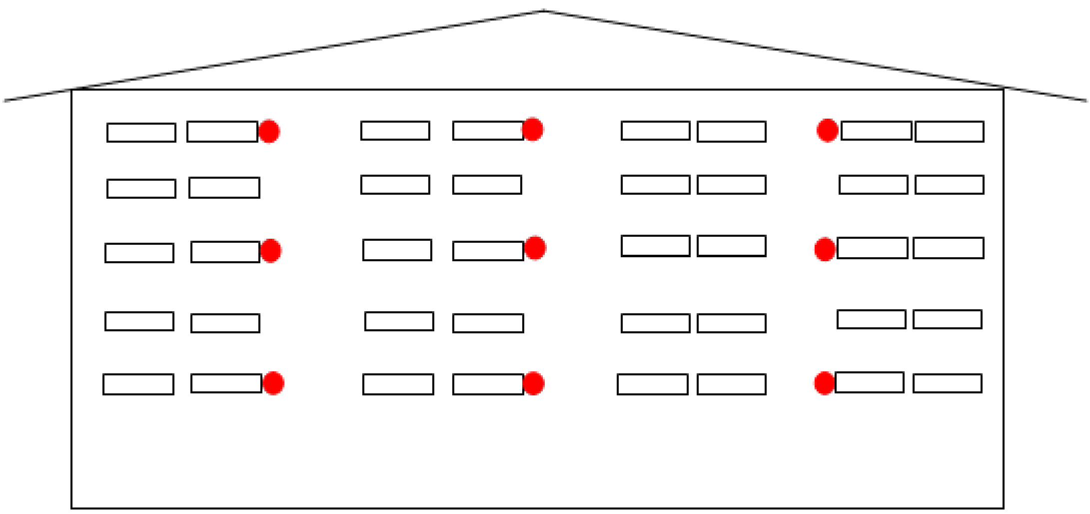
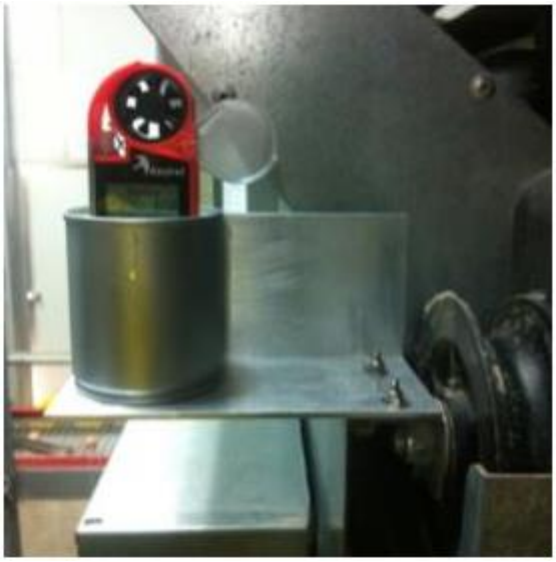


Figure 3-6 - Positioning of Kestrel 4200 meters within shed



Photograph 15 - Kestrel 4200 mounting arrangement

For measurement and recording of ambient temperature and relative humidity, a Kestrel 4000 weather meter was placed inside a Stevenson screen adjacent to the shed. The Stevenson screen was used to protect the Kestrel 4000 from direct sun light. The Stevenson screen and Kestrel 4000 arrangement are shown in Photograph 16. The Kestrel 4200's have an internal logging capability with pre-programmed intervals of 2, 5, 10, 20, 30 seconds, 1, 2, 5, 10, 20, 30 minutes, 1, 6, 12 hours. The nine Kestrel 4200's inside the shed were set to log at 30 second intervals. The Kestrel 4000 measuring ambient temperature was set to measure at 5 minute intervals.

Photograph 16 - Stevenson Screen and Kestrel 4000 mounted outside shed

3.5.3 Static pressure

Static pressure was measured inside and outside the shed using rubber tubing and differential pressure sensors attached to a data logger. To record static pressure inside the shed, the tube was securely fixed to the wall at the fan end of the shed. To record the static pressure outside of the shed the tube was attached to a bracket inside the Stevenson screen as displayed in Photograph 17.

Photograph 17 - Rubber tube attached to the Stevenson screen (left) and inside shed (right)

3.5.4 Airflow

In conjunction with the temperature, relative humidity and airflow monitoring using the Kestrel 4200's a FLIR i5 infrared camera was used to check for air leaks inside the test layer shed during minimum ventilation in winter and to view air movement during maximum ventilation in summer. The infrared camera is shown in Figure 3-4. The FLIR i5 infrared camera measures and images the emitted infrared radiation from an object. The FLIR i5 technical specification is listed in Table 3-4.

Table 3-4 - FLIR i5 Infrared camera technical data

Measurement	Object temperature range	0°C to +250°C (+32°F to 482°F)
	Accuracy	±2°C (±3.6°F) or ±2% of reading, for ambient temperature 10° to 35°C (+50° to 95°F)
Detector Data	Detector Type	Focal plane area (FPA), uncooled microbolometer
	Spectral Range	7.5-13 µm
	Resolution	80 x 80 pixels
Imaging & Optical Data	Thermal Sensitivity/NETD	<0.1°C (0.18°F)

Photograph 18 - FLIR i5 IR camera

3.6 Data collection and collation

3.6.1 Energy data collection

During April 2012, an electrical energy analysis was conducted on the total farm and the feedmill energy consumption using a portable Powermonic Power Meter. Total site power and power factor was recorded by the Powermonic portable power analyser on a 1 minute basis. The power usage was measured over two typical operating weeks. The power factor provided an analysis of the energy use efficiency for these two areas.

Continuous energy logging was performed between June 2012 and March 2013 using the Nemo 72-L power meters. The purpose of this data was to provide a comprehensive energy use profile for the total site, shed and fans within the shed. Data from summer and winter months were also compared.

This report presents data from the intensive data collection period in April 2012 and from the continuous data collection period between June 2012 and March 2013. Site visits were carried out regularly to download the logged energy data and discuss farm operation and collect updated production figures from the farm manager. The data was imported into a spreadsheet and data checks were undertaken.

Photograph 19 - Downloading the logged data at the farm

Energy data collection was also performed by visually inspecting and recording each individual energy use device for energy use (kW) and counting the motors, lights etc. on the farm. This data was used as a guide to estimate how much energy the farm should be typically using.

Photograph 20 - Recording the size of the egg belt motor on the farm

3.6.2 Ventilation performance

3.6.2.1 Initial Data Collection Period

To assess the operating performance of the shed, ventilation data was collected over two one week periods during February 2012 and March 2012. This collection period allowed quantification of the daily variation in temperature, humidity and air speed inside the shed, along with the variation of these parameters at different positions within the shed.

3.6.2.2 Minimum Ventilation Trial during winter (July and September 2012)

To assess the performance of the ventilation system at the farm during minimum ventilation, data on temperature, humidity and air speed were collected using the nine Kestrel 4200 weather meters located across the shed. These trials were carried out on the 16th July and 9th September 2012.

As with the initial data collection period, the 9 Kestrel 4200's were attached to the travelling hopper feed delivery system to allow for data to be collected on temperature, relative humidity and air speed along the length of the shed as the feed system moved back and forth throughout the day. The Kestrel 4200's were set to record climate readings at 10 second intervals. Ambient temperature was also collected with a 10th Kestrel (4000) located outside the shed in a Stevenson screen.

At the same time, the FLIR i5 infrared camera was used to record images of temperature variation within the shed and detect locations of air leaks of cold air. During the first visit to the farm in July 2012 the winches on the mini vents were broken which allowed cold air to flow into the shed. Once the mini-vents were repaired, a second site visit with the FLIR i5 infrared camera was carried out in September 2012, which enabled a comparison of the operating performance of the shed, with and without the mini-vent system functioning.

3.6.2.3 Maximum Ventilation Trial during summer (18 January 2013)

To assess the performance of the ventilation system at the farm during maximum ventilation on a hot day, data on temperature, humidity and air speed were collected using the nine Kestrel 4200 weather meters located across the shed. Coinciding with this, the FLIR i5 infrared camera was used to record images of temperature variation within the shed and assess the ability of the sheds cooling system to control temperature within the shed.

An instantaneous temperature measurement was taken to analyse a snapshot of temperature throughout the shed coinciding with an outdoor ambient temperature of 36°C. It was assumed that all the fans were running continuously, no adjustments were made to the ventilation openings, and the water supply to the cool pads ran continuously. The experiment started at 13:15; the Kestrel 4200's were placed on the bottom egg belt, 400 mm above ground level, at nine different locations. Temperatures were recorded for five minutes. At 13:27 the Kestrel 4200's were moved up to the third tier of egg belts 1700 mm from ground level. After a further five minutes of logging the Kestrel 4200's were again moved upwards to the fifth and highest tier of egg belts 3150 mm from ground level where the final recordings were taken from 13:40.

Photograph 21 - Kestrel 4200 placed securely on the bottom egg collection belt

Fan performance measurements were taken at noon on the 18th January 2013. The air velocity generated by the fans was recorded each five seconds over three individual five minute periods where the Kestrel 4200 was moved horizontally and vertically along a cross section of the shed in-between the fans and the end of the cage system; approximately 1.5 m from the fan casing. The bottom right fan located next to the power box was also assessed over five minutes. Two Kestrel 4200's were used to record the top, bottom, right and left sides of the fan for 2.5 minutes.

Photograph 22 - Fan cross sectional performance data collection

As with the initial data collection period, the nine Kestrel 4200's were attached to the feed delivery system to allow for data to be collected on temperature, relative humidity and air speed along the length of the shed as the feed system moved back and forth throughout the day. The Kestrel 4200's were placed into a secure position on the feed delivery on January 17 and set to record climate readings at 30 second intervals.

Ambient temperature was also collected with a 10th Kestrel (4000) located outside the shed in a Stevenson screen to compare internal and external shed temperatures.

To estimate the liklihood of heat stress upon the birds, effective temperature was assessed during the maximum ventilation trial. This is defined as the temperature perceived by the birds, caused by the combination of air temperature and wind speed as described by Czarick et al. (1999). Tunnel-ventilated housing is designed to provide a wind-chill effect on the birds, which is cooling produced through air movement (Czarick et al. 1999). The effective temperature was calculated by subtracting the wind-chill factor from the shed's air temperature. Research by the USDA Poultry Research Laboratory precisely determined the wind-chill effect produced at different wind speeds on meat chickens. A wind-chill factor curve for mature age broiler birds was produced from the project outcomes. This curve was adapted for use in tunnel ventilated layer sheds. From an extensive search of the literature, no wind chill factors have been determined for layer hens. For this reason, there was no accurate guide to modify the wind chill effect to take into account the reduced velocity in the cages. The wind chill reported is the representative of the air movement over the birds head and neck while feeding.

Coinciding with this, the FLIR i5 infrared camera was also used to record images of temperature variation within the shed and detect locations of heat penetration of the shed cladding and insulation and air leaks.

3.6.3 Production data

The amount of eggs produced for the shed and the entire farm was directly supplied by the farm for the period over which energy consumption was analysed. Farm records provided the following production data in weekly intervals; age in weeks, mortalities, birds remaining, total number of eggs produced, feed used, kg of feed per bird and average egg weight. The total weight of eggs produced per week was calculated by multiplying the average egg weight by total eggs produced for the interval.

Energy usage of the major shed activities as a function of their respective indices was calculated, including on a per bird basis and per kilogram of eggs produced. This allows the energy efficiency of the total site and the tunnel-ventilated layer shed to be analysed and compared.

4 Results and discussion

4.1 Energy usage

4.1.1 Initial intensive logging of power usage

Initial energy monitoring was conducted at the site for a two-week period in late April / early May 2012. Total farm, feed-mill and total power for the individual layer shed were monitored using a portable Powermonic three-phase power, quality and disturbance analyser. The Powermonic portable power analyser recorded total power usage and power factor. The results for total farm power load and power factor are shown in Figure 4-1 and Figure 4-2 respectively. The total power load and the power factor for the test layer shed are shown in Figure 4-3 in Figure 4-4 respectively. The feed-mill power load and power factor are shown in Figure 4-5 and Figure 4-6 respectively.

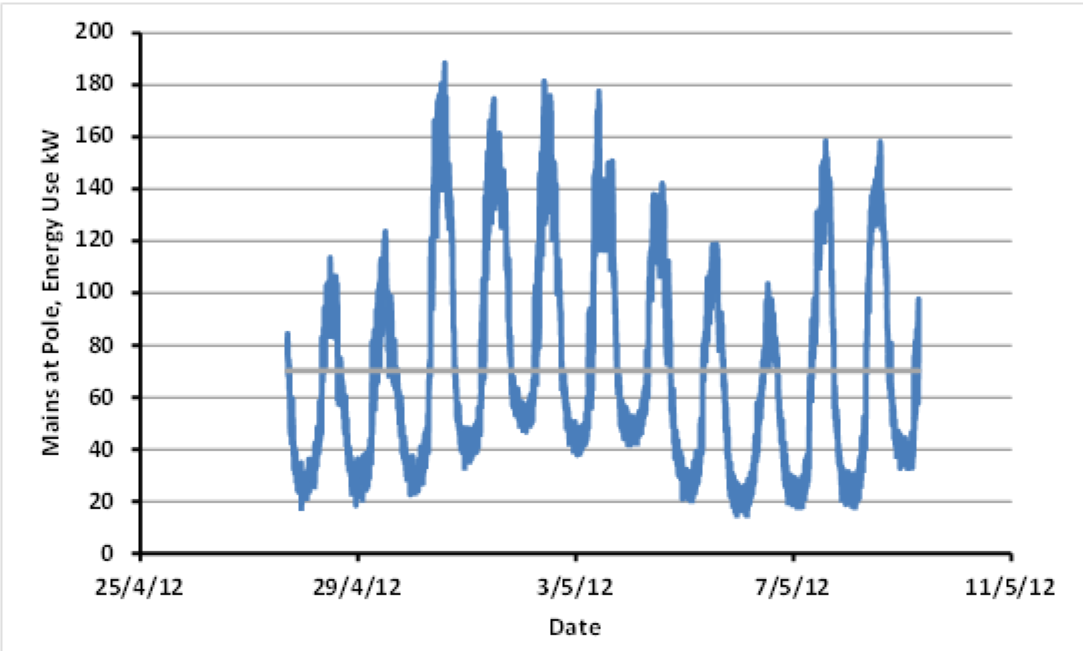


Figure 4-1 - Total farm power load

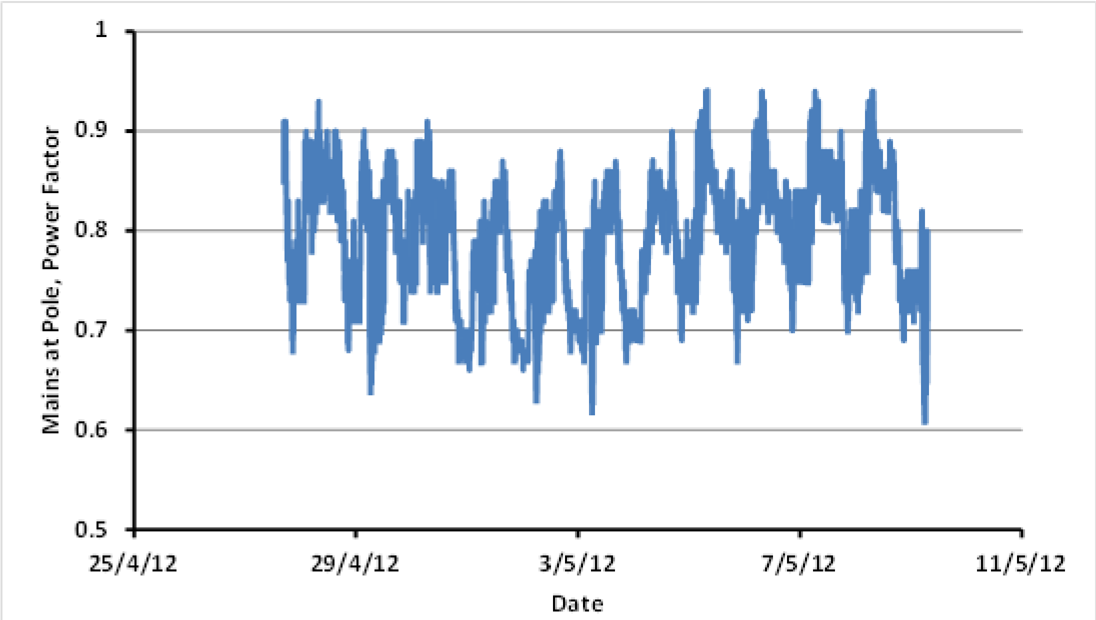


Figure 4-2 - Total farm power factor

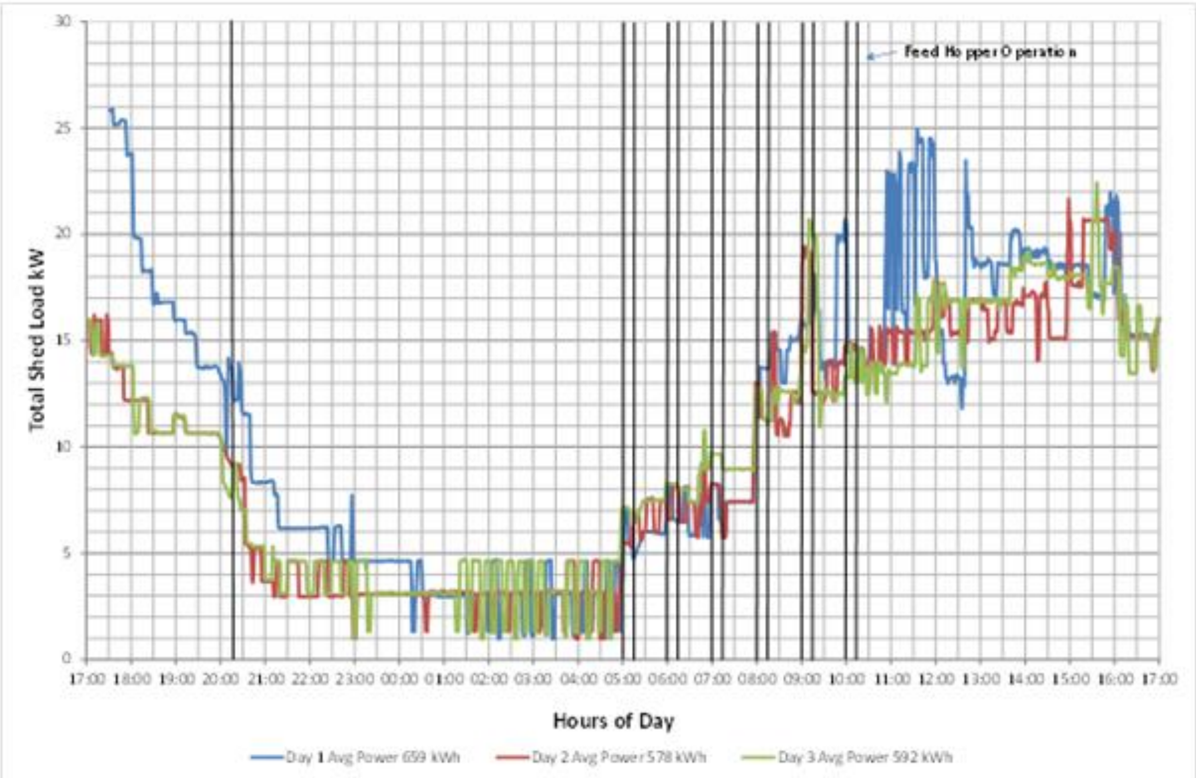


Figure 4-3 - Test layer shed power load

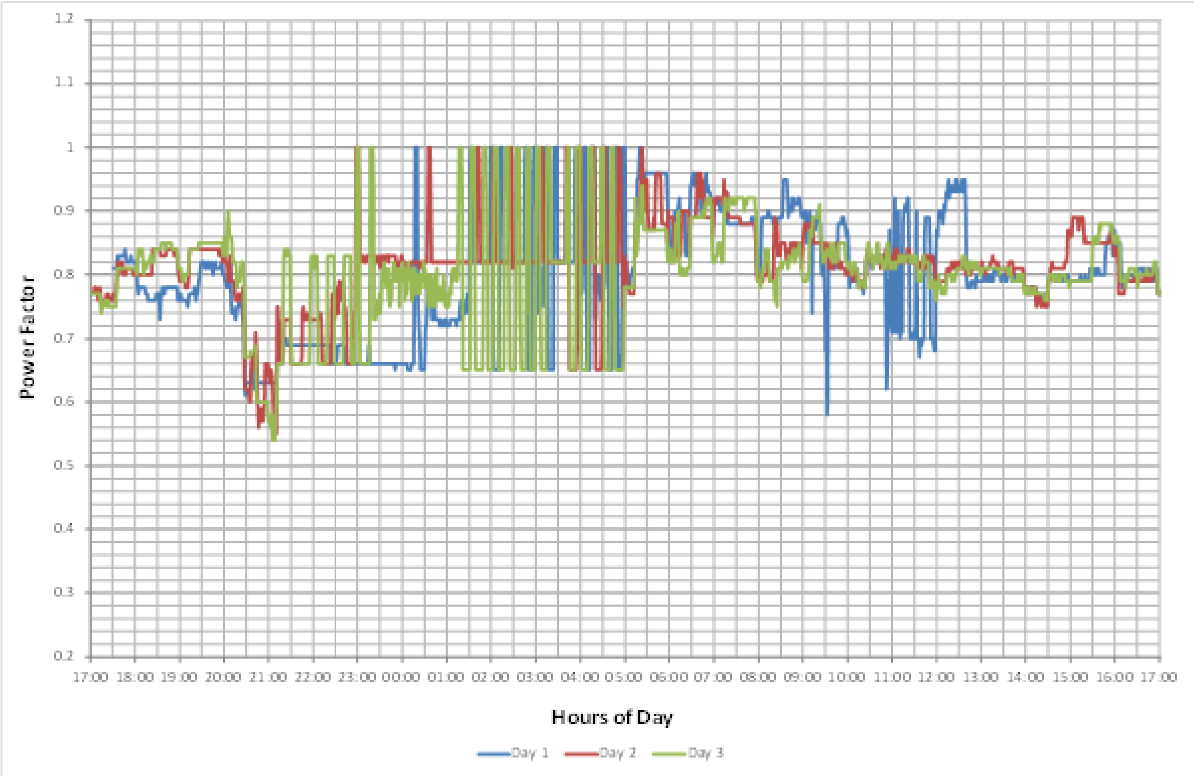


Figure 4-4 - Test layer shed power factor

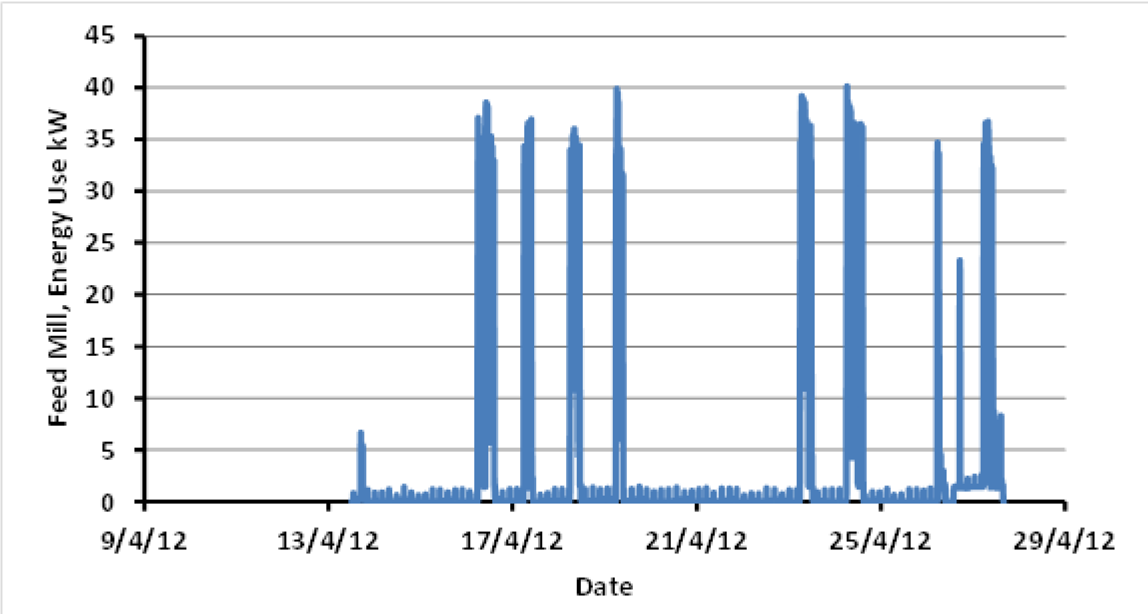


Figure 4-5 - Feed-mill power load

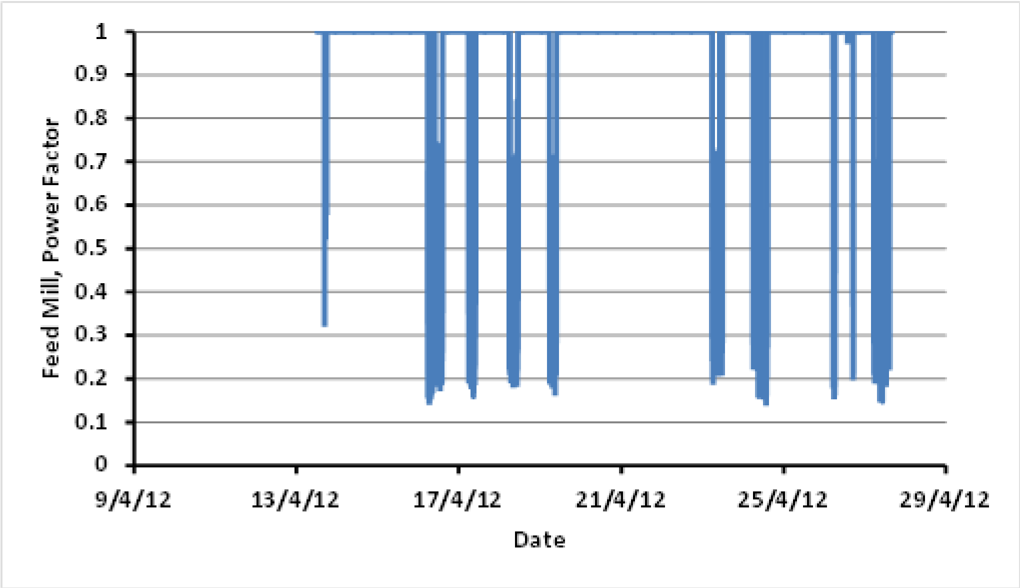


Figure 4-6 - Feed-mill power factor

The intensive energy graphs displayed above provides the instantaneous load over time rather (kW) than the average demand per unit time (kWh). This form of monitoring provides greater detail into what the major loads are, and the time and level of maximum power consumption. The average power usage over the day can also be determined.

Figure 8 shows that the power load for the total site over the logging period ranges from approximately 100 to 180 kW. Each peak in load occurs for a short period in the middle of each day, corresponding to higher temperatures and hence higher ventilation rates. The total farm has a base load of between 20 and 40 kW at night. The average power consumption for the logged period was 1721 kWh/day.

Figure 10 shows that the peak load for the test layer shed for the three days of logging ranged from 20 to 25 kW or approximately 20% of the total farm load. From this figure, average power consumption for the three days can also be calculated and this ranged from 578 kWh/d to 659 kWh/d. For the 40,000 bird shed, this equates to approximately 16 kWh/day for 1000 birds. The raw data presented in Figure 4-3 can be further interrogated to determine the power consumption of the various operations within the shed. For example, the operation of the feed conveyor system is clearly shown at those times when the system is in operation. Feed is dispensed at 5, 6, 7, 8, 9, 10am and 12, 2, 4, 5, 7, 8:15pm. Figure 4-3 clearly shows that the maximum power usage is during the middle of the day (highest temperature) when the fans are operating and the fans dominate power consumption.

Figure 4-5 shows the power load for the feedmill over two weeks of electricity logging. The feedmill operated four to five times a week generally in the morning from 6am to 10am. Under full operation, the peak load reached between 35 and 40 kW. When milling was not required, there was a small base load of less than 1 kW.

The power factor for the entire site (Figure 4-2) ranged from 0.6 to 0.95 with an average of about 0.8. For the test layer shed, shown in Figure 4-4, the measured power factor ranges from 0.54 to 1 with an average of approximately 0.8. Induction motors, as used by the fans typically have a reasonably high power factor of 0.8 to 0.85. The power factor of unity was recorded at night when power consumption is at the lowest. The feedmill power factor, displayed in Figure 4-6, ranged dramatically depending upon the electricity usage. When electricity usage was highest, between 35 to 40 kW, the power factor dropped below 0.2.

Discussions with the electrical contractors at CEC said this is most probably due to motors (on augers) being operated with no load, essentially running when they could be turned off.

4.1.2 Energy use profiling

Energy use profiles were generated from the three data loggers installed at the farm. Total farm power, total power for the test layer shed and test layer shed exhaust fans and manure belts were individually monitored over approximately six months. Figure 4-7 shows the energy use profile for the total site in kWh/day. They grey horizontal line displays the average daily energy use over the data collection period. Maximum daily energy use was 3000 kWh/d from mid-October to early January. The higher energy use occurred in three distinct periods. According to historical climate data, the maximum energy use coincided with days of higher temperature. The minimum daily energy use recorded was 1050 kWh/d, which occurred throughout August. The site consumed less energy during cooler periods than warm periods. This is due to lower demand for energy intensive ventilation and cooling.

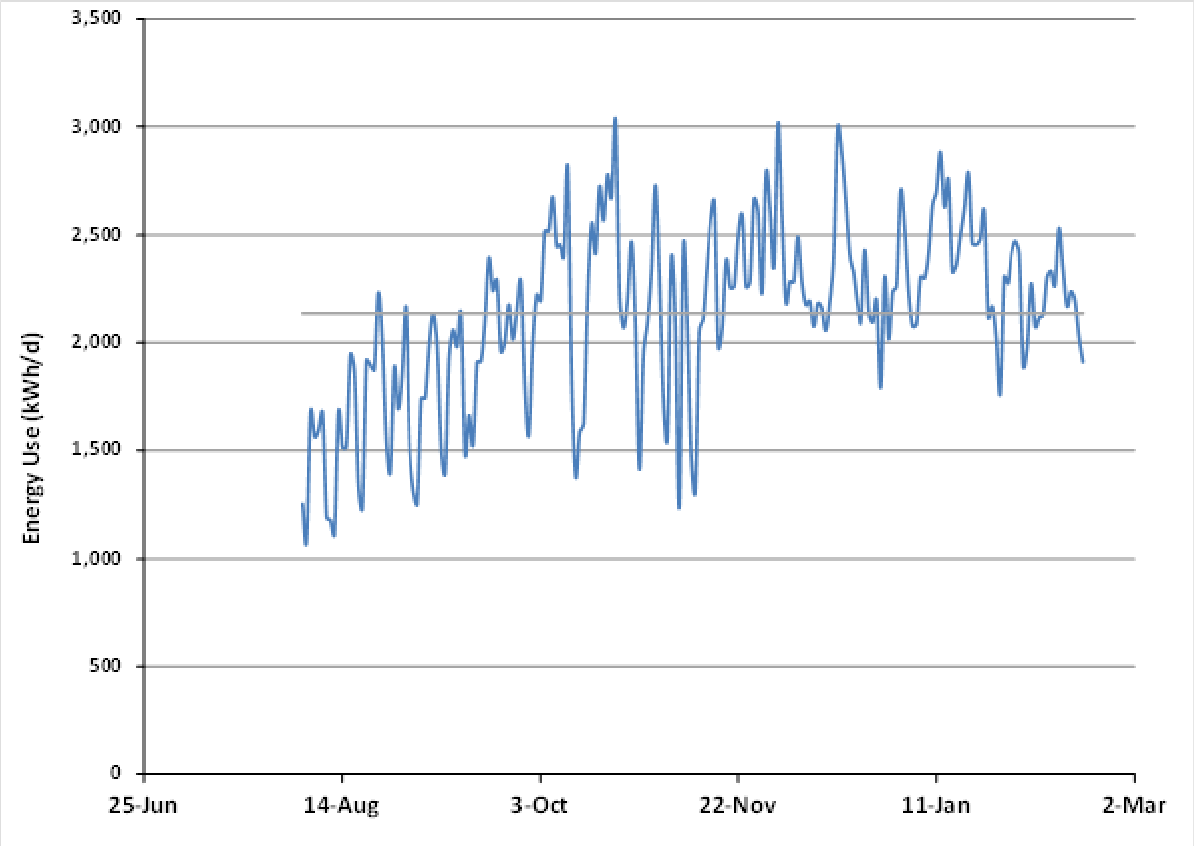


Figure 4-7 - Total farm energy use profile

Figure 4-8 shows the energy profiles (kWh/day) for the total power for individual layer shed and individual layer shed exhaust fans and manure belts. The horizontal lines show average energy use over the data collection period. The average consumption for the whole shed was 310 kWh/d and the fans and manure collection was 220 kWh/day. Maximum energy usage within the shed reached 520 kWh in January, over the same period the fans and belts reached a maximum of 370 kWh/day. From the 25th October to the 1st November, the shed was emptied of hens and prepared for a new batch. During this time energy consumption significantly reduced, as fan operation was not required. Excluding this period, the minimum energy usage fell to 190 kWh/day for the shed and 110 kWh/day for the fans. As expected, this occurred in August under cooler low ventilation requirement.

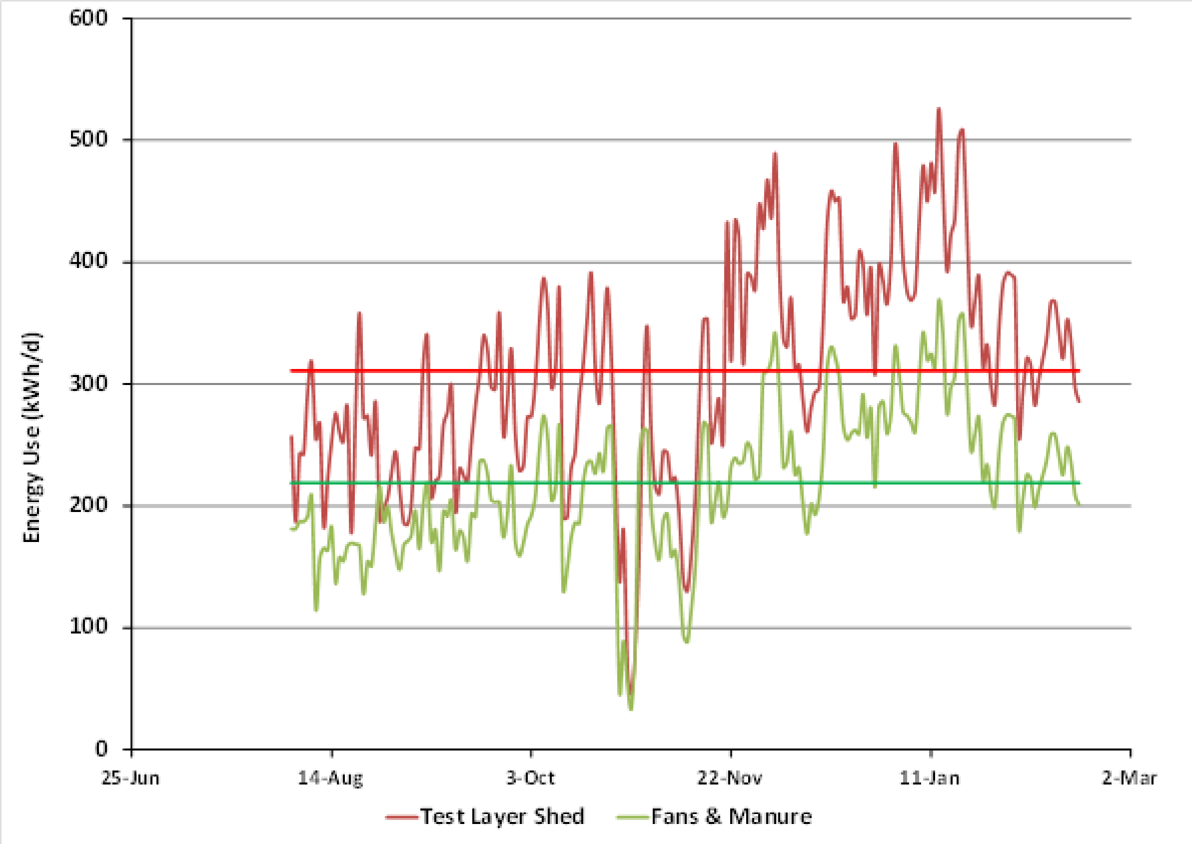


Figure 4-8 - Test layer shed total energy use profile (kWh/day)

4.1.3 Breakdown of energy use

The energy use of the entire farm, the test layer shed and the feed mill were broken down and compared. Figure 4-9 shows the average energy use in kWh/week for each logged component. In six months of continuous logging, the total farm energy use averaged 14,500 kWh per week. Over the same logging period, the weekly energy use of the test layer shed averaged 1800 kWh, or about 12.5% of the total farm energy use. The energy consumption of the feed mill was monitored for two weeks and averaged 500 kWh/week or about 3.5% of the total farm energy use.

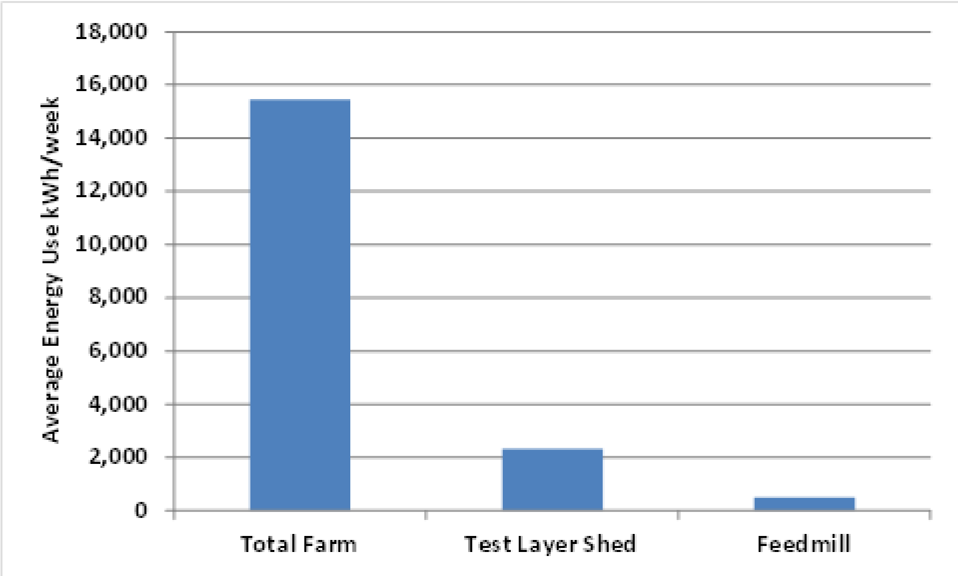


Figure 4-9 - Whole farm energy breakdown for measured components (average energy use in kWh/week)

For the test layer shed, the contribution of each process, electrical energy use as a percentage of total shed electrical energy use was calculated on an annual basis. The energy use of various components the within shed is displayed in Figure 4-10. Results were calculated over the entire logging period (Aug 2012 to Feb 2013) using logged data and equipment specifications. Exhaust fan energy use makes up the largest portion of electrical energy demand at 69% of total shed electrical energy use. Lighting represents the second highest energy use at approximately 17% of total shed energy use. Although fan performance represents the greatest opportunity for potential electrical energy savings, there may also be opportunities to reduce lighting costs by replacing the current fluorescent tubes with more energy efficient lighting.

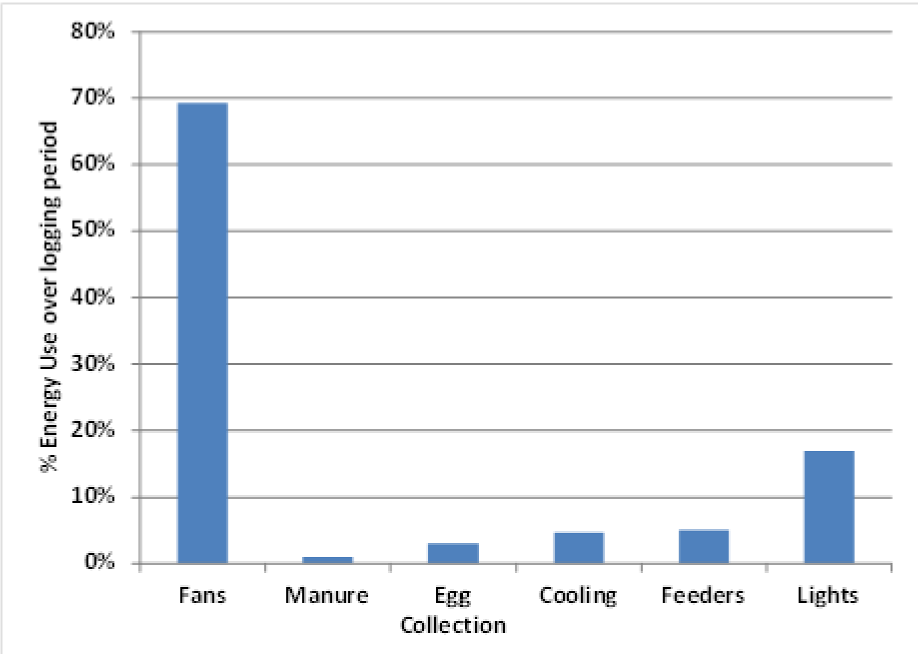


Figure 4-10 - Test layer shed energy use breakdown comparisons (%)

Energy using components within the test layer shed were also compared between summer and winter as displayed in percentage energy use in Figure 4-11 and kWh/week in Figure

4-12. Winter data was collected in early August and summer data during December. Fan electricity usage increased from 1200 kWh/week in winter (67% of total electrical energy), to 1800 kWh/week in summer (70% of total electrical energy), due to a higher demand for ventilation. The higher demand for ventilation in summer is met by running more fans to increase the ventilation rate. Cooling pads do not operate in winter due to significantly cooler climatic conditions.

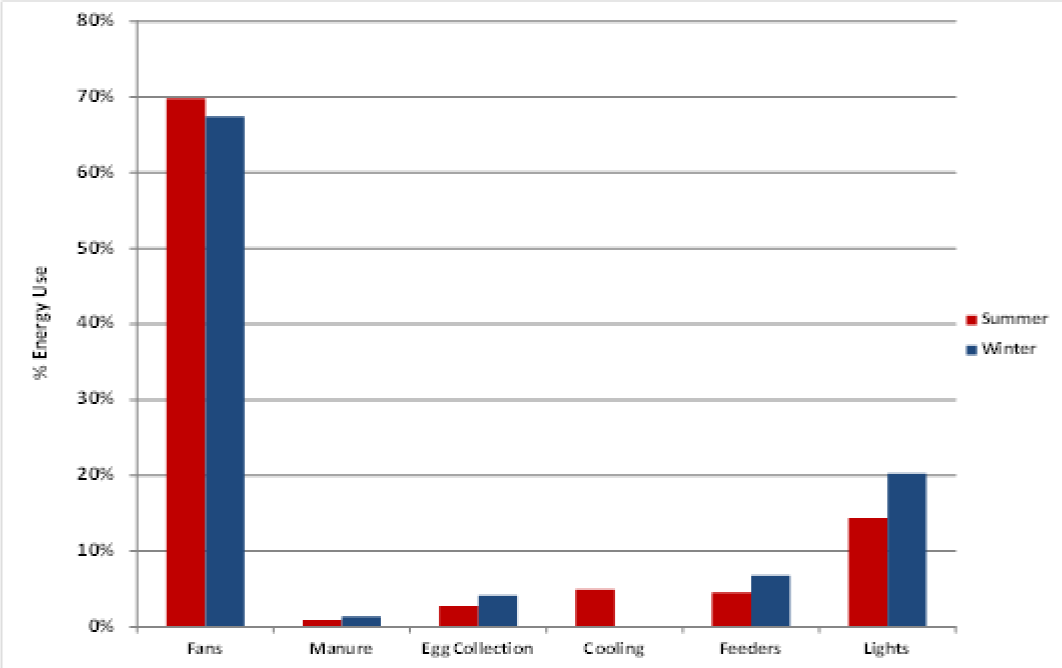


Figure 4-11 - Test layer shed summer and winter energy use breakdown comparison (%)

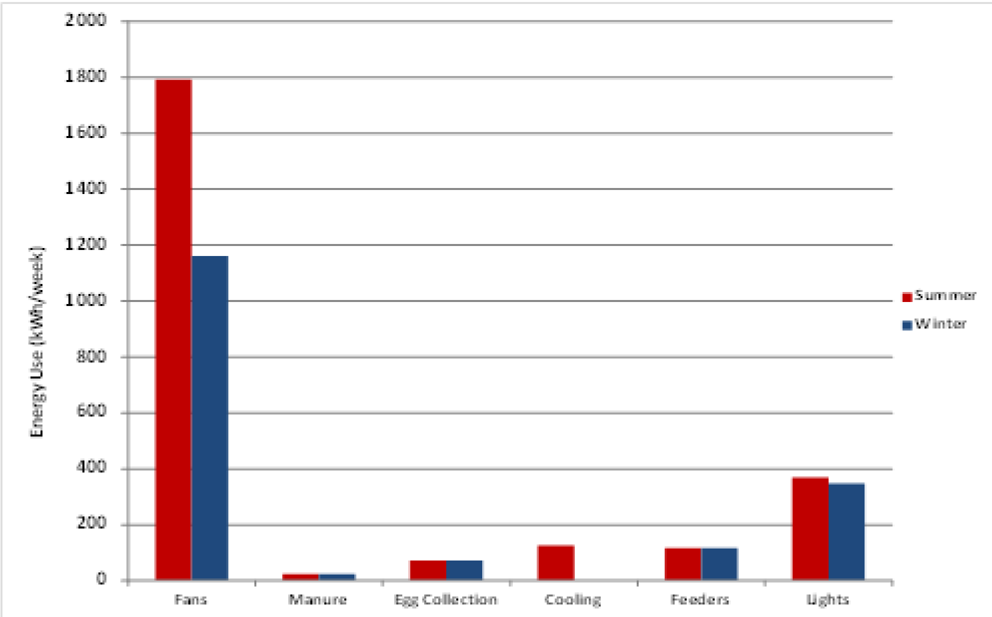


Figure 4-12 - Test layer shed summer and winter energy use breakdown (kWh/week)

Figure 4-12 shows an average increase of 600 kWh/week in electricity consumption for exhaust fans from winter to summer months.

4.2 Production efficiency

The production data for the whole farm and the test layer shed were obtained for the same period energy was monitored.

A comparison of the test layer shed energy use (kWh/week) and test layer shed egg production is shown in Figure 4-13. Energy use in summer was substantially higher (1000 to 1500 kWh/week) than in winter. There was a drop in electricity use for just over three weeks due to a change over in bird batches. The production of the old batch was steadily decreasing in production from 14 tonnes of eggs per week to 13. The length of downtime, from when the spent hens left the shed to when new pullets entered the shed was 23 days (15 October 2013 to 7 November 2013). Pullets are placed in the shed at 16 weeks of age and the approximate age at first egg was 19 weeks. It then took several weeks to reach typical production levels. After this initial period, production continued to increase from 13 to 16 tonnes of eggs per week.

Figure 4-14 shows the comparison between total site energy use (kWh/week) and total site egg production. Electrical energy use increased by approximately 4000 kWh/week during the summer months. Drops in energy use related to times where sheds were emptied and a new batch of pullets introduced. The introduction of a new flock of birds into the test shed influenced and decreased the total site production; approximately 60 tonnes of eggs per week were produced whilst the birds were in lay. These graphs show that the test layer shed monitored was responsible for about 27% of the farms egg production.

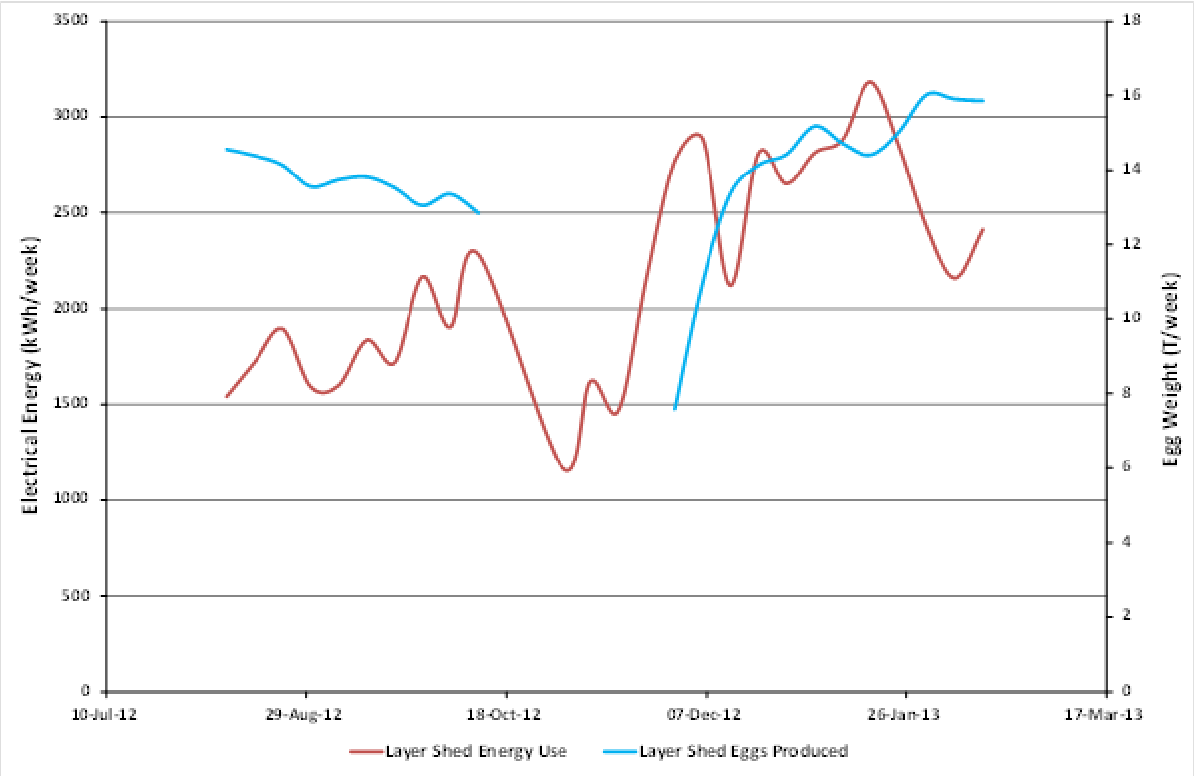


Figure 4-13 - Comparison of test layer shed energy use (kWh/week) and egg weight produced (T/week)

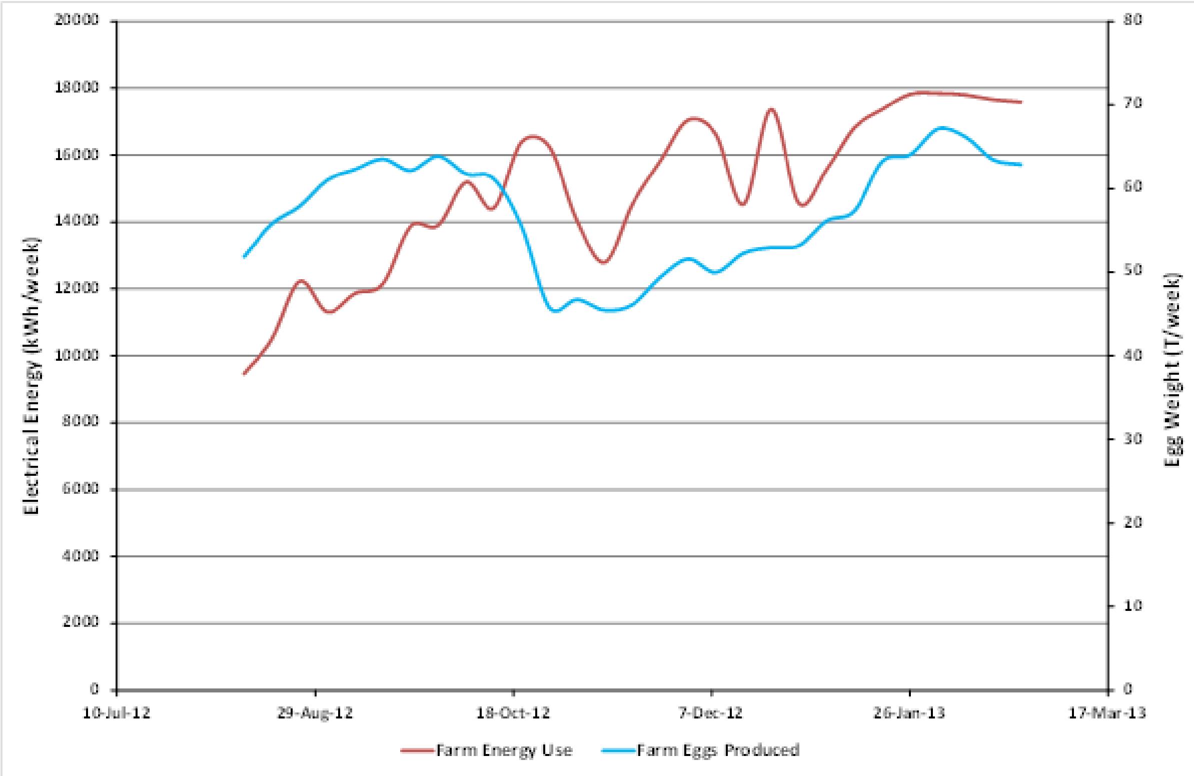


Figure 4-14 - Comparison of total site energy use (kWh/week) and egg weight produced (T/week)

Figure 4-15 displays the electrical energy efficiency as a function of production data for the total farm and the test layer shed. The overall electrical energy efficiency displayed in Figure 4-15 is a function of the electrical energy and total weekly egg weight shown in Figure 4-13 and Figure 4-14. For example if electricity use is high and production is low, the energy efficiency will be poor. If electricity use is low and production is high, better energy efficiency will result, i.e. a lower electrical energy use per weight of eggs.

In the test layer shed, as the energy use increased in summer and the batch of hens reached the end of a cycle, the energy efficiency (kWh/kg eggs produced) of the shed reduced. The energy efficiency was also lower in the early summer months as the new pullets began production. As the new pullets became productive and began producing eggs the efficiency improved. The energy efficiency of the total farm was more stable due to the larger number of birds and eggs produced. The largest influence on efficiency for the whole site is electricity usage. Increases in electrical demand for cooling and ventilation during warmer months reduced the energy efficiency.

The average efficiency of energy for the whole farm ranged from 0.2 in winter to 0.3 in summer (kWh/kg eggs) while the test layer shed ranged from 0.12 in winter to 0.17 in summer (kWh/kg eggs). The test layer shed showed greater efficiency in production related to energy use compared with the whole site. This may be caused by the total farm data including ancillary components like the grading floor, workers quarters, and office buildings etc., which are not considered in the test layer shed. As the feedmill power use was logged this was negated from the total farm energy efficiency.

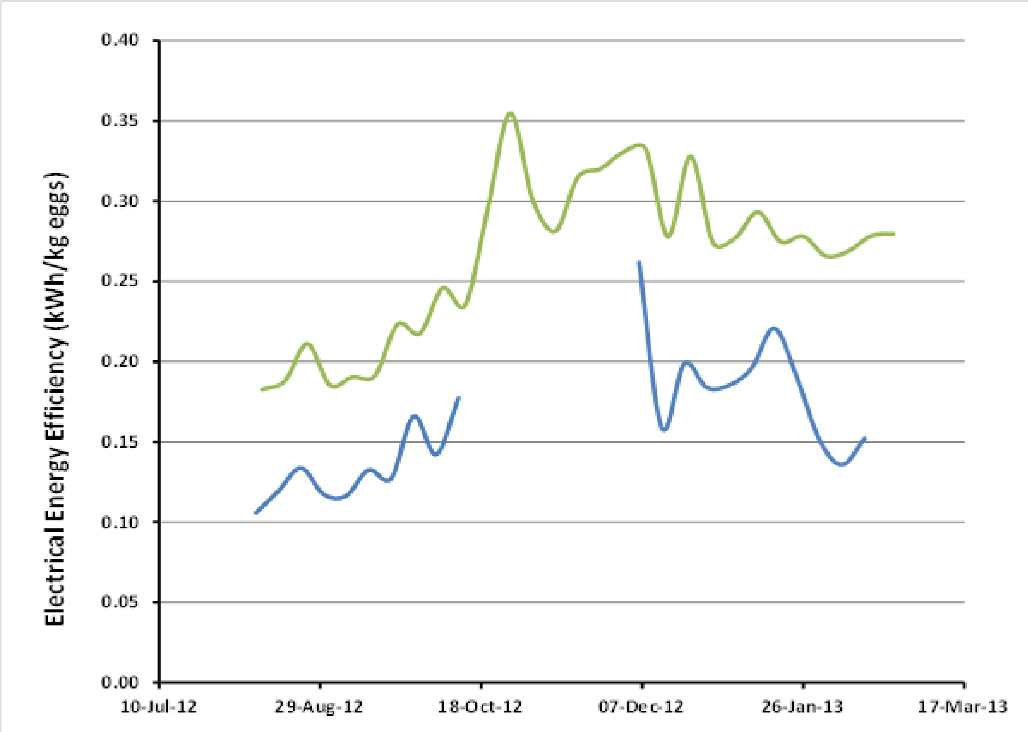


Figure 4-15 - Electrical energy efficiency (kWh/kg eggs) for weekly periods for total farm (green) and individual layer shed (blue)

The egg production as a function of electrical energy use at the test layer shed was compared against data collected from a range of sources. The conditions and operational nature of some of the other layer farms is unknown, so these results do not necessarily provide a direct comparison. Farms B, C and D data were collected for tunnel ventilated farms in southern Queensland and northern New South Wales (Wiedemann and McGahan, 2011) and do represent only layer shed energy efficiency, with ancillary sources such as feedmill, rearing and grading excluded. Figure 4-16 shows the test layer shed at the farm (Farm A) used 0.56 MJ of energy to produce a kilogram of eggs. These results are higher energy use per unit of production when compared with other layer farms, with only one farm from the previous study of Wiedemann and McGahan (2011) having a similar energy use per unit of egg production.

When the whole farm energy use efficiency was investigated for Farm A, there was a 70% increase in energy use per kilogram of eggs produced to 0.96 MJ. This data included all ancillary energy use at the farm (grading floor and office buildings etc.). It also includes the other four layer sheds at the farm which may be less efficient at producing eggs on an energy use basis as they house less birds each (30,000), however individual energy use at these sheds was not recorded. Further information regarding the methodology for data collection from other sources and a more accurate breakdown of electricity use from Farm A would be required for an accurate comparison.

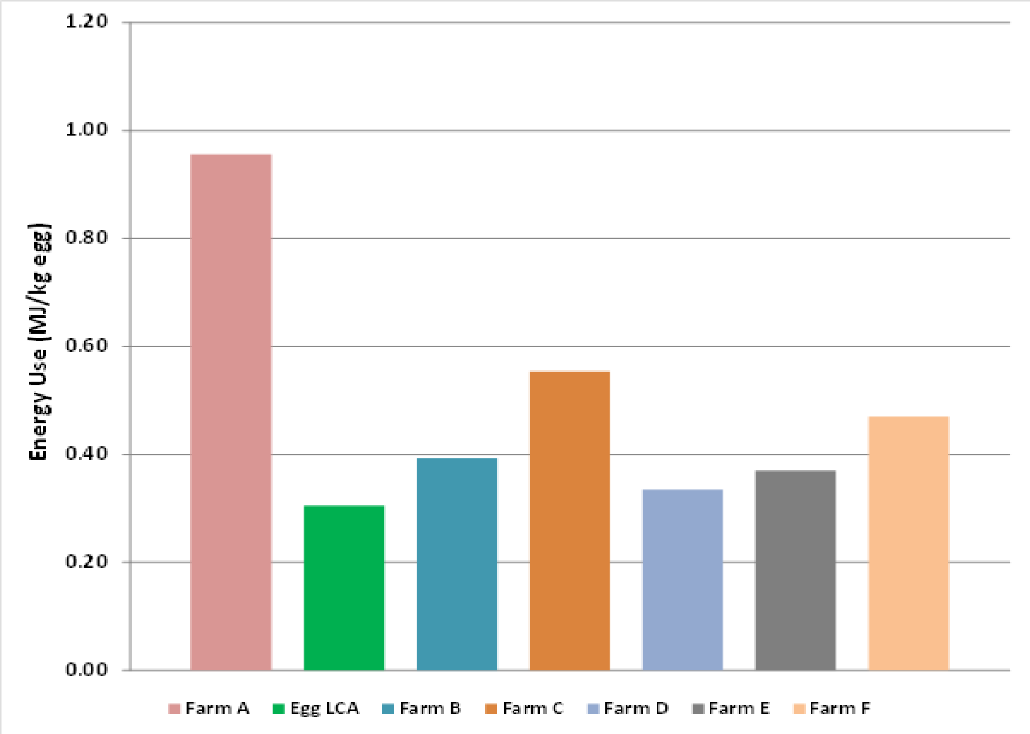


Figure 4-16 - Energy use (MJ) per kilogram of eggs, obtained from a range of sources

The average energy use (kWh) per bird per year was calculated for the monitoring period. Results were compared with three alternative sources as displayed in Figure 4-17. The individual layer shed at Farm A used 3.55 kWh/bird/year, which was once again higher than the other farms. On a whole farm basis, with all energy use included (except the feedmill), electrical energy use was 4.9kWh/bird/year.

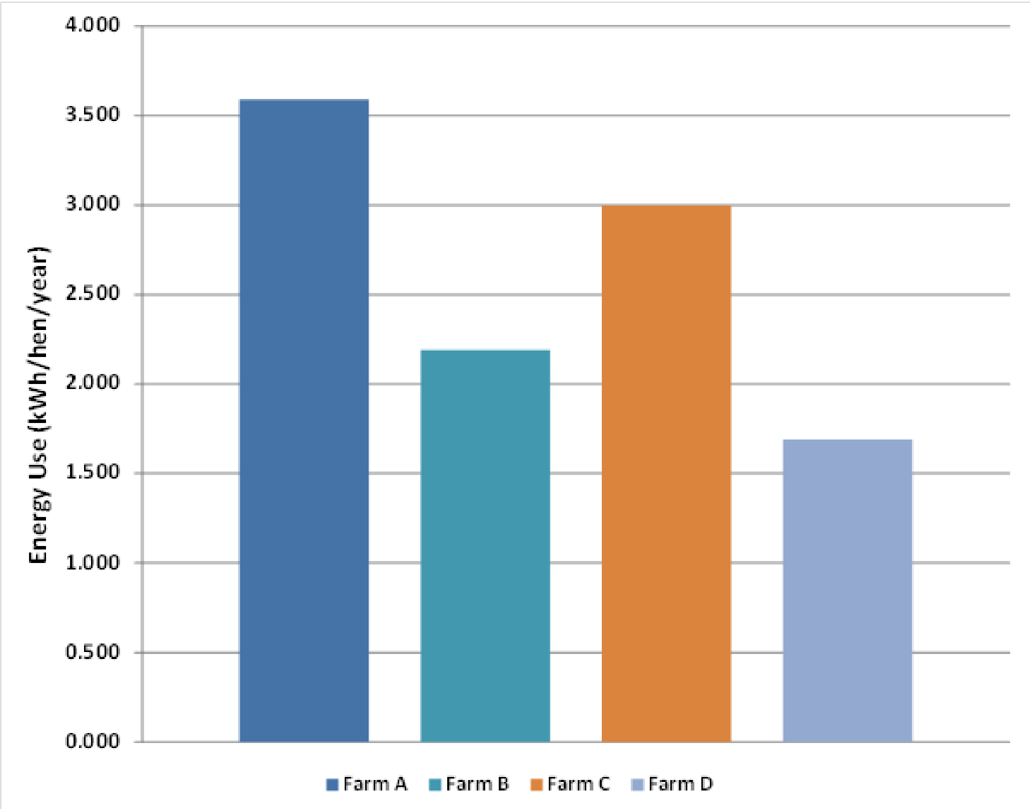


Figure 4-17 - Energy use (kWh) per bird per year comparison

4.3 Ventilation performance

4.3.1 Trial 1 – February and March 2012 (summer)

Initial ventilation trials were conducted in February and March 2012 to assess the effectiveness of the tunnel ventilation system in the test shed. The recommended temperature for bird production and health within the shed are >29°C for maximum ventilation, provided humidity is below 70%, and <21°C for minimum ventilation. The settings on the shed controller are 26.5°C for maximum ventilation and 21°C for minimum ventilation. The kestrel climate monitoring devices were placed on the automatic feeders which moved along the length of the shed at predetermined times throughout the day. These times were 05:00, 06:00, 07:00, 08:00, 09:00, 10:00, 12:00, 14:00, 16:00, 17:00, 19:00 and 20:30. The feeder commenced its daily run at the inlet end of the shed and stopped at the fan end. It takes 15 minutes to travel the length of the cages. On the next run, it travels back to the inlet end. This resulted in the kestrel recording shed temperature and humidity from both ends of the shed at different times during the day. The times when the kestrel had stopped at the fan end of the shed are marked on the graphs. The kestrel temperatures are not representative of the temperature sensor that controls fan staging within the shed. Even though the shed contains multiple temperature sensors, farm management only operates fan staging based on a single sensor as they believed this achieved better results.

The diurnal variation at the lowest bird level at the feed trough on the southern side of the shed was measured during day four and five of the trials, the results are shown in Figure 4-18 and Figure 4-19. Due to the kestrel being placed on the feeders the temperature gradient between the cooling pad and fan end of the shed can also be seen at the various times of the day. In the early morning at 5am, there is approximately a 4-6 degree variation along the shed. This variation became less pronounced during the warmest part of the day. If the time when the shed temperature is recorded at the fan end of shed is ignored, it can be assumed the overall shed temperature follows the trends of the ambient temperature.

Fan activity is at its greatest during the hottest part of the day as expected. On the study period days, the maximum temperature inside the shed was about 1ºC greater than the controller set-point temperature but still below the recommended bird comfort temperature limit of 29°C. When the ambient temperature falls below 18°C the shed is only able to maintain an internal temperature of 18- 19°C, this may be caused by the controller not using at least three sensors to monitor shed temperature. This suggests that the use of one sensor by the controller to monitor shed temperature rather than multiple sensors, results in the shed over ventilating and running cooler than necessary. Leakage of cold ambient air into the shed could also be an issue.

There are discrepancies in the fan staging between day 4 and day 5 data. During day 4, there were drops in number of fans on within the shed at 12:30 and again at 16:00. These drops do not follow shed temperature as recorded by the kestrel. They show that the temperature gradually increased in accordance with the rising ambient temperature. Maximum ventilation never occurred on day 4 even though the temperature recorded by the kestrels exceeded the controller set point. This is likely due to the fan staging controller-reading temperature from a different point in the shed, which may be slightly cooler.

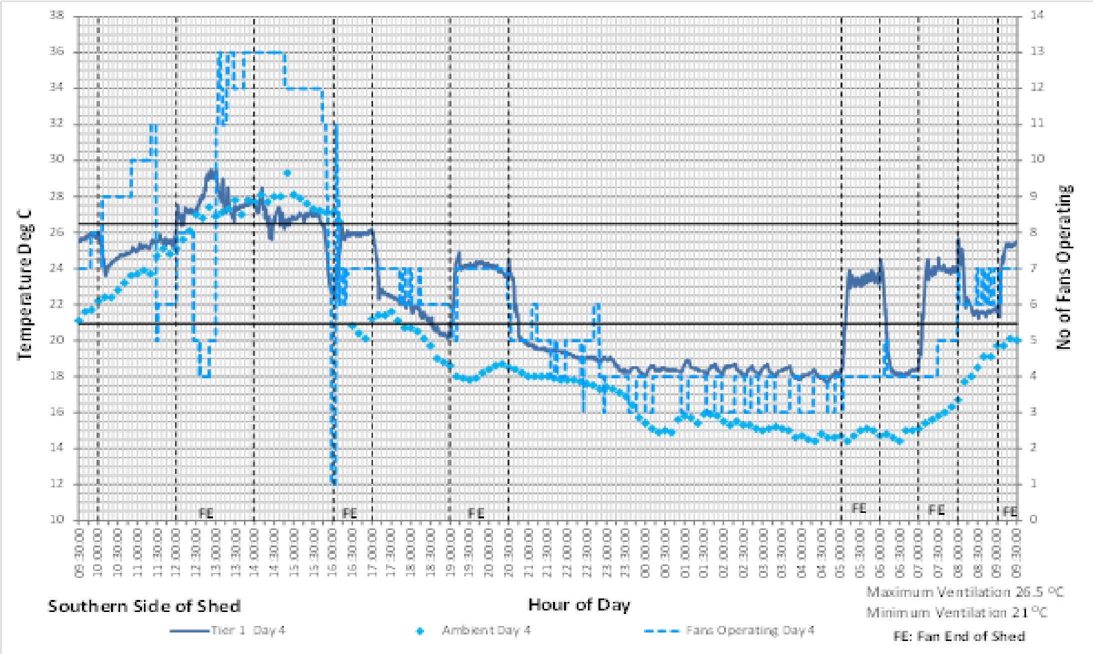


Figure 4-18 - Diurnal temperature variation southern side of layer shed (day 4)

The fan staging response to shed temperature more closely matches the recorded temperature throughout day 5 in Figure 4-19. The drop in shed temperature occurs from 17:00 through until midnight. The spike in temperature between 19:00 and 20:30 is due to the kestrel being located at the fan end of the shed. Negating this period it can be assumed the shed temperature at the inlet end drops at a similar rate to the ambient temperature. The shed temperature recorded by the kestrel's drops below the minimum controller set point at 21:00. When this occurs the fans begin to stage off in-line with the dropping shed and ambient temperature. The temperature recorded by the kestrel at the fan end between midnight and 9.30am indicates a temperature difference with the inlet end of 4 – 6 degrees. The difference in temperature may be contributed to by air leakage. These results suggest that one sensor attached to the controller is inadequate for monitoring shed temperatures below about 26 degrees.

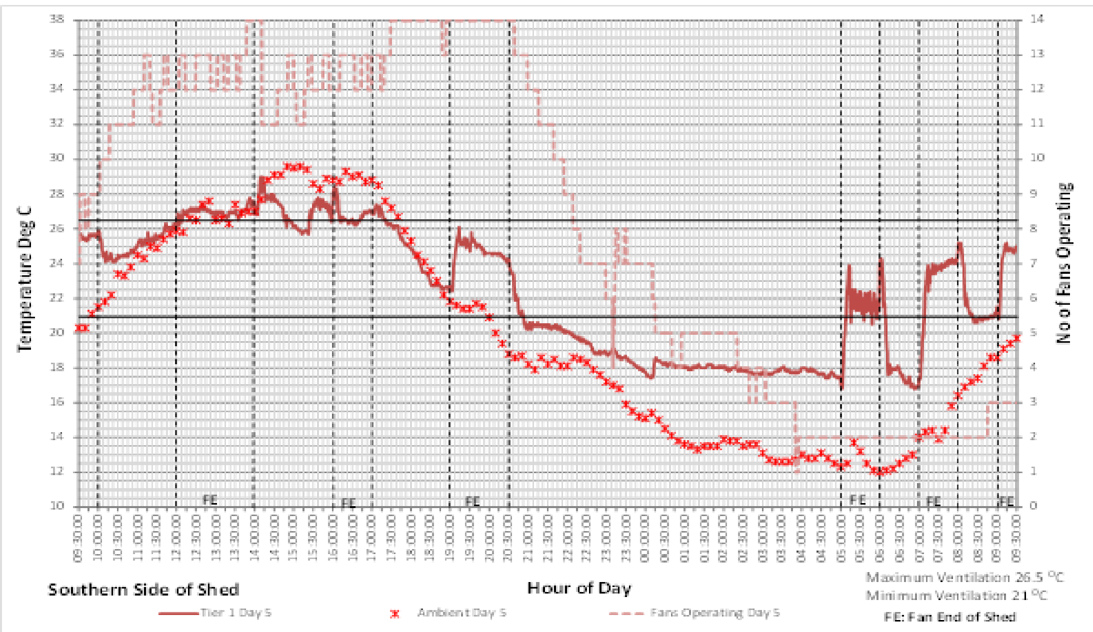


Figure 4-19 - Diurnal temperature variation southern side of layer shed (day 5)

Figure 4-20 shows the variation between Tier 1 and Tier 5 on the southern side of the individual layer shed. As expected, the temperature at Tier 5 is similar or greater than Tier 1. Observing the graph, when there are less than seven fans on the temperature variation between tiers increases to 3ºC irrespective of whether the kestrel is at the inlet or fan end. The larger temperature difference between tiers would be expected at the inlet end as the shed air and incoming air are mixing. The temperature difference between tiers at the fan end suggests a shed design issue; there is too much air space above the cages. As the air is drawn down the aisles it is moving upward into the area of least resistance above the cages, taking the heat generated by the birds.

The large difference in temperature between shed ends between 4:30 and 7:15 shows the error created when the shed's ventilation is controlled by a single sensor. As in previous days, the maximum temperature recorded by the kestrels inside the shed was about 1ºC higher than the controller set-point temperature of 26°C for maximum ventilation.

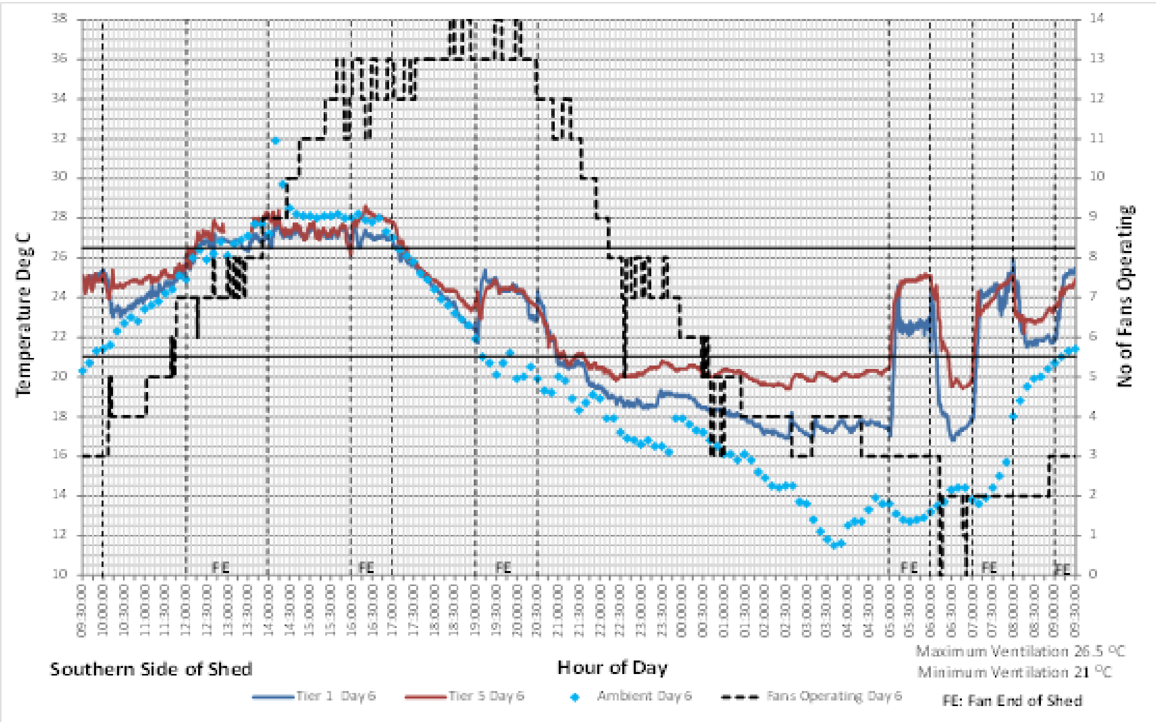


Figure 4-20 - Cage tier level temperature variation

The diurnal variation at the lowest bird level on the northern side of the shed was measured and shown in Figure 4-21 (day 4) and Figure 4-22 (day 5).

The maximum temperature measured by the kestrel on the northern side of the shed compared better with the maximum controller set-point compared to the southern side, apart from one small period on day 4 between 12:30 pm 14:00. This is likely due to the kestrel being situated at the fan end of the shed at this time. The temperature recorded by the kestrels provides a guide to the shed temperature but will differ from the controller temperature sensor, especially when it moves along the shed with the feeder.

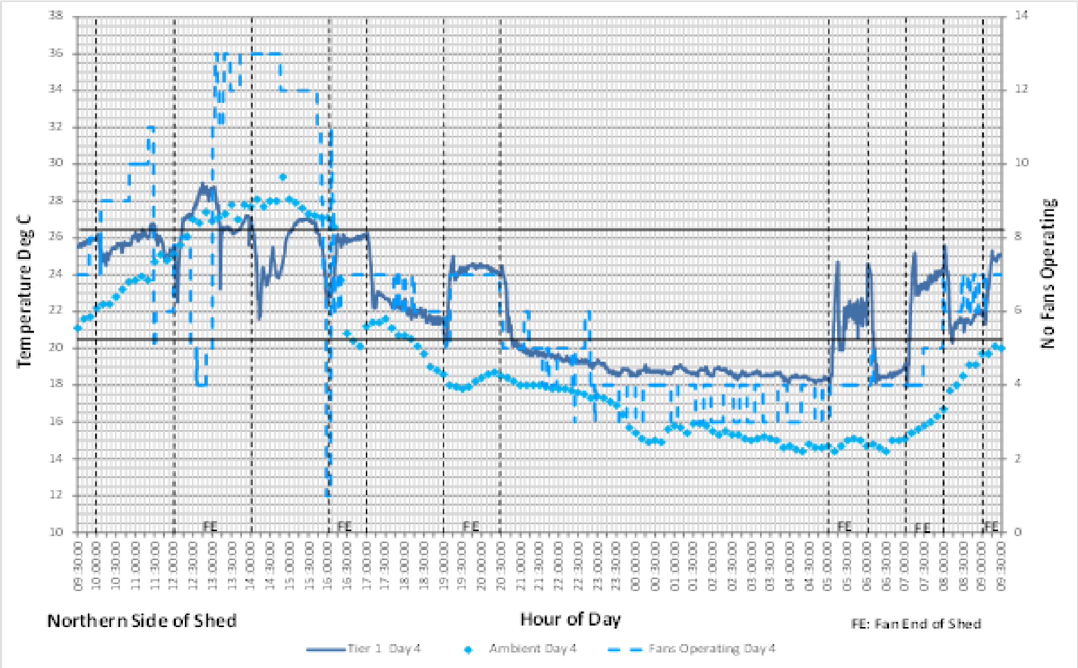


Figure 4-21 - Diurnal temperature variation northern side of layer shed (day 4)

The temperature on the northern side of the shed during day 5 shows the potential for the shed to cool itself when the ambient temperature is 30°C. Between 14:00 and 16:00 the temperature of the shed decreases when the controller set point of 26.5°C is exceeded. The shed temperature reduces down to 22-23°C during this period, likely due to increased fans operating (11 to 13).

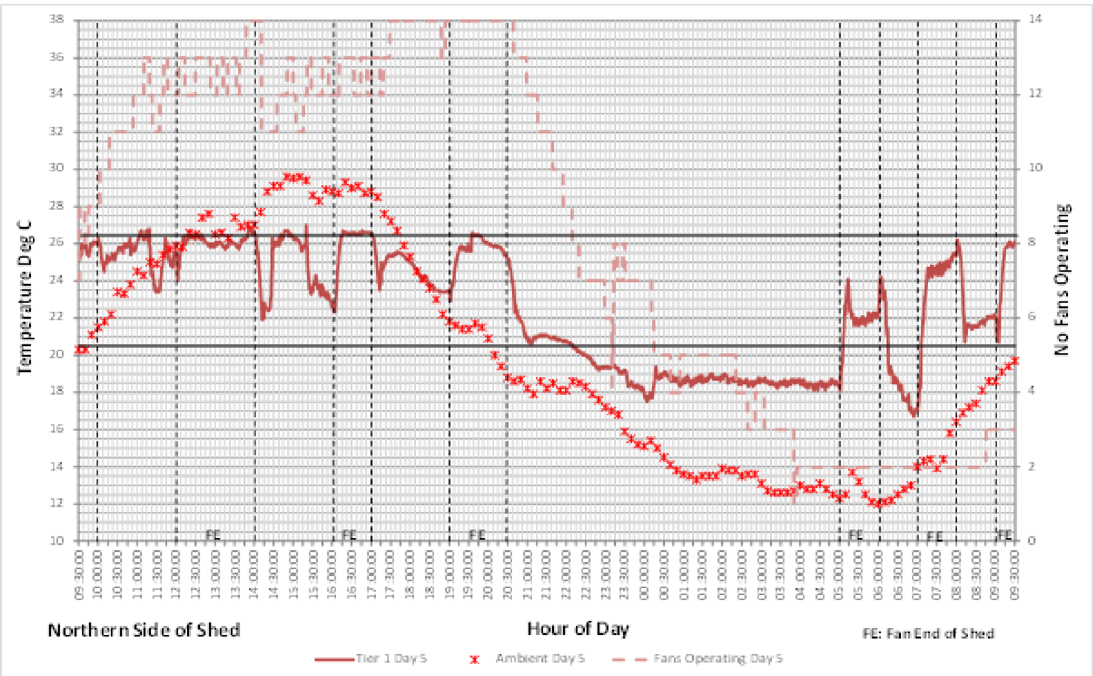


Figure 4-22 - Diurnal temperature variation northern side of layer shed (day 5)

The difference between the shed temperature on day 4 of tier 1 of the southern row and northern row is displayed in Figure 4-23. This provides an indication of the temperature gradient across the width of the shed. The temperature profile on the northern side of the shed shows a different characteristic when compared to the southern side. During the day, the maximum temperature on the northern side of the shed was approximately 1°C greater than the southern side, except when the cool pads were operating and between 5:00-9:30 am. The sudden drop in temperature on the northern side at 11:30 a.m indicates when the cool pads switched on. Once the ambient temperature dropped and cooling was no longer required to keep the temperature between the set limits, the pads turned off, occurring around 16:00.

During the night, the temperature was also slightly warmer on the northern side, varying between 19 and 20°C. This indicates that air leakage may be greater along the southern length of the shed. A temperature difference across a well-designed and managed shed of less than 1.5°C is considered acceptable; therefore, in this case there is no major concern.

A number of reasons cause a temperature difference between sides of the shed. The south side cool pads may not be working effectively (not clean, uneven water flow, inadequate water flow), resulting in slightly higher temperature under maximum ventilation (cool pads operating). There may also be issues with the wind pressure on the inlets on one side of the shed, or air leakage into the shed. This variation further highlights the difficulty for the controller to manage shed ventilation using one sensor.

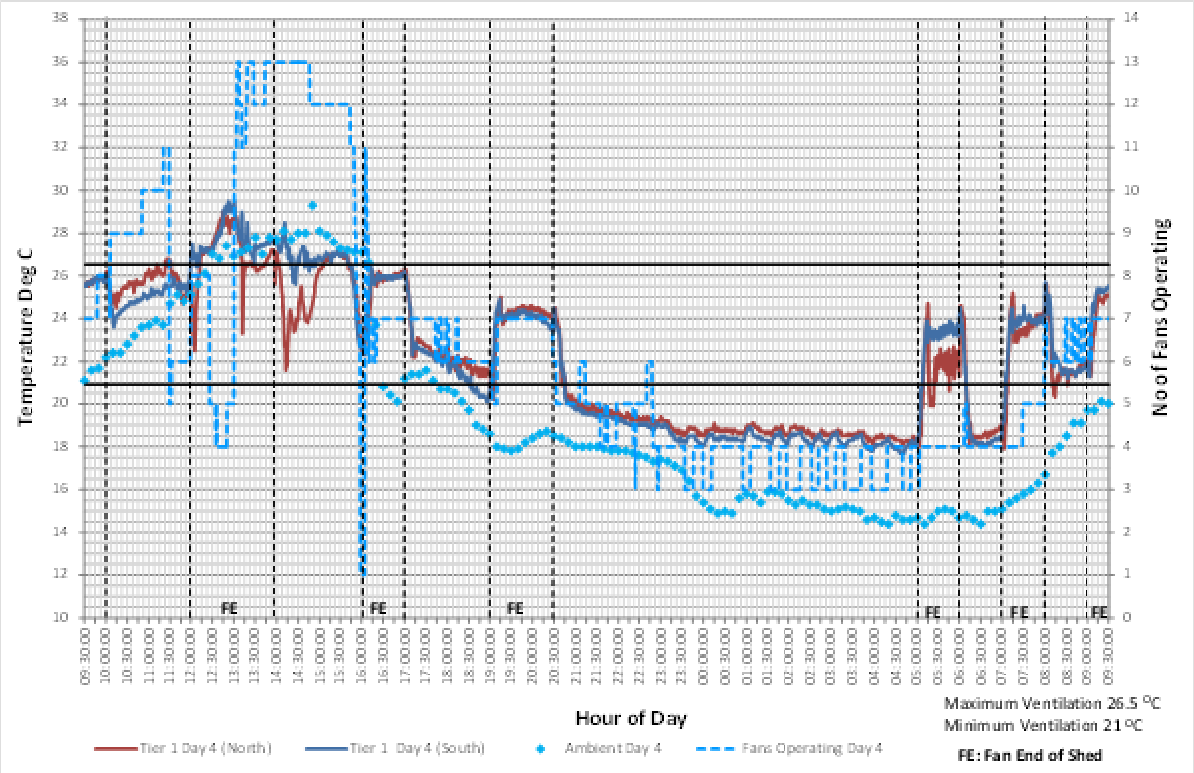


Figure 4-23 - South and north shed rows temperature variation

A comparison of shed and ambient relative humidity at the south side of the shed is displayed in Figure 4-24, Figure 4-25 and Figure 4-26. The humidity inside the shed generally followed the trend of ambient humidity. The maximum ambient relative humidity during the three days was 88% while the maximum shed humidity was 75%. Maximum levels occurred in the early morning from 2:00 to 7:00 am. Minimum relative humidity was recorded at approximately 32% both inside and outside the shed at 4 pm. The ambient temperature was approximately 31°C and the average shed temperature was 27°C.

All three days show a relative humidity decreased from 2 to 15% as the kestrel placed within the feeder moves from the inlet end to fan end during the mornings. A sharp increase in shed relative humidity was experienced on each day between 17:00 and 20:00. This followed the pattern of ambient relative humidity which also increased at a similar rate during this time. The difference between shed ends decreases throughout the day. During day 2 (Figure 4-25), there are spikes in humidity when the kestrel is positioned at the inlet end at 11:00 and 15:00. The cooling pads turning on are a likely explanation. The humidity also increases at 17:30, this occurs in sequence with the ambient humidity rising sharply.

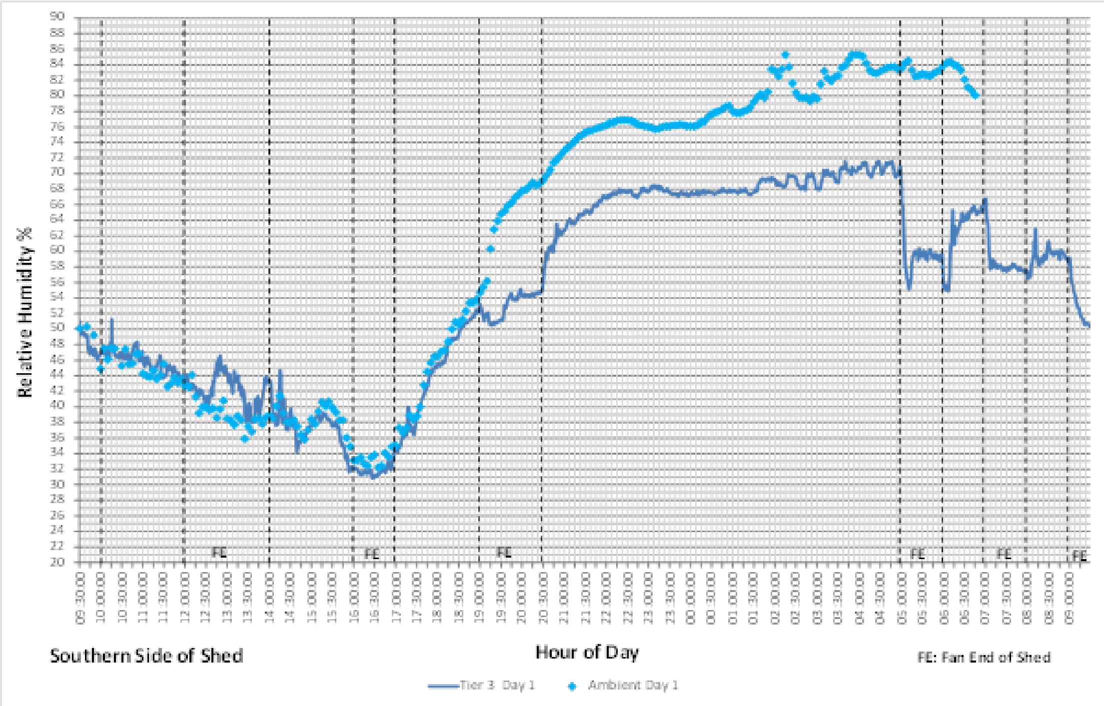


Figure 4-24 - Diurnal relative humidity variations southern side of shed (day 1)

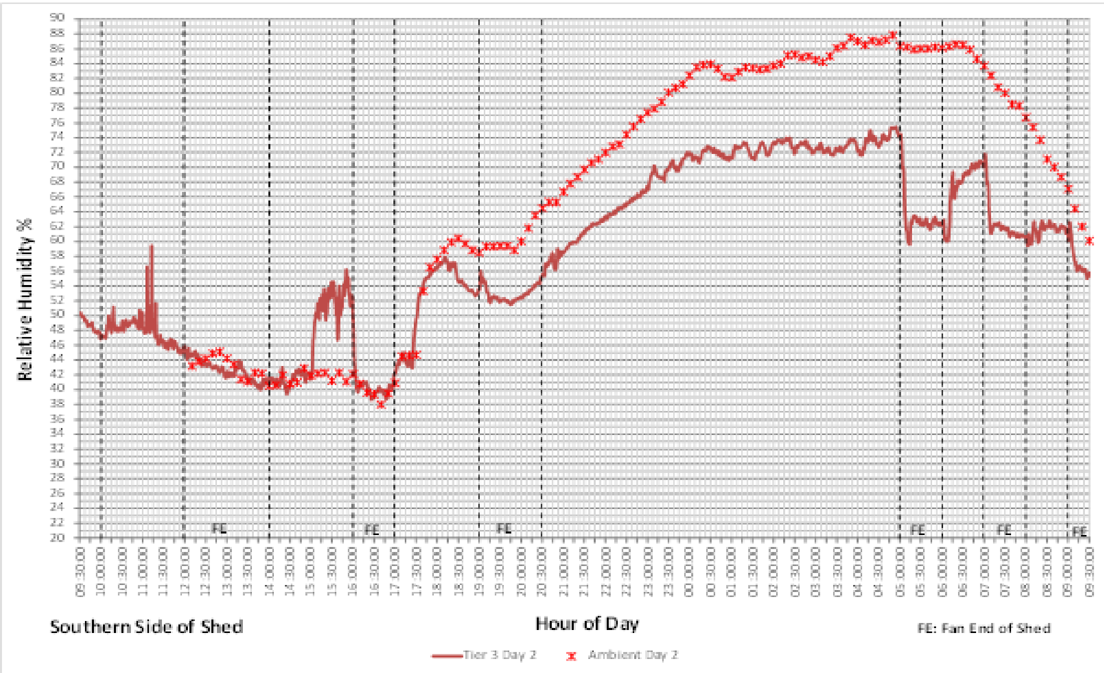


Figure 4-25 - Diurnal relative humidity variations southern side of shed (day 2)

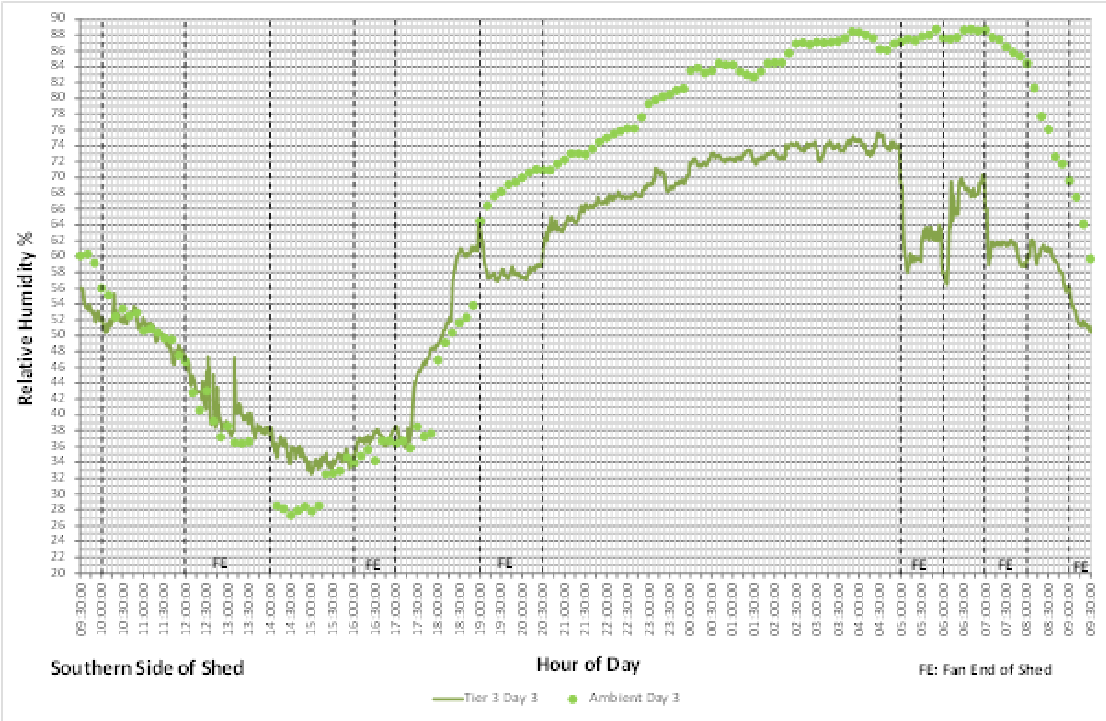


Figure 4-26 - Diurnal relative humidity variations southern side of shed (day 3)

Table 4-1 shows the mean daily and maximum and minimum temperature in different areas of a tunnel ventilated layer shed. There was little difference in temperature recording between February and March trials. In both trials the maximum temperature increased by 0.4°C (Feb) and 1°C (Mar) from the bottom to top of the shed. The minimum temperature also increased from bottom to top by 0.3°C (Feb) and 0.5°C (Mar).

Table 4-1 - Initial trial (summer) mean daily temperature variation and maximum and minimum temperatures in different cage levels of the layer shed

5	Cage Level	Feb	March
Max (°C)	Top	30.3	30.7
	Middle	30.1	30.6
	Bottom	29.9	29.7
Min (°C)	Top	16.9	17.2
	Middle	17	16.9
	Bottom	16.6	16.7
Standard Deviation (°C)	Top	3.19	3.07
	Middle	3.28	3.17
	Bottom	2.93	3.31

The mean daily and maximum and minimum relative humidity in different cage levels of a tunnel ventilated layer shed was recorded and shown in Table 4-2. There is a greater variation between maximum and minimum humidity in March. Maximum shed humidity reached 86% in February and 81% in March. Minimum humidity was 26% in February and 13% in March.

Table 4-2 - Initial trial (summer) mean daily relative humidity variation and maximum and minimum relative humidity in different cage levels of the layer shed

6	Cage Level	Feb	March
Max (%)	Top	86.0	80.3
	Middle	85.1	78.7
	Bottom	84.9	81.2
Min (%)	Top	26.3	13.5
	Middle	30.2	20.7
	Bottom	27.7	24.7
Standard Deviation (%)	Top	12.7	13.2
	Middle	11.3	15.0
	Bottom	11.5	13.5

6.1.1 Minimum ventilation trial (winter) July and September 2012

The ventilation performance of the test layer shed was analysed in two periods of winter to assess shed temperature and relative humidity under cooler conditions. Temperature along the shed was measured by placing the Kestrel 4200's on the feed hopper system, which travelled the length of the shed at pre-determined time intervals. The distance along the shed equals 110m. There are five meters of flooring before the cages start which includes the drive units for egg collection and manure equipment and water flow system and a work area. At the fan end of the shed, there is approximately three meters that includes the manure collectors and a work area. The cooling pad is fitted in the side wall from the start of the cages (5m) to 30m along the shed.

Figure 4-27 shows the data collected at 5am when the feeder with Kestrels attached moved from the inlet end to fan end on 16 July. The ambient temperature was approximately 1°C. The temperature increased as the feeder moved towards the fan end of the shed. There was a difference of approximately 7°C between the first and fifth tier of birds at the eastern end (cool pad end) of the shed. The temperature difference decreased to approximately 5°C at the outlet end (fan end) of the shed. The increase in temperature along the layer shed is likely due to the minimum ventilation inlet shutters not working correctly They were letting in more cold air than required, at a lower velocity and not controlling the direction of the air jet. This caused poor mixing of the incoming air with the shed air and a layer of colder air to run along the lower level of the shed as shown by the green line for the bottom Kestrel. The heat generated by the birds contributed to the temperature increase accumulating down the shed towards the outlet (fan) end.

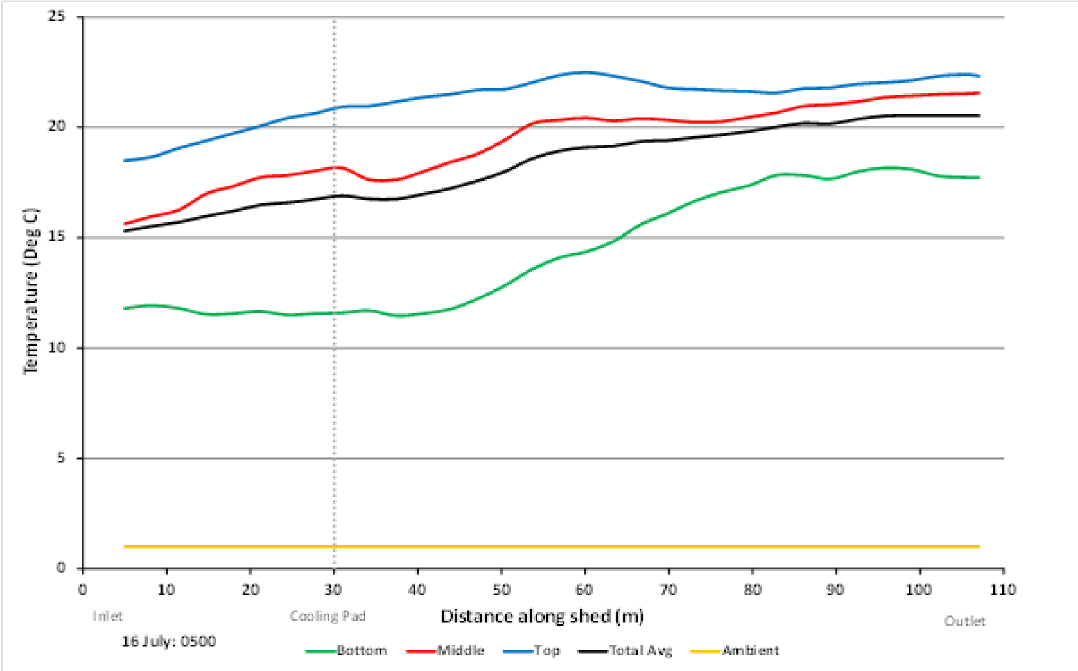


Figure 4-27 - Temperature along shed in July for minimum ventilation requirements

During a trial in September under minimum ventilation conditions, the temperature along the test layer shed was again recorded at 5am to test the ventilation performance under low ventilation requirements. The minimum ventilation inlets had been repaired. The ambient temperature was 6.5°C. Figure 4-28 shows the temperature measured along the individual layer shed at 5 am with the Kestrel 4200's placed in the feeding system hopper. The difference between the temperature of the bottom tier of birds and the top tier recorded by the Kestrel 4200 decreases from 7°C at the inlet (cool pad end) to 2°C at the outlet (fan) end.

Once again, the temperature at the outlet was greater than the inlet due to the ventilation system accumulating warm air from the birds along the length of the shed. The increase in temperature along the shed indicates that the minimum ventilation inlets were not effective in mixing the incoming air with the warmer shed air. This suggests that the position of the inlets, the opening size, the direction of flaps jetting air into the shed, and the air velocity at the flats require attention. Air leaks in the shed may have also contributed to poor mixing of air.

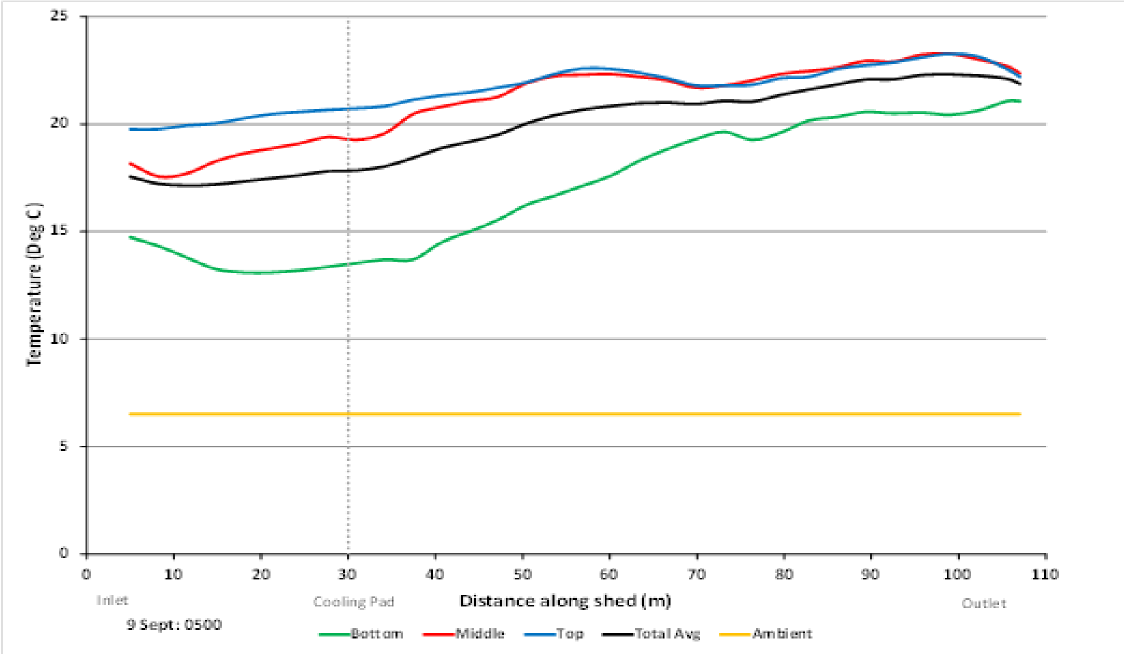


Figure 4-28 - Temperature along shed in September for low ventilation requirements

The results for relative humidity (averaged for each shed tier) along the shed compared against ambient readings are displayed for the July trial in Figure 4-29 and the September trial in Figure 4-30. In July the relative humidity outside was very high at 92%. Inside the shed, the relative humidity ranged from 52% to 72%. Relative humidity was greatest at the lower cages. The average relative humidity decreased by approximately 14% from the eastern end of the sheds (cool pad end) to the outlet (fan end). This is likely due to the effect of cold air mixing with warmer air and warmer air has the ability to hold more moisture. There is also cool moist air being brought in at the eastern (cool pad) end of the sheds and this becomes diluted with dryer air in the shed as the air moves down the length of the shed.

The relative humidity outside the shed in September was lower than July at 64%. Inside the shed, the relative humidity ranged from 40% to 49%. Once again, the relative humidity was significantly higher at the lowest cage tier of the shed. This the argument above that the minimum ventilation system requires attention. The inlet average relative humidity was 5% higher than the outlet relative humidity.

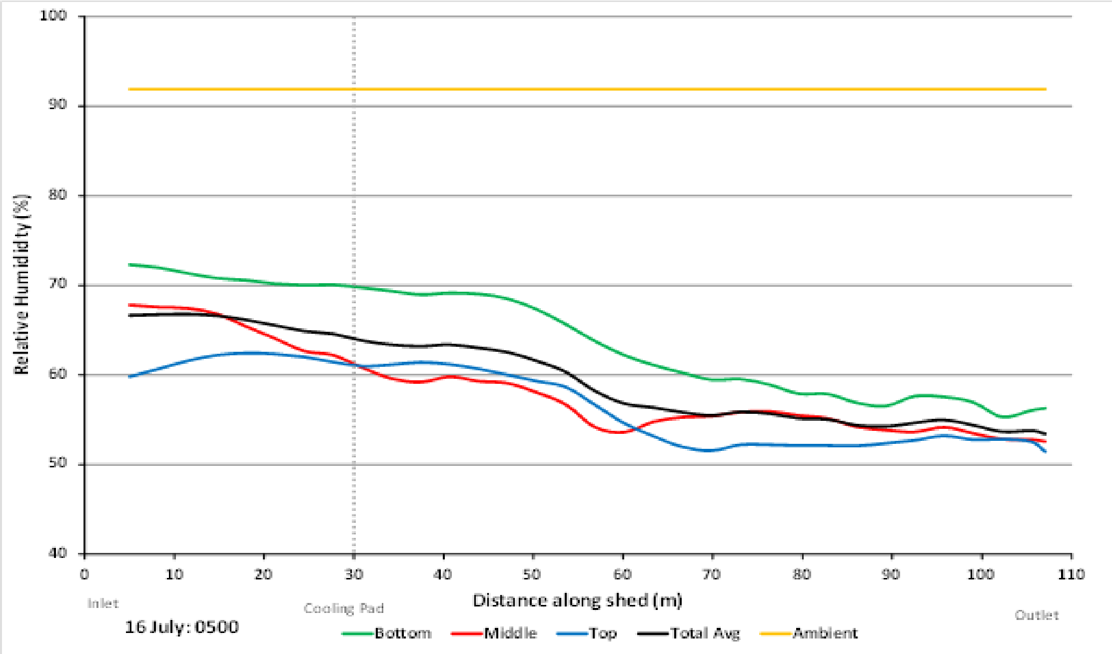


Figure 4-29 - Relative humidity along shed in July

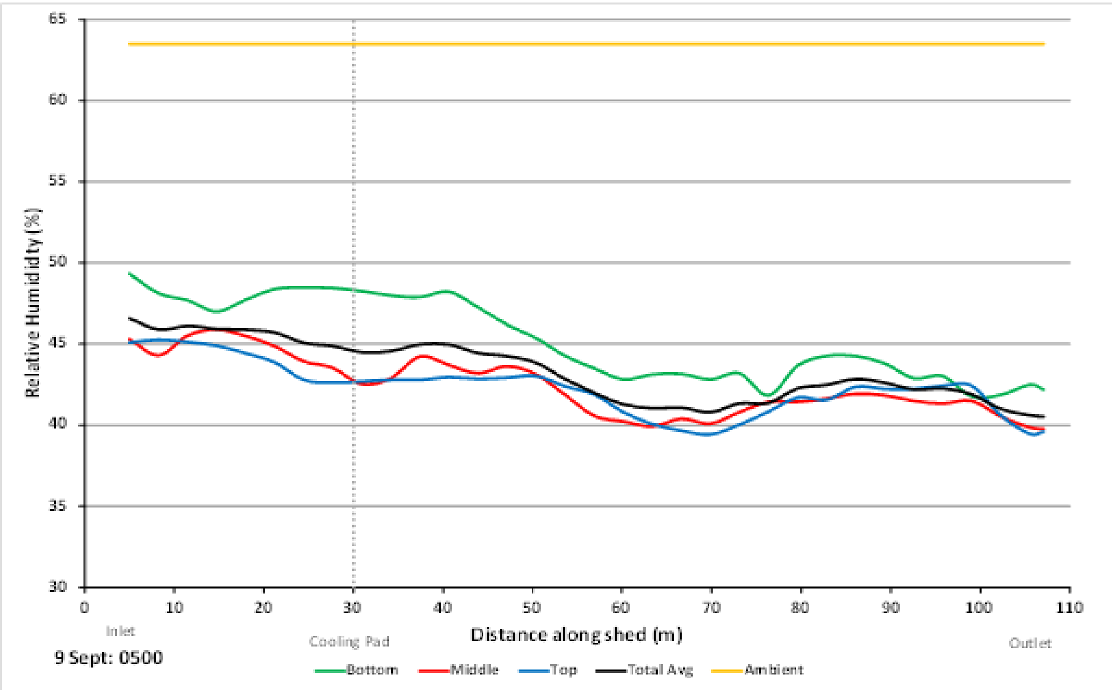


Figure 4-30 - Relative humidity along shed in September

Table 4-3 shows the average maximum, average minimum, and standard deviation for temperature and relative humidity recorded for each respective trial. The July data was logged from 5:00am to 9:00am while the September data was captured from 5:00am to 6:00am. The shed minimum and maximum temperatures were greater in September due to a higher ambient temperature.

Warmer temperatures were recorded on the top tier of the shed. This could be due to several reasons including, less dense, hot air rising and becoming trapped underneath the shed roof, and inadequate mixing of ambient air with the shed air due to poor inlet vent design, placement or management. A greater variation in temperature was experienced at the bottom of the shed. Maximum average shed temperatures ranged from 22.6°C (July) to

22.2°C (September). Minimum average shed temperatures ranged from 13.7°C (July) to 16.4°C (September). During the time of the trails the minimum ambient temperature was 0.8°C in July and 6.3°C September while the maximum ambient temperature was 15.0°C in July and 13.9°C in September.

Table 4-3 - Minimum ventilation trial mean daily temperature variation and maximum and minimum temperatures in different cage levels of the layer shed

7	Cage Level	July	September
Max (°C)	Top	22.6	22.2
	Middle	20.2	21.8
	Bottom	15.7	17.6
Min (°C)	Top	20.4	21.1
	Middle	18.8	20.3
	Bottom	13.7	16.4
Standard Deviation (°C)	Top	1.1	1.0
	Middle	2.1	1.8
	Bottom	3.0	3.0

The relative humidity measurements for July and September are presented in Table 4-4. Due to the higher ambient relative humidity in July, the shed relative humidity is also higher than the data obtained in September. There was a greater variation in relative humidity data collected in July than September. This is an effect of air leakage from the broken inlet vents which had maintenance performed on them before the September trial in an attempt to improve air mixing and reduce air leakage. Maximum average relative humidity ranged from 74% in July to 50.1% in September. Minimum average relative humidity ranged between 44.5% in July and 35.8% in September.

Table 4-4 - Minimum ventilation trial mean daily relative humidity variation and maximum and minimum relative humidity in different cage levels of the layer shed

8	Cage Level	July	September
Standard Deviation (%)	Top	3.1	1.7
	Middle	4.2	1.9
	Bottom	5.2	2.5
Max (%)	Top	64.8	46.0
	Middle	69.2	47.9
	Bottom	74.0	50.1
Min (%)	Top	44.5	37.0
	Middle	44.5	37.1
	Bottom	50.0	35.8

Thermal images were captured using the FLIR i5 infrared camera during July and September site visits. Air leaks during cold climatic conditions result in uneven temperature throughout the layer shed, particularly at bird level and make it difficult for the shed control system to maintain set-point temperatures. From this thermal imaging it was evident that cold air was leaking through the access door and cooling pads (Figure 4-32), with some mini-vents jammed closed and others fully open (Figure 4-33 left). This was causing very cold air to be reaching the birds on the bottom tier near the cool pad. This leakage reduced the volume of air being drawn in through the mini-vents (above bird level) and air leaking wherever the shed was not fully sealed (around the edges of the cool pads and door jams).

Between the July and September trials, the mal-functioning ventilation system was repaired, with the broken mini-vents control system replaced. After fixing the broken mini-vents and applying insulation to the door, the leaks were substantially reduced. Figure 4-33 (right) shows how the cold air entering the shed was mixed with warmer air before contacting the birds. As a result, less temperature variance within the Shed was observed in the September trial. However, Figure 4-31 demonstrates there is still poor mixing of incoming cool air with warmer air in the aisles during September, even after the vents were fixed. This could be a result of air leakages from the shed. Figure 4-31 also indicates the majority of the cool air is being directed down the sidewall. There appears to be little air being directed into the airspace above the cages.

Figure 4-31 - Inadequate mixing of cold air with warm air during September trial

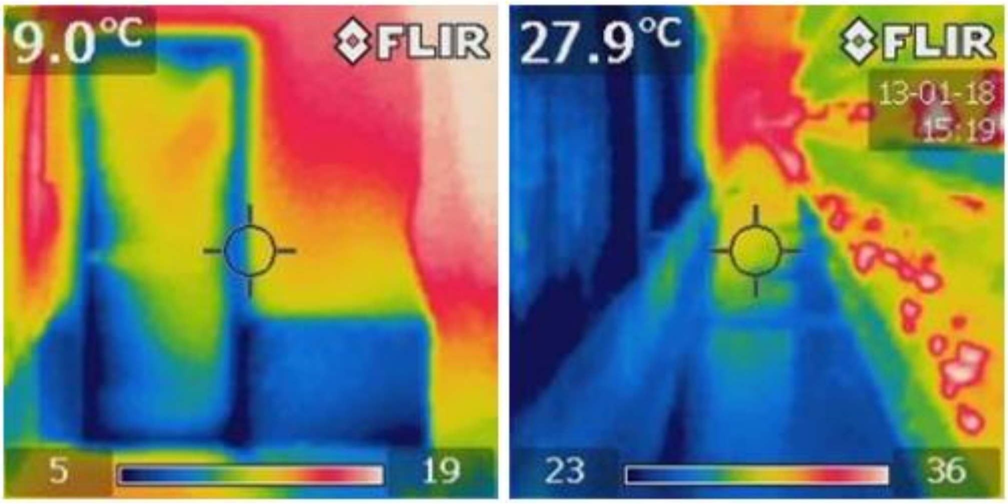


Figure 4-32 - Cold air leaking through the door (left) and cool pad (right)

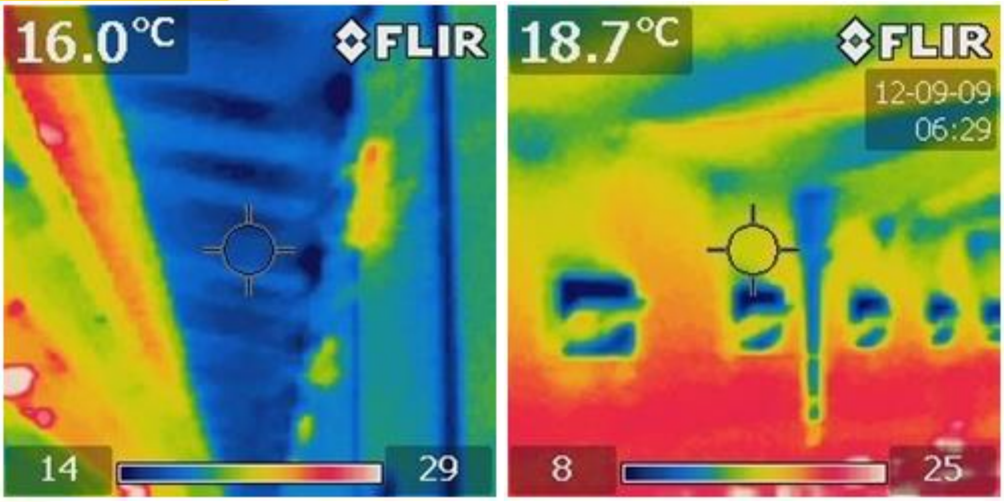


Figure 4-33 - FLIR i5 image of air flowing into the shed from the broken mini-vents (left) and the fixed mini-vents (right)

8.1.1 Maximum ventilation trial (summer) January 2013

The maximum ventilation effectiveness was analysed in a third trial taking place during hot summer conditions. All 14 fans and the cooling pads were operating. It is vital for the shed climate to be strictly controlled under these demanding conditions to ensure bird health, welfare and egg productivity is not impacted.

The temperature along the shed measured by each Kestrel 4200 is compared against ambient temperature for maximum ventilation in Figure 4-44. The feeder operated at 12 noon, and travelled from the inlet end to the fan end. All nine Kestrel 4200's were in their respective locations. Ambient temperature was measured as 33°C. The cool pads were operating during this trial; the pads began approximately 5m along the shed and continued to 30 m along the shed. The total length of the cool pads was 26m on each side.

Temperature at the shed inlet (cool pads) varied between 26°C to 28°C as mixing of the incoming cooled air with the shed air occurred. Temperature decreased for the first 30m along the shed, this is where the cooling pads are located. This shows the effect of poor mixing due to the pads being on the sidewalls, compared to the inlet end wall. After the feeder passed the cooling pads, the temperature gradually increased down the shed, due to the birds adding heat to the air along the length of the shed. At the shed outlet, the average temperature was approximately 29°C at each level of the shed. The temperature difference between cage levels from the end of the cool pads to the fan end was less than 1^{o}C. The recommended conditions to maintain bird comfort are a maximum temperature of 29°C providing humidity does not exceed 70%. If relative humidity is greater than 70% air movement is required to maintain bird comfort.

With layer production, at temperatures above 29°C egg production will fall. Above 23°C there will be a slight effect on egg weight. At temperatures above 25°C, feed consumption will be effected; however this can be corrected by increasing the diet density. Above 31°C there will be effects on not only egg production, but egg weight and shell quality. Above 36°C mortality starts. High relative humidity will have the effect of reducing these critical temperatures. These temperature limits relate more to the average temperature the bird is exposed to over 24 hours, except if temperature exceeds 36°C and, or if mortalities are likely to occur. Exposure to a temperature range of 31 to 36°C for several hours can have serious health effects.

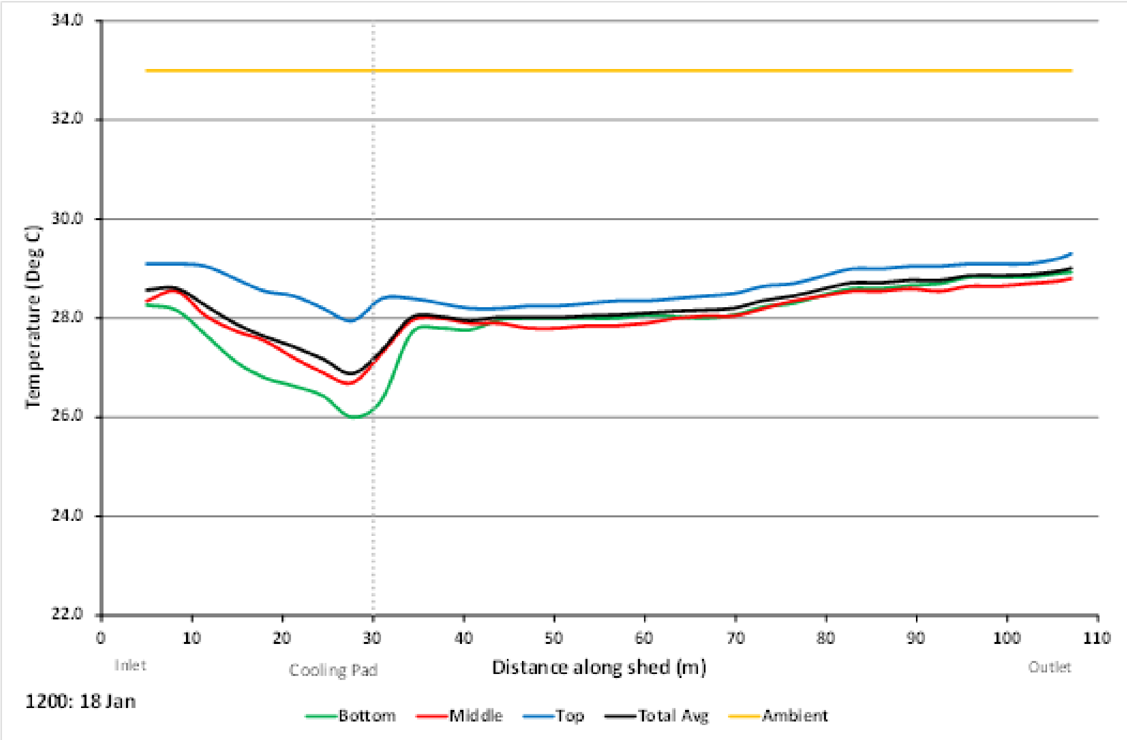


Figure 4-34 - Temperature along shed in January for maximum ventilation requirements

The relative humidity was also measured inside the test layer shed under maximum ventilation. The average relative humidity for each tier is displayed in Figure 4-35. The ambient relative humidity was 41% during the trial. The relative humidity at the shed inlet varied between 54% to 60% as mixing of the incoming cooled air with the shed air occurred. The relative humidity noticeably increased to a maximum of 72% at the end of the cool pads before slightly decreasing and becoming stable for the remainder of the shed length. This is due to the air warming and the increased moisture holding ability of the warmed air. After the cooling pads, the relative humidity gradually decreased as the Kestrel 4200's approached the fans. At the shed outlet, the relative humidity was 62%.

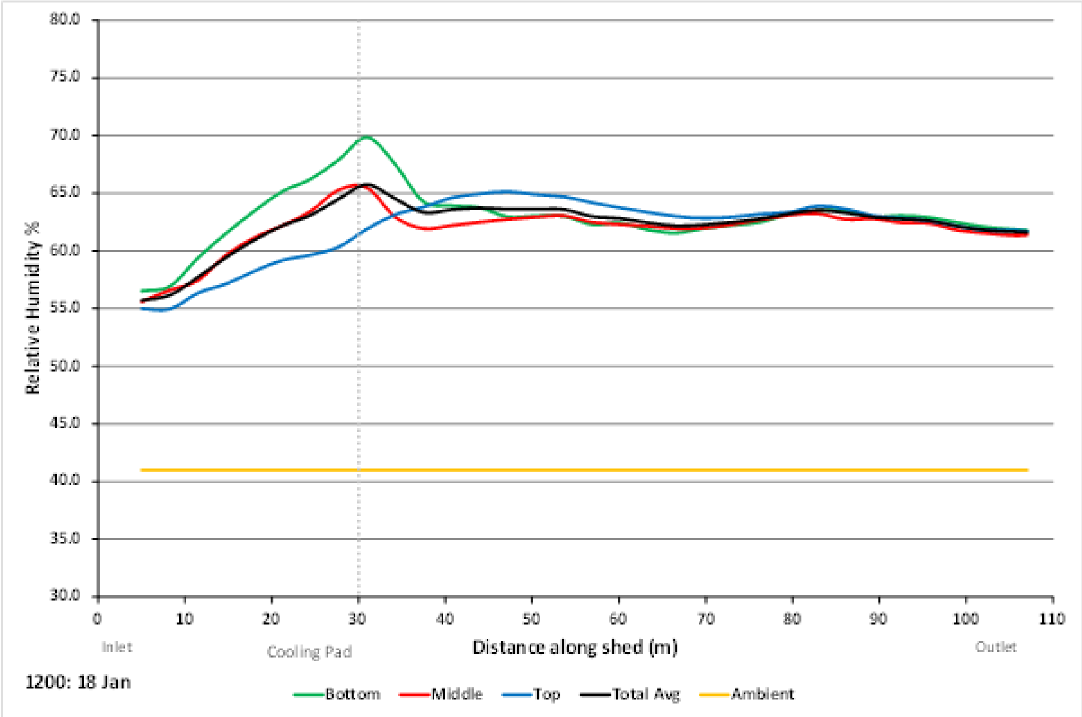


Figure 4-35 - Relative humidity along shed in January

Shed air velocity was also monitored to analyse the evenness of air velocity and air flow patterns within the shed and to estimate wind chill effect. The air velocity recorded along the shed when the fans were operating at maximum capacity, i.e 14 fans on, is shown in Figure 4-36. Air velocity recordings from each of the Kestrel 4200's stabilised at 30m along the shed approximately 5m past the end of the cools pads.

In the inlet area, the movement of air through and around the cages before the air flow patterns stabilise just past the end of the cool pads causes large variations in air velocity.

For the first 5m of the shed, there are no recordings, as the kestrels contained in the feeders do not reach this area. The middle tier Kestrel 4200's recorded lower air velocities than the bottom and top tiers, this is likely due to the obstructions (cage infrastructure) in the shed. At the inlet end of the shed, air velocity ranged from 1 m/s to 1.8 m/s. At the outlet of the shed, the air velocity increased, ranging between 1.25m/s and 2m/s. This is due to a change in air flow pattern as it approaches the exhaust fans. The air from the upper levels moving down to be exhausted by the fans.

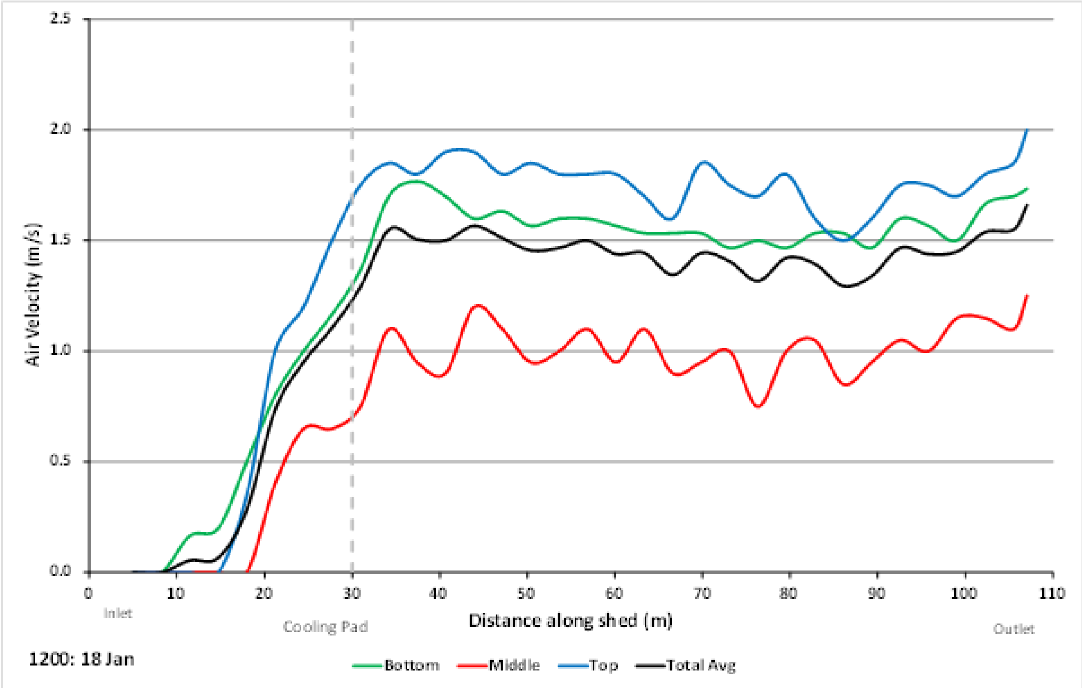


Figure 4-36 - Air velocity along shed in maximum ventilation trial

A comparison of ambient temperature, shed temperature and apparent temperature (wind chill factor) is displayed in Figure 4-37. Using a regression equation based on research by Czarick et al. (1999), outlined in report section 3.6.2.3, the apparent temperature was calculated under maximum ventilation requirements. Due to the operation of the cool pads, relative humidity within the shed was higher (65%) compared with the ambient humidity (40%).

To assess ventilation effectiveness during maximum ventilation (14 fans running) the wind chill effect upon the birds was estimated by applying a wind-chill to air velocity relationship curve produced by the USDA Poultry Lab and reported by Czarick et al (1999). The effect of wind chill reduced the temperature felt by the birds, the effective temperature, by up to 2.5°C compared to shed temperature.

Figure 4-37 shows that at high ambient temperatures (33°C), the effective temperature due to wind chill factor is well within the temperature conditions specified for bird comfort. This shows that under maximum ventilation requirements the wind speed generated by the ventilation fans effectively keeps the birds within the recommended temperature limits of below 29°C; however, it could be argued that greater wind speeds are required to offset the effects of high humidity on the comfort of the birds.

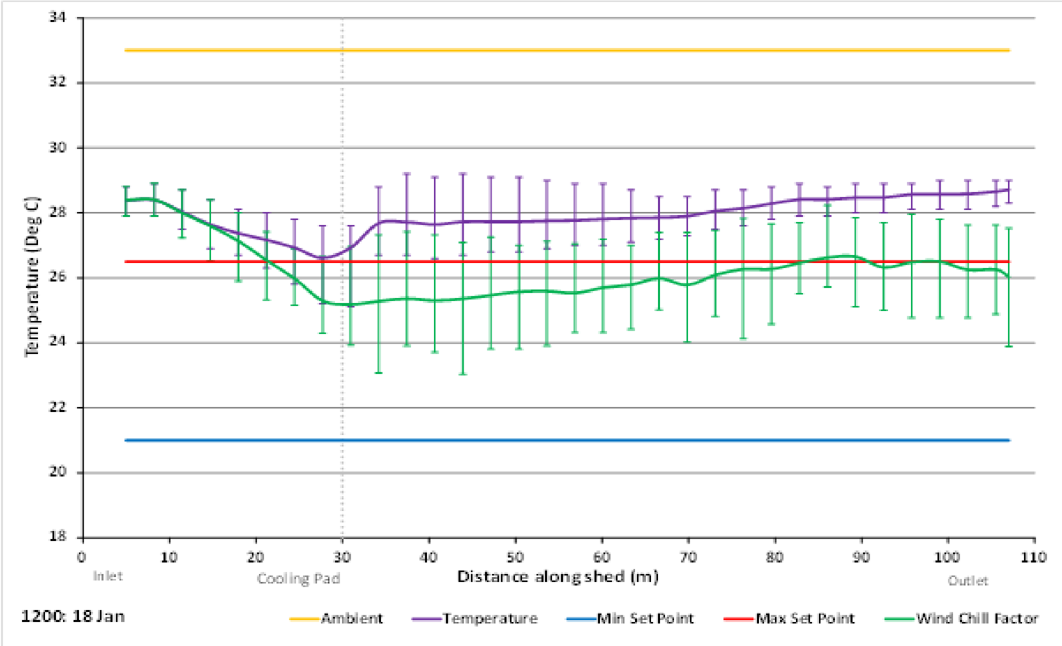


Figure 4-37 - Wind chill effect on birds (error bars show max and min temperatures recorded by the Kestrel 4200's)

Figure 4-38 presents a comparison of average shed temperature and shed apparent temperature against ambient temperature during the maximum ventilation trial. Data was collected over 22 hours. The shed temperature was nearly identical to the outdoor temperature between 9pm and 11am. When the ambient temperature increased to a maximum of 40°C, the average shed temperature did not exceed 30°C. The variations seen in shed temperature are due to the kestrel moving along the shed on the feeder runs. The contribution of wind chill due to air velocity from the shed ventilation system reduces the temperature felt by the birds to approximately 2°C below the shed temperature and 12°C below the maximum ambient temperature.

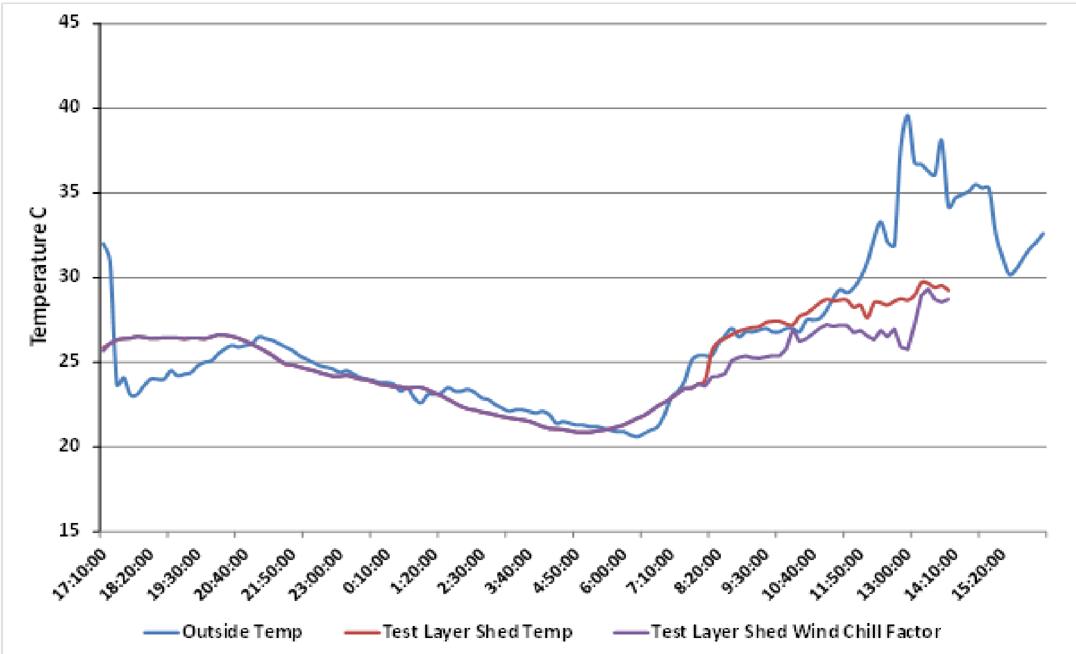


Figure 4-38 - Shed temperature, shed win chill and ambient temperature

The average maximum, minimum and standard deviation for data collected on the 18th January 2013 are displayed in Table 4-5. Averages represent the three Kestrel 4200 readings taken along the bottom, middle and top cage tiers of the shed. Data was recorded over approximately 22 hours. The maximum shed temperature was 31.3°C on the top tier and 30.9°C on the bottom tier. The minimum shed temperature was similar for all levels, ranging from 20.5°C to 20.8°C.

Table 4-5 - Maximum ventilation trial mean daily temperature variation and maximum and minimum temperatures in different cage levels of a tunnel ventilated layer house

9	Cage Levels	January
Standard Deviation (°C)	Top	2.70
	Middle	2.72
	Bottom	2.57
Max (°C)	Top	31.3
	Middle	30.9
	Bottom	30.9
Min (°C)	Top	20.5
	Middle	20.7
	Bottom	20.8

Thermal images were captured using the FLIR i5 infrared camera during the January 2013 site visit. The camera shows the warming air being drawn towards the outlet by the exhaust fans in Figure 4-39 (right). The cool air being emitted by the cooling pads is shown entering the shed on the left in Figure 4-39. The air at the cooling pads was approximately 23°C, while the air at the fans reached into the low 30°C range. The hottest areas in the shed are located at the fans as shown in Figure 4-40 (left). The final camera shot in Figure 4-40 (right) shows how the temperature increased towards the roof of the shed. The temperature in the top left of each image is the temperature at the position the cross hairs are aimed.

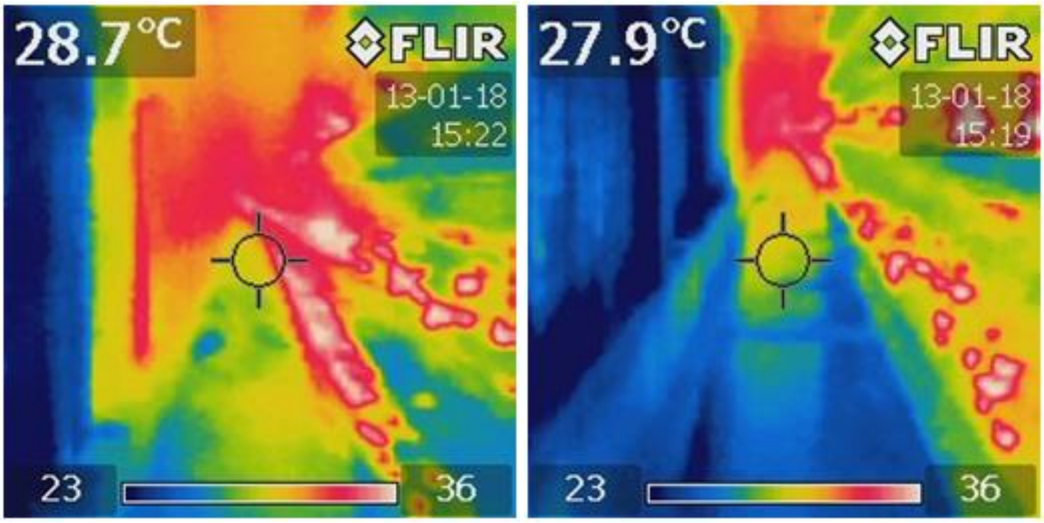


Figure 4-39 - Warm air being pulled towards shed oulet (left) and cooling pads effect (right)

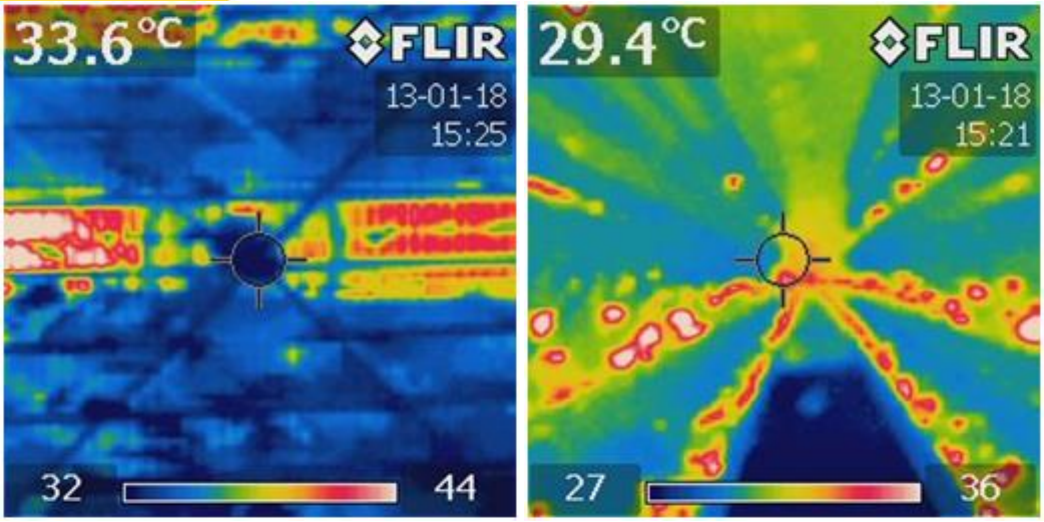


Figure 4-40 - Fans drawing warm air from shed (left) and temperature for separate shed tiers (right)

9.1.1.1 Instantaneous Kestrel 4200 measurements maximum ventilation requirements

The temperature, air velocity and relative humidity throughout nine locations in the test layer shed were measured in extreme dry summer heat. The ambient temperature averaged 36.2°C and the relative humidity averaged 32% during the trial. The nine locations in the shed were measured three times, on the first tier, third tier and fifth cage tier, at intervals of five minutes. Temperature results are displayed in Table 13, air velocity readings in Table 14 and relative humidity throughout the shed in Table 15.

The maximum temperature measured inside the shed under extreme conditions was 32.7°C, which occurred 40m along the shed on the northern side. During this measurement period it was noted that all 14 fans were running. The temperature on the northern side of the shed tended to be warmer than the southern side. The operating cooling pads are located on the southern side; the cooling pads on the northern side were not operating during this trial due to a pump failure. This allowed hot ambient air into the shed resulting in the higher temperatures recorded in Table 4-6. The temperature on the fifth tier was usually slightly warmer than the lower tiers. The fan end of the shed was 110m, 80m was in-between the fans and cooling pads and 40m was just past the end of the cool pads. Due to the closer proximity to the cooling pads, the temperatures at 40m tended to be cooler than 80m or 110m along the shed.

Table 4-6 - Instantaneous temperature (ºC)

10 Length along shed (m)	11 Cage Row		
	South	Middle	North
	First Tier		
110	29.6	28.8	29.9
80	29.9	28.8	30.2
40	27.5	27.7	31.6
	Second tier		
110	30.5	29.3	30.5
80	30.5	29.2	30.8
40	28.2	27.6	32.7
	Third tier		
110	30.7	27.6	30.8
80	30.8	29.1	30.9
40	29.5	28.1	31.8

Air velocity within the shed under maximum ventilation ranged from 0.3 m/s to 1.5 m/s. This was a lower air velocity than presented in Figure 43, likely due to the kestrels being placed on the egg collection belt instead of the moving feeder. This area of the shed is less exposed as air movement is inhibited by the cages. The recorded data shows no obvious trend in air speed throughout the shed rows or tiers. This may have been caused by obstructions within the shed affecting the accuracy of the Kestrel 4200 readings.

Table 4-7 - Instantaneous air velocity (m/s)

12 Length along shed (m)	13 Cage Row		
	South	**Middle**	**North**
	First Tier		
110	1.2	1.0	0.9
80	0.9	0.4	1.0
40	1.0	1.1	0.6
	Second tier		
110	1.3	1.2	0.8
80	0.9	0.3	1.0
40	1.1	1.3	0.5
	Third tier		
110	0.9	0.3	0.7
80	0.7	0.5	1.0
40	0.8	1.5	0.7

Relative humidity inside the shed ranged from 43% to 67%. Humidity was greatest at 40m along the shed due to the cooling pads adding moisture to the air. The south side of the shed experienced higher relative humidity than the northern side. The fifth tier of the shed had a higher humidity than the first tier by 5% on average.

Table 4-8 - Relative humidity inside the shed

Length along shed (m)	Cage Row		
	South	**Middle**	**North**
	First Tier		
110	54.5	60.0	56.5
80	55.0	60.4	52.0
40	65.2	65.6	43.2
	Second tier		
110	52.7	60.4	56.6
80	54.8	60.6	51.4
40	65.7	65.4	41.8
	Third tier		
110	64.6	62.7	63.4
80	64.8	64.0	52.9
40	67.2	62.0	50.9

13.1.1.1 Fan Performance

Fan performance was analysed by calculating the cubic feet per minute (CFM) rating. The experimental value could then be compared against manufacturer's specifications to test how effectively the fans were operating. The average air velocity was recorded over three, five minute time intervals using the Kestrel 4200's at a range of points along the width and height of the fan end of the shed, giving 15 minutes of collected data in total. An air velocity measurement was made every five seconds, giving 300 recorded air velocity measurements. At the time of all recordings, all fans were operating with the shed operating in tunnel ventilation mode. The location of the recording covered the full cross section of the shed, just in-front of the manure belts and approximately two metres from the fan housing. The process of data collection is displayed in Photograph 23.

Photograph 23 - Fan performance data collection for shed cross section

The three, five minute trials all recorded a similar average air velocity, with the overall all velocity of all measurement being 2.27m/s. The cross section of the shed was 57.6m^2. From these measurements, the average ventilation rate of the shed was calculated as 131m^3/s. The units were converted into m^3/h and divided by the number of fans to obtain a rating of 33,710m^3/h or 19,841 CFM. The fan performance was also rated by the University of Illinois as 23,700 CFM or 40,266m^3/h, which is higher than the experimental results.

The Multifan 130 (3 blade) installed in the layer shed are designed to operate at 26,839 CFM as per the manufacturer's manual which equals 45,600m^3/h. This is greater than the Illinois University testing results and FSA on-site tests. Considering both results, it was assumed that the exhaust fans were operating below their rated capacity. It is recommended to check that the fans are running at the same RPM as their specification, as Australian equipment often has different motors and pulleys to that used in the USA. To improve the fan performance and ventilation rate the fans should be serviced and cleaned and the ventilation re-analysed before deciding if the fans require replacement.

14 Conclusions and recommendations

Continuous energy monitoring at the selected farm showed that electrical energy use ranged from an average of 1500 kWh/d in winter to 2500 kWh/d in summer. Peak loads of between 140 and 185 kW were recorded during warmer periods of the day. A single tunnel ventilated layer shed (Shed 5) was assessed on the farm and electricity energy consumption varied between averages of 280 kWh/d in winter to 350kWh/d in summer, representing approximately 15% of the total site electrical energy use.

Intensive energy monitoring on specific areas of the selected farm over a two-week period revealed that the power factor for the entire site and the test layer shed averaged 0.8, which is acceptable. This was expected, as most induction motors have a reasonably good power factor of 0.8 – 0.85 and they dominate electrical energy use at the site to operate the ventilation fans. During the intense monitoring period, the feedmill power factor dropped to an undesirable ratio of 0.2. This may be a result of the motors being over-specified or if they are running with no load. This highlights the issue of ensuring motors are either properly specified or turned off when augers are empty to reduce energy use. Correction of the power factor at the feedmill is however unlikely to have a reasonable pay-back period (not economically viable) if the feedmill continues to operate for only 16 hours per week. The most likely economic benefit would come from operating the feedmill at night on off-peak tariffs.

The electrical energy efficiency of egg production was analysed by calculating energy use (kWh) per kilogram of egg produced and by the energy used per bird. The test shed alone had an average energy efficiency of 0.15 kWh per kg of eggs produced. Average energy use for the total farm was 0.25 kWh per kg of eggs produced. However, the total farm electricity logging includes components that do not contribute to egg production at a layer shed level, such as the grading floor and rearing shed. Feedmill energy use was not included in this figure for total site energy use. As expected, electrical efficiency in winter was better due to lower cooling requirements.

When compared against other tunnel ventilated layer farms the energy use was relatively high for both total egg weight produced and per hen. This is likely due to electricity logging for Farm A including all facets of the farm. High temperatures during the summer monitoring period are also likely to have contributed to a high demand in electrical energy use to operate the ventilation system. Direct comparison over the same time periods would be required to provide any definitive comparison of energy efficiency between different production systems.

Optimising electricity usage is important factor in improving the bottom line of egg production systems. Some methods of reducing electricity usage are more effective than others. The key is to concentrate on areas of the system that will not have an adverse effect on bird performance.

To enable this, the energy use of individual components needs to be known via some monitoring system that gives more detail than just whole site energy use. The contribution of each electrical energy use process was analysed for a single tunnel ventilation shed at the selected farm. Fan energy made up the largest portion of electrical demand at between 65 and 70% of the total electrical demand. Thus, ventilation fans represent the greatest opportunity for potential electrical energy savings through improved ventilation efficiency. Methods for improving fan performance and hence reducing fan operating costs include:

1) General maintenance of pulleys and belts.
2) Regularly cleaning fan blades, motors and shutters.
3) Replace burnt-out motors with energy efficient motors.

4) Maintain and clean cool pads to ensure airflow is not restricted.
5) Investment in more capital (e.g. energy efficient fans and cowlings). This decision should be based on potential pay-back.
6) Ensuring shed ventilation (fan performance) is meeting manufacturer requirements.
7) When constructing new ventilation sheds choose energy efficient fans, pay attention to the fan's energy efficient rating (cfm/watt) and air flow ratio.
8) Reducing the fan speed with a variable frequency drive (VFD) unit reduces airflow rate and the energy consumption of the fan; operate in accordance with ventilation requirements.

Lighting represented the second highest electrical energy use in the selected shed, at approximately 17% of total electrical energy use. Lighting technology is rapidly evolving with more energy efficient bulbs becoming available including compact fluorescent lamps, triphosphor bulbs and cold cathode fluorescent lamps. Another option for consideration is the replacement of fluorescent tube lighting with LED tubes.This will save significant energy usage and will not require new infrastructure. For example, replacing the current 36 watt fluorescent tubes with 18 watt LED tubes can potentially save 150 kWh/week on the shed. The current electric dimmers would have to be replaced with newly available universal dimmers that enable the brilliance from LED lights to be controlled. These cost approximately $50 from electrical retailers. Agrilamp now have led lamps suitable for poultry farms available in Australia.

Other sources of energy consumption on the farm can also be managed more efficiently. Gas usage can be minimised by ensuring the rearer shed is well sealed from cold air leaks and reducing air leaks via broken, bent or missing shutters on fans.

Although not necessarily reducing energy use, but has the potential to reduce costs is to manage and reduce peak energy loads. Peak energy may be reduced by minimising the operation of any additional equipment when the fans are running at full load. Another option in reducing electrical energy costs is to negotiate with the supplier for a reduced tariff. For example, using a diesel backup generator during peak energy load will reduce reliance on grid electricity, creating bargaining power for a cheaper tariff rate.

There are opportunities to replace existing fossil fuel energy consumption by using a solar photovoltaic (PV) cell system designed to fit on the available roof space. Solar Cells could be used to reduce peak electricity load during hot hours of the day. As mentioned, decreasing peak load allows farm management to negotiate a cheaper rate with power suppliers due to reducing the burden on supply electrical infrastructure.

Improvements in energy efficiency can only be accurately assessed and confirmed by measuring usage. Measuring energy use can be aided by installing additional power and gas meters to allow measurement of individual sheds and components within sheds. Power usage meters provide a measurement of energy consumption (kWh) and also record total energy consumed. This provides an invaluable tool for assessing the electrical performance between sheds and will assist in reviewing energy efficiency measures.

The ventilation efficiency trials assessed layer shed environmental conditions under both minimum ventilation (cold) and maximum / tunnel ventilation (hot) conditions. During cold winter temperature trial, the shed was functioning under minimum ventilation conditions with a single fan and mini-vents. During the summer trial all exhaust fans and the cool pads were functioning under tunnel ventilation conditions. In both trials temperatures increased towards the exhaust fan end of the shed due to heat generated by the birds warming the air. There was also a noticable difference between the temperature at different heights in the shed. The bottom of the shed was several degrees cooler than the top, likely due to poor air flow patterns. This is a design issue, which is a problem for the design of the ventilation system and the issue will be exacerbated under summer conditions. For the winter, this uneven air temperature will be caused by inlet placement, opening size and airspeed at the inlet to achieve adequate mixing of cold and warm air.

During the trial, it was established that the sheds ventilation control system was only using one temperature sensor within the shed. The differences in temperature throughout the shed highlight the difficulties and error created when allowing the entire ventilation system to be controlled by an individual sensor located in a stationary position. It is highly recommended that the shed control system be programmed to use an average of several sensors located throughout the shed.

Layer shed temperature in winter fell below the minimum recommended level for optimum layer production of 21°C. This only occurred at the inlet end of the shed. Reducing air leaks at this point of the shed would be the first step in improving bird comfort and productivity before additional heating (via gas heaters) is considered. On a hot summer day (ambient temperature 40°C), the actual shed temperature reached approximately 30°C, this is several degrees above the controller set point of 26.5°C but still within the recommended bird health temperature limits provided exposure is limited to a short time period. Ensuring the cooling pads and fans are operating efficiently may improve shed cooling under extreme summer conditions.

The apparent temperature (wind chill effect) was also calculated for the shed under maximum (tunnel) ventilation conditions. Wind chill effects reduced the temperature felt by the birds by approximately 2-3°C and within the recommended temperatures and climate conditions for optimum layer production of between 21 and 26.5°C. The method of fitting the kestrels to the feeder to measure shed ventilation along the shed was effective and could be used in other cage sheds with a robotic feed delivery system.

Total shed ventilation performance under maximum ventilation conditions (tunnel ventilation) was assessed and was found to be performing below the manufacturer's specifications. It is recommended the fans receive maintenance and servicing to achieve a higher ventilation rate. However, more detailed monitoring of individual fan performance would be required to obtain accurate performance variability between the fans via method such as those described by Casey et al. (2008). The test method used could be improved by taking more spot measurements at designated points through the cross section of the shed or detailed assessment of each individual fan to assess which fans are under-performing.

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16 Plain English Summary

Project Title:	Evaluation of energy usage and ventilation performance of tunnel-ventilated layer sheds
AECL Project No	1FS111
Researchers Involved	E.J. McGahan, R.J. Davis, B.R. Warren and A.Ni Cheallaigh
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Objectives	• Quantify energy use and energy use profile for an egg production farm. • Assess tunnel ventilated layer-shed design from a ventilation and energy efficiency perspective. • Provide actual segregated energy use data.
Background	To remain competitive and meet the demand for eggs, the egg industry recognises the need for it to continue to make significant gains in areas of technical and cost efficiency. Increasing the efficiency and profitability of egg production systems and ensuring hen welfare are key outcomes for the AECL. Ventilation fans are the key component of mechanical ventilation systems and are used to create both airflow and air exchange. The fresh air conveyed by the fans supplies oxygen to the animals and removes heat, moisture, and aerial contaminants from the shed. Ventilation fans are usually selected by a designer based on a fan performance characteristic and appropriate environmental control relies on the fan capacity to supply the required volume of air as well as properly configured and operated inlets for fresh air. Shed design and tunnel ventilation technologies have been imported from overseas manufacturers and adapted to Australian conditions.
Research	Stage 1 – Selection of participating enterprise, site assessment and instrumentation selection. Stage 2 – Acquisition and installation of instrumentation, literature review, data collection/collation Stage 3 – Evaluation of Tunnel Ventilation Research Stage 4 – Industry Workshops Stage 5 - Reporting
Outcomes	Electrical energy monitoring at the selected farm showed that electrical energy use ranged from an average of 1500 kWh/d in winter to 2500 kWh/d in summer. Peak loads of between 140 and 185 kW were recorded during warmer periods of the day. A single tunnel ventilated layer shed (Shed 5) was assessed; electrical use was 280 kWh/d in winter and 350kWh/d in summer. Operating ventilation fans required 60-70% of the total energy while lighting required 17%. The electrical energy efficiency of egg production was analysed by calculating energy use (kWh) per kilogram of egg produced and by the energy used per bird. The test shed alone had an

	average energy efficiency of 0.15 kWh per kg of eggs produced. Average energy use for the total farm was 0.25 kWh per kg of eggs produced. The ventilation performance of a single layer shed was assessed during minimum ventilation (cold) and maximum tunnel ventilation (hot). Results from both maximum and minimum ventilation trials showed that the temperature increased by several degrees towards the exhaust fan end of the shed. There was also several degrees temperature difference at seperate heights in the shed, with the bottom cooler than the top. These results are due to poor air flow patterns. Air mixing can be improved by rectifying inlet placement, opening sizes and airspeed at the inlet to achieve adequate mixing of cold and warm air. During both trials the sheds ventilation control system was responding to a single temperature sensor within the shed. The differences in temperature throughout the shed highlight the difficulties and error created when this occurs. It is highly recommended that the shed control system be programmed to operate on the average of several sensors located throughout the shed. The layer shed temperature in winter fell below the minimum recommended level for optimum layer production of 21°C at the shed inlet. Reducing air leaks will improve bird comfort and productivity, if results are not achieved, additional heating (via gas heaters) should be considered. During hot conditions (ambient temperature 40°C),shed temperature reached 30°C, this is several degrees above the controller set point of 26.5°C but still within the recommended bird health temperature limits. The apparent temperature (wind chill effect) was calculated for the shed under maximum (tunnel) ventilation conditions. Wind chill effects reduced the temperature felt by the birds by approximately 2-3°C and to within the recommended temperatures and climate conditions for optimum layer production of between 21 and 26.5°C. Total shed ventilation performance (air-flow volume) under maximum tunnel ventilation conditions was assessed and found to perform below the manufacturer's specifications. It is recommended to service and maintain the fans to improve ventilation rate.
Implications	Provided information to enable producers to identify farm energy use and reduce energy costs and use, therefore increasing profitability and reducing emissions. Identified issues with tunnel ventilation performance in caged layer sheds. Producers need to be aware of tunnel ventilation performance and control the system to achieve optimal performance.
Key Words	Tunnel ventilation, eggs, egg layer farms, energy efficiency, energy use, fan performance, wind chill, egg production
Publications	R.J. Davis, E.J. McGahan & A. Ni Cheallaigh 2012. Energy usage

and ventilation performance of tunnel ventilated layer housing in Australia, Poultry Information Exchange Proceedings 2012.

E.J. McGahan, R.J. Davis & B.R. Warren 2014, Energy useage and ventilation performance of tunnel ventilated layer sheds, Poultry Information Exchange Proceedings 2014 – (Not yet published, in progress)