

15. Environmental and management effects associated with improved production efficiency in a respiratory disease free pig herd in Australia

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Abstract

The combined effects of a number of housing related parameters were evaluated in relation to the production efficiency of pigs under commercial farm conditions. These parameters included, air temperature, stocking rate, stocking density and the concentrations of different airborne pollutants. The commercial piggery buildings were divided into two separate compartments containing control and experimental groups of animals. The compartments containing the experimental groups were managed in order to reduce the airborne pollution load on the animals, while the other sections were managed according to normal farm procedures (control groups). The growth rate and environmental variables of both groups were monitored and compared. The statistical analysis (using general linear models) identified key factors contributing to improved production efficiency, including ammonia concentrations in the compartments, the quantity and size of airborne particles and stocking density. This efficiency improvement was achieved without the opportunity to see any perceivable change in clinical health of the animals. Thus improving housing conditions on farms may improve profitability even in cases where livestock are not affected by well-defined infectious diseases.

Keywords: pig houses, environmental quality, dust, bacteria, ammonia, stocking rate, performance

15.1 Introduction

The major airborne pollutants that farm animals are exposed to in livestock buildings (Banhazi *et al.*, 2008c, 2009; Groot Koerkamp *et al.*, 1998; Seedorf *et al.*, 1998; Takai *et al.*, 1998) have the potential to significantly reduce the animals' production efficiency, health and welfare (Done *et al.*, 2005; Kovacs *et al.*, 1967; Lee *et al.*, 2005; Wathes *et al.*, 2004). Airborne pollutants that are commonly found in the airspace of commercial piggery buildings include ammonia (NH₃), airborne bacteria (total airborne bacteria, gram positive and fungal species), inhalable and respirable particles. A mixture of these bioactive materials, known as bio-aerosol (dust particles, clumps of bacteria, noxious gases and toxins), can be inhaled into the lungs of the pigs. Subsequently, these pollutants can attack the animals' immune systems, triggering an inflammatory reaction, and a reduced resistance to respiratory infection (Urbain *et al.*, 1998). Feed intake may also be reduced, resulting in reduced growth rates (Lee *et al.*, 2005).

In addition to the potentially negative effects of airborne pollutants on the health and welfare of animals; airborne pollutants can also increase the occupational health and safety risks for

farm workers (Banhazi *et al.*, 2009). Compared with non-agricultural workers, the occurrence of symptoms related to respiratory problems (including a decline in lung function) increase when workers are exposed to the airborne pollutants found in piggery buildings (Donham, 2000; Dutkiewicz, 1997; Von Essen and Donham, 1999; Zejda *et al.*, 1994). The synergic effects of exposure to airborne pollutants may also increase the number of health problems experienced by humans and livestock (Donham *et al.*, 1977). Additionally, airborne pollutant emissions from livestock buildings could damage the surrounding environment (Banhazi *et al.*, 2008a). For example, in Australia particle emissions have impacted receptors up to 2000 m away from average-sized piggery buildings (Banhazi *et al.*, 2007).

Commonly, Age Segregated Rearing (ASR) is a method adopted in pig production systems to minimise the transmission of respiratory diseases between successive batches of pigs and thus to reduce the impact of these diseases on pigs. However, due to the fact that this experiment was conducted in a high health status herd, in this specific study health improvement of pigs was not a study objective. In addition, ASR facilitates the improvement of air and surface hygiene of piggery buildings (Cargill *et al.*, 1998). Under this regime pigs are housed in groups, with an age spread of less than two weeks, and facilities are managed on an all in/all out (AIAO) basis. This management method allows for a thorough cleaning to be implemented between batches of pigs. It has been hypothesised that the growth rate of pigs will increase by improving the quality of air and the general environment within their housing systems (Cargill and Banhazi, 1997). The cleaning regime adopted in an AIAO system may facilitate this improvement.

Therefore, the aim of this study was to improve environmental conditions within experimental piggery buildings situated on a respiratory-disease-free farm and to determine the effect of these improvements on the growth rate of pigs. To facilitate this experiment, the growth rate (average daily gain, ADG) and air quality (AQ) parameters were monitored in piggery buildings with (AIAO) and without improved management system (continuous flow, CF).

15.2 Materials and methods

It was expected that implementing ASR would generally result in health improvement, in addition to production efficiency improvements. The respiratory-disease-free status of the study herd was essential so that the benefits of AQ improvement could be demonstrated effectively, as respiratory-health improvements would not be a contributing factor during analysis.

15.2.1 Experimental farm

A farrow-to-finish farm with 600 sows, located in South Australia, was used as an experimental site. This farm had been free of *Mycoplasma hyopneumoniae* and *Actinobacillus pleuropneumoniae* for 10 years prior this experiment.

15.2.2 Experimental buildings

The experimental facilities (a second-stage weaner and a grower building) used in this study were naturally ventilated, with controlled-shutters on both sides and the buildings had partially slatted

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floors (approximately 30%). Pelleted feed was fed 'ad lib' from multi-space feeders within these buildings. Approximately 20 pigs were housed per pen without the provision of any bedding materials and the liquid slurry was flushed to outside manure lagoons, weekly. Approximately 200 pigs were housed in the AIAO sections, which were created at the end of each building using tarpaulin material (Cavacon 5000Q, Tolai marketing, Adelaide, Australia). Approximately 650 grower and 950 weaner pigs were housed in the CF sections of the buildings. The tarpaulin partitions, erected across the buildings, were either attached directly to the roof line or hung from a wire at the eave-level of the building. This divided the buildings into two separate airspaces (Figure 15.1). The bottom of the tarpaulin wall was attached to the top of the existing pen wall. Hence air movement between each section was significantly reduced.

15.2.3 Experimental treatment

The AIAO building sections were cleaned thoroughly between each batch of pigs to completely remove the accumulation of dirt, dust and dung. The cleaning treatment included soaking, hosing and power-washing the walls, floors, ceilings and pen fixtures within the sections. The CF sections of the building were treated according to the existing farm procedure, which did not include regular cleaning.

The experimental setup ensured that the animals' genetics, medication, diet and general management (such as feeding, ventilation and effluent systems and husbandry) were identical for both CF and AIAO building sections.

15.2.4 Experimental animals

At the age of approximately 6 weeks, 100 pigs were randomly selected and tagged before being divided into two equal subgroups. One group was allocated to each treatment in each building. Conventional weigh-scales (Weigh Crate, Ruddweigh, Guyra, Australia) were used to monitor the ADG of the second-stage weaner (6 to 10 weeks of age) and grower (10 to 20 weeks of age) pigs in

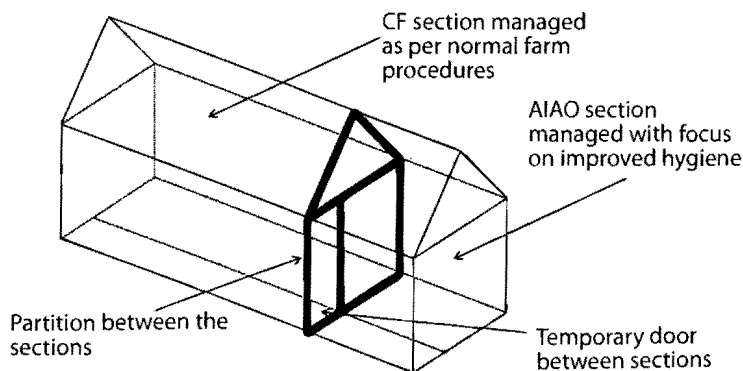


Figure 15.1. Drawing depicting the partitions erected in the buildings to create the separate sections.

both the experimental treatment groups. Tagged pigs were weighed each time they were moved, and when they were approximately 6, 12, 14 and 16 weeks of age. Over approximately a 2.5 year period, data was collected from seven batches of pigs, which were divided into the treatment groups. Approximately once a month, average daily gain (ADG), stocking density (SD), stocking rate (SR), temperature and AQ parameters were determined at the facilities.

15.2.5 Environmental and management related measurements

The concentrations of airborne particles (total and respirable), airborne microorganisms (total, gram positive and fungi), NH₃ and carbon dioxide (CO₂) were monitored to determine AQ in both the experimental and control building sections. The measurements were averaged for the monitoring period spanning between weight measurements and were treated as representative of the AQ conditions throughout the given period. Preliminary trials were undertaken before the main experiment, to determine the reliability/consistency of the measurement and the representative nature of airborne pollutant concentrations in the experimental and control sections.

Particle measurement

Concentrations of airborne particles were determined gravimetrically using cyclone samplers for respirable (<5 µm) and Institute of Occupational Medicine (IOM) samplers for total particles (Casella, Ltd., Kempston, UK), respectively. The sampling rate was set at 1.90 l/min for respirable particles and at 2.00 l/min for total particles, which were the standard sampling rates at the time of the study (Takai *et al.*, 1998). The samplers were connected to GilAir air pumps (Gilian Instrument Corp., West Caldwell, NJ, USA) and were usually placed above the walkways. To determine the concentration of airborne particles, the particles that the filters collected were weighed to the nearest 0.001 mg, in a controlled environment room.

On one occasion, an OSIRIS light-scattering instrument (Turnkey Instruments, Ltd., Northwich, UK) was used to monitor airborne particle distribution in the CF and AIAO sections of the weaner building (Figure 15.4). This measurement was used to demonstrate the consistent difference between the dust concentrations in the CF and AIAO section of the building. Both the OSIRIS particle monitors and the gravimetric filters were installed at a height of 1.1-1.3 m. For statistical comparison, only gravimetric measurements were used, due to the reliability of this particle measurement method (Takai *et al.*, 1998).

Bacterial measurement

A standard six-stage bacterial impactor was used to sample the total airborne microorganisms, gram positive bacteria and fungal species (Seedorf *et al.*, 1998). To determine the total number of bacterial, gram positive bacterial, and fungal colonies (colony forming units, or cfu), horse-blood agar (HBA) and selective plates (HBA+CAN and Sabourauds) were used (Medvet Science Pty. Ltd., Stepney, Australia), respectively. Samples were taken at about midday (11:00 h to 15:00 h), usually in the centre of the animal building and above the pens. The flow rate during sampling

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was 1.9 l/min, and the sampling time was 5 min. The exposed plates were incubated at 37 °C under aerobic conditions, and bacterial colonies were counted after 24 h.

Gas concentration measurements

A multi-gas monitoring (MGM) machine was developed to continuously monitor NH₃ and CO₂ gases within the building sections. The machine incorporated an electrochemical gas monitoring head (Bionics TX-FM/FN, Bionics Instrument Co., Tokyo, Japan), and an infrared sensor (GMM12, Vaisala Oy, Helsinki, Finland) to detect internal concentrations of NH₃ and CO₂, respectively. These components and other supporting electrical components were enclosed in a sturdy, shock-resistant electrical box. MGM machine's built-in air sampling system drew air samples into the gas monitoring heads from points located both inside and outside the buildings. The air was drawn at a nominal rate of 0.5 to 0.8 l/min from the sampling points. After each sampling point had been monitored for 15 minutes, the system was purged for 15 minutes with fresh air drawn from outside the buildings. This flushed out the sampling lines and enabled the NH₃ monitoring head to be re-calibrated to zero. In general, the sampling inlets were placed at a height of about 1.1 to 1.3 m during monitoring.

Stocking rate and density

The SR (m² pen floor/pig) was calculated for each group of pigs after measuring the length and width of the pens in all sections of the farm. Similarly the volume of airspace in each building and section was also measured, and the SD (m³ airspace/pig) calculated. The number of pigs in each section or airspace was recorded at each visit.

Air temperature monitoring

In all buildings, temperature data was recorded using Tinytalk temperature loggers (Tinytalk-2, Hastings Dataloggers Pty. Ltd., Port Macquarie, Australia) (Banhazi *et al.*, 2008c). In general, these sensors were installed as close to the pigs' height as practically possible (above the pens), so that interference from the pigs was prevented.

15.2.6 Statistical method

A number of statistical methods were used during this study, as it was difficult to identify significant effects using the data collected.

First, general linear models (GLM) were developed to explain as much variation in the dependent variable as possible (StatSoft, 2001). The dependent variable was the ADG of pigs in the AIAO and paired CF sections. The explanatory effects and covariates examined statistically were, total airborne particles (g/m³), respirable particles (g/m³), total airborne bacteria (cfu/m³), gram positive bacteria (cfu/m³), fungal species (cfu/m³), NH₃ (mg/m³), CO₂ (mg/m³) air temperature (°C), SR (m²/pig) and SD (m³/pig), in the AIAO and CF sections. As the number of data points available was limited, only main effects were tested. The statistical models were developed from the maximum model, by sequentially removing non-significant effects ($P < 0.05$, based on type

III estimable functions) until only significant effects remained. GLM statistical procedure was used, as it is able to interpret results reliably when handling unbalanced field data (StatSoft, 2001).

However, as only a few factors were identified separately for grower and weaner pigs; further analysis was undertaken based on the combined dataset. To minimise the natural variation caused by the ADG recorded for the weaner and grower pigs, the percentage change in ADG recorded in the AIAO and CF building sections was analysed as dependant variable using GLM procedure. The second analysis incorporated the same explanatory variables as in the first analysis.

The third analysis was designed to identify the relationship between the percentage change of key variables identified in the second analysis, and the percentage change in ADG recorded in the AIAO sections compared to the CF sections. ADG improvements were calculated in the same manner as in the second analysis. The combined percentage of AQ improvement was calculated by adding together the percentage change relative to continuous flow for ammonia, respirable and total particles and then dividing the calculated value by 3.00 as the maximum potential reduction (in %) for the three airborne pollutants was 300%. This was done to ensure that the calculated value is readjusted for a 0-100% scale; otherwise the combined reduction could have been more than 100%.

15.3 Results

15.3.1 Reliability of measurements

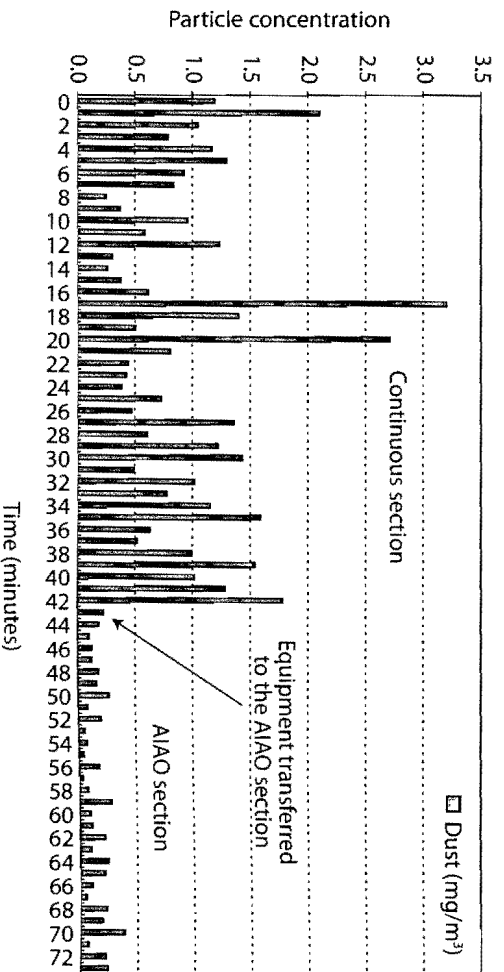
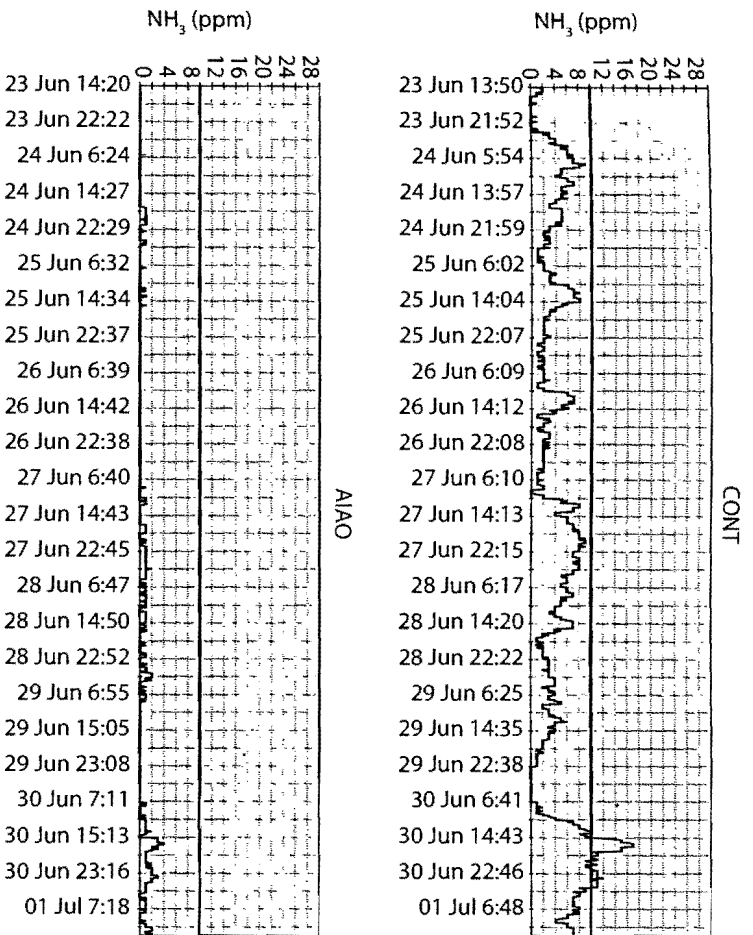
Figure 15.2 shows the NH_3 concentration recorded in the AIAO and CF sections of the grower building. The level of ammonia is consistently lower in the AIAO section.

On average for this recording period, the NH_3 concentrations for the AIAO and CF sections were less than 1 ppm, and 5.4 ppm respectively. The average ammonia concentrations remained relatively constant in both the AIAO and the CF sections.

Figure 15.3 shows a short comparative measurement taken with the OSIRIS optical particle counter. This measurement was taken to demonstrate the consistent reduction achieved in airborne particle concentration in the AIAO section compared to the CF section, and to validate the measurements taken with the gravimetric devices.

Although these measurements were not used during the statistical analysis, they provided confirmation that there were consistent differences in airborne pollutant concentrations in the AIAO and CF sections of the building.

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15.3.2 Average daily gain (ADG)

Initial analysis

Table 15.1 shows the mean, maximum and minimum values of the key parameters that were considered in the model developed for grower and weaner pigs. Figure 15.4 show the SR and SD data recorded in the AIAO and CF sections throughout the study.

These raw values indicated that environmental conditions were similar in both sections of the buildings (i.e. second stage weaner and the grower buildings.) This was not surprising as the management and structure of the second stage weaner building were very similar to the grower building. Both buildings were naturally ventilated with similar wall structure, insulation and ventilation systems.

Extreme values that deviated from optimal AQ were recorded in the grower building sections. For example, up to 1.1 mg/m³ of respirable particulate concentration was recorded in the CF grower sections (Table 15.1). These levels are approximately four times the currently suggested upper limit for respirable particles (Banhazi *et al.*, 2008b; Donham *et al.*, 2000). Occasionally, the maximum concentrations of NH₃ and total airborne bacteria also exceeded suggested maximum limits (Table 15.1) (Banhazi *et al.*, 2008b, 2009).

Table 15.1. The mean, minimum and maximum ADG and pollutant concentration values recorded in the study buildings.

	AIAO			CF		
	Mean	Min.	Max.	Mean	Min.	Max.
Variables (grower)						
Average daily gain (g/day)	0.687	0.532	0.932	0.644	0.523	0.901
Total airborne particles (mg/m ³)	0.779	0.121	1.328	1.706	0.727	2.954
Respirable particles (mg/m ³)	0.159	0.032	0.417	0.446	0.031	1.076
Total bacteria (×1000) (cfu/m ³)	128	57	174	158	101	195
Fungi (×1000) (cfu/m ³)	17	3	31	21	4	36
NH ₃ (mg/m ³)	3.3	1.1	8.3	10.9	3.4	19.9
Variables (weaner)						
Average daily gain (g/day)	0.473	0.241	0.645	0.447	0.234	0.587
Total airborne particles (mg/m ³)	0.770	0.288	1.298	1.494	0.679	2.889
Respirable particles (mg/m ³)	0.255	0.088	0.619	0.652	0.128	1.472
Total bacteria (×1000) (cfu/m ³)	132	81	175	154	103	201
Fungi (×1000) (cfu/m ³)	20	3	41	21	6	48
NH ₃ (mg/m ³)	1.8	0.1	4.7	8.3	0.6	25.2

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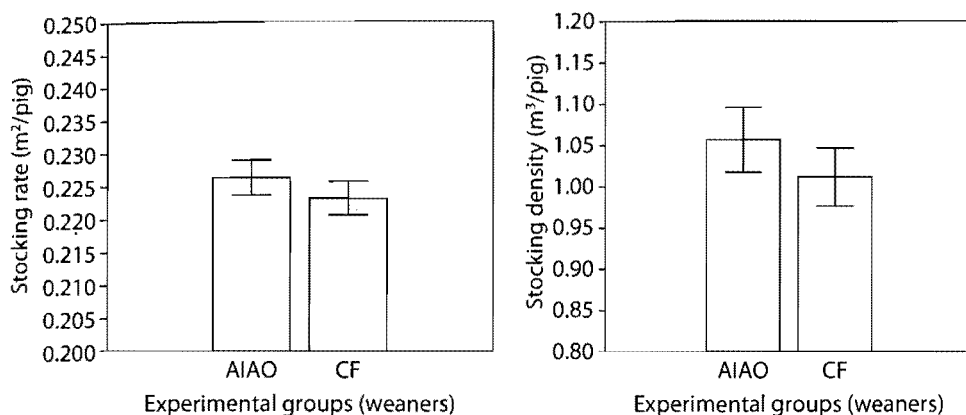


Figure 15.4. Average stocking rate and density values recorded within the AIAO and CF sections of the weaner building (mean \pm confidence interval).

The SR and SD were similar in both sections, however on average, in the AIAO section more air and floor space were available per pig (Figure 15.4). A one-way ANOVA indicated that the SR and SD values were not statistically different (SR and SD in the grower sections are not shown).

In the first analyses, a limited number of variables were identified that had an effect on ADG in the piggery buildings. The results of the analyses are summarized in Table 15.2 including the R^2 values for the models developed.

One experimental effect and two covariates (concentrations of airborne microorganisms and fungal species) were identified as having a significant effect on the ADG of the pigs housed in the sections of the weaner building. One factor (experimental effect) and one covariate (SR) were identified as having a significant effect on the ADG of the pigs housed in the sections of the grower building (Table 15.2). The concentrations of airborne microorganisms and fungal species were negatively correlated with ADG, while SR was positively correlated. Pigs in both

Table 15.2. Tests of significance for effects associated with average daily gain (ADG) in the models developed.

	ADG	Slope
Effects for weaner sections (Model $R^2=34\%$)		
Experimental effect (CF, AIAO)	$P=0.0375$	
Concentration of airborne fungal species (cfu/m ³)	$P=0.0316$	negative
Concentration of airborne bacteria (cfu/m ³)	$P=0.001$	negative
Effects for grower sections (Model $R^2=25\%$)		
Experimental effect (CF, AIAO)	$P=0.0101$	
Stocking rate (m ² /pig)	$P=0.0079$	positive

AIAO sections had significantly higher ADG when compared with pigs housed in their paired CF sections. Experimental effects accounted for approximately 20% in R^2 value achieved for both models. The models in (Table 15.2) indicate that the experimental effect, and to some extent, the improvements in SR and the reduction in the concentrations of airborne bacterial and fungal particles, were significantly associated with the improvement in production-efficiency observed for the pigs housed in the AIAO sections.

Second analysis

Table 15.3 shows the data used in the second analysis. A summary of the analysis concerning ADG improvement percentages is presented in Table 15.4, which includes the R^2 value for the model developed.

Throughout the study, an increase in airborne particle concentrations was not recorded in the AIAO sections, although at times, the reduction in the concentration of airborne particles was small (approximately 3%). The maximum reduction in the concentrations of airborne

Table 15.3. Mean, maximum and minimum percentage of change in average daily gain and pollutant concentration values recorded in the study buildings (AIAO vs. CF).

Change in variables (%)	Mean	Minimum	Maximum
Average daily gain	6.1	0.5	11.6
Total airborne particles	48.4	8.8	83.3
Respirable particles	51.2	3.2	88.9
Total bacteria	17.1	3.6	55.5
Gram positive bacteria	22.8	0.5	62.0
Fungi	16.5	5.6	69.7
NH ₃	68.8	-3.6	97.3
Stocking density	3.7	-4.4	9.4

Table 15.4. Tests of significance for effects associated with percentage improvement in average daily gain (ADG) in the model developed.

Effects for weaner sections (Model $R^2=58.9\%$)	ADG	Slope
Reduction in the concentration of total airborne particles (%)	$P=0.0327$	positive
Reduction in the concentration of respirable particles (%)	$P=0.0029$	positive
Reduction in the concentration of ammonia (%)	$P=0.0425$	positive
Improvements in stocking density (%) ¹	$P=0.0044$	positive

¹ Increase in available airspace per pig.

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particles ranged between 85-90%, thus, the AIAO management did not completely eliminate airborne particle pollution. Across all batches of pigs, improvements in ADG varied between 0.5 (essentially no improvement) and 11.6%. On average, the respirable and total airborne particles were reduced by approximately 50% and the concentrations of viable airborne particles (total bacteria, gram positive bacteria and fungal species) were reduced by approximately 20%. The greatest reduction was achieved in the concentration of ammonia, however, on at least on one occasion the ammonia concentration increased by approximately 4% in the AIAO sections.

Four variables were identified during the second analysis that had a significant positive affect on the percentage-ADG. These variables were the percentage-change in concentration of (1) total airborne particles, (2) respirable particles and (3) ammonia. In addition, (4) the percentage of improvement in SD (i.e. more airspace availability per pig) was identified as the fourth factor. All of these variables were positively associated with ADG improvements. The model developed explained approximately 60% of the variation in ADG improvement.

Regression analysis

The regression analysis shown in Figure 15.5 demonstrates a highly significant relationship ($P=0.00006$) between the combined AQ parameters percentage change (i.e. combined percentages of reduction in the concentration of ammonia, respirable and total particles) and the per cent improvement in ADG. Figure 15.5 indicates that to trigger a positive effect on ADG; an improvement of between ~35-40% in the combined (and re-adjusted) concentrations of these airborne pollutants is required. Furthermore, the analysis indicates that by reducing these pollutants by up to 80%; an ADG improvement of between ~10-12% can be potentially expected.

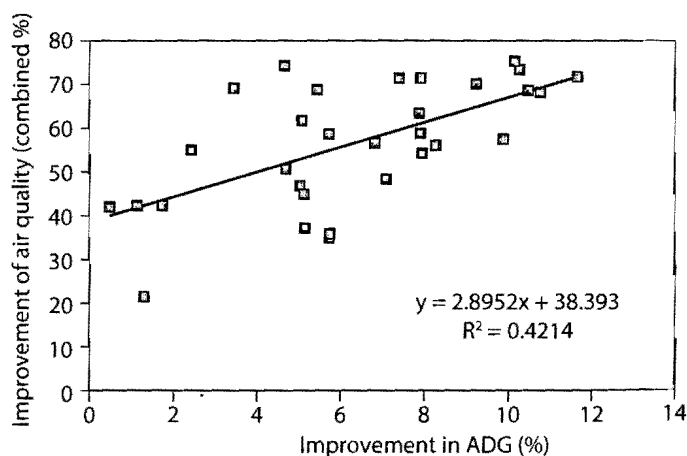


Figure 15.5. The relationship between percent improvement in average daily gain (ADG) and combined percent improvement in air quality in the study buildings (%).

15.3.3 Temperature and ventilation rate

Neither temperature (Figure 15.6a) nor CO₂ concentrations (indicator of ventilation levels, Figure 15.6b) were significantly different between the sections. These variables did not influence ADG in the weaner or grower sections either. These findings confirm the reliability of the study results, as according to the analysis these variables did not interfere with the main experimental effect of AIAO vs. CF management. The similarity between air temperatures and CO₂ concentrations recorded in the AIAO and CF sections of the weaner building can be observed in Figure 15.6. Results were similar in the grower buildings and are not shown here.

15.4 Discussion

15.4.1 Reliability of measurements

The initial measurements taken demonstrated that both the particle and ammonia measurements were highly likely to be representative of the AQ conditions in the AIAO and CF sections. The experimental treatment, involving cleaning of the AIAO sections between batches, consistently resulted in a reduction of airborne pollutants compared to that of the CF system. These concentration reductions can be observed in Figures 15.2 and 15.3.

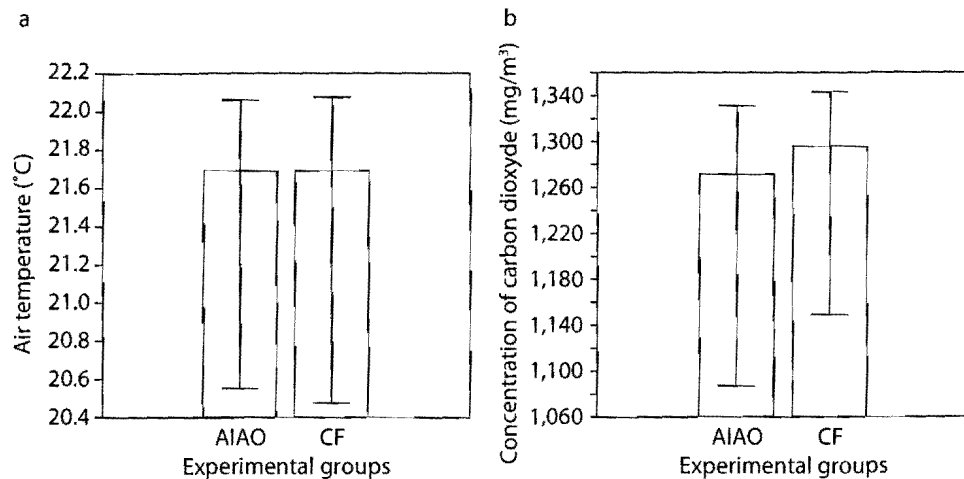


Figure 15.6. Similarities in (a) air temperatures and (b) CO₂ concentrations recorded within the AIAO and CF sections of the weaner building (mean ± standard error).

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15.4.2 Average daily gain

First analysis

The mean ADG of the pigs reared in the AIAO section of the grower building was 687 g/day from 10 weeks of age to slaughter. This was an increase of 6.7%, compared with the 644 g/day of pigs reared in the CF sections ($P=0.01$) (Table 15.1). For pigs reared in the AIAO and CF sections of the weaner building the difference in ADG was 5.8% ($P=0.04$). The mean ADG of pigs reared in AIAO section was 473 g/day from 6 weeks of age to 10 weeks, compared with 447 g/day for pigs reared in the CF sections (Table 15.1).

The effect of the experimental treatment (AIAO vs. CF section) was significant for both weaner and grower pigs (Table 15.2). The AIAO treatment can be considered a 'combination treatment' as it facilitates smaller group sizes and improved environmental conditions. Hence, this management method directly results in a reduced exposure level to a number of airborne pollutants. Because of that, it has to be acknowledged that based on the current study design; it was difficult to evaluate the influence of the management system *per se* (CF vs. AIAO) and the effects of air quality *per se*, as the two factors were naturally linked within this study. In addition, the potential effects of a 'permanent mixing' of pigs within the CF sections were not corrected within the study design. Even animals sourced from the same sow herd tend to have slightly different health and immune status. Thus, the mixing of pigs within the CF section most probably ensured a constant immune challenge of the CF animals. In addition, mixing unacquainted pigs typically results in fighting for the establishment of a social hierarchy. Thus animals in the AIAO sections definitely enjoyed better health and welfare status that most likely contributed to their improved production performance.

However, within the above mentioned limitations of the study, the statistical analysis highlighted the factors that were significantly associated with improved ADG. Only one covariate was identified as having a significant effect on ADG in the grower building and together with the experimental effect it only explained a very modest percentage of the observed variation in ADG ($R^2=25\%$). Thus a large percentage of the variation was still unexplained. This relatively modest result could potentially be explained by the relatively small number of data points that were available for model development ($n=16$ per treatment). In addition, the individual data points were highly variable as they were collected over a long period of time. Nonetheless, for growing pigs a reduction in SR (more floor space available per pig) was identified statistically as having a significant effect on ADG. This was so, despite the fact that the initial (exploratory analysis using simple one-way ANOVA) indicated no statistically significant differences in SR and SD between the experimental and control group. This highlighted the importance of using appropriate analysis methods when identifying statistically significant effects.

Evidently, weaner pigs responded well to a reduction in the concentrations of airborne microorganisms and fungal particles, with the statistical model developed explaining 34% of the variation observed in ADG for weaner pigs. Weaner pigs are more likely to be susceptible to bacterial challenge, even from micro-organisms which are not involved in well-defined specific infectious diseases. Thus, the reduction in the concentration of airborne bacteria may provide

reasoning why their production efficiency was positively affected. Approximately 14% of the variation in ADG was explained by the effects of airborne fungi and bacteria concentrations, while the experimental effect accounted for approximately 20% of the variation in ADG.

Second and third analysis

The statistical analysis determined the factors that were significantly associated with percentage improvement in ADG (AIAO vs. CF sections). Four covariates were identified as having a significant effect on percentage of ADG improvement and the model developed explained a large percentage of the observed variation ($R^2=60\%$). While approximately 40% of the variation in ADG improvement is still unexplained, the second model developed appears to be more robust than the first models (Table 15.4). This improvement in the model R^2 value might be explained by the increase in available data points (by the virtue of combining the previously separated datasets for weaner and grower pigs) and by reducing the variation in ADG by converting absolute values into percentages. The covariates identified were the reductions in the concentrations of, ammonia (%), respirable (%) and total airborne particles (%). In addition, improvement in SD (% improvement in available airspace space per pig) was identified statistically as having a significant effect on ADG increase (%). According to the model, ADG of pigs was positively associated with the reduction in the concentrations of these key airborne pollutants.

The final regression analysis and the correlation depicted in Figure 15.5 further demonstrated the association between ADG improvements and combined reduction in the concentrations of the key airborne pollutants mentioned above. While the results of this study can still be regarded as limited, it is likely that certain level of airborne pollution reduction must be achieved, before any ADG improvement can be expected. The results of this study appear to confirm this theory and demonstrated that approximately 40% of combined airborne pollutant reduction must be achieved before ADG will increase. Similarly, the results of this study also shown that there might be an upper limit above which ADG increase cannot be expected.

The results achieved on this farm are in agreement with other publications (Cargill *et al.*, 1997,1998; Murphy *et al.*, 2012) and demonstrate the benefits of converting existing CF facilities into AIAO production systems, even in high health status herds. During this experiment, the AIAO management system allowed the facilities to be thoroughly cleaned between batches, which resulted in considerably improved air quality. It is likely that the better AQ and improved environmental conditions reduced the stress on the pigs' immune system, resulting in increased production efficiency (ADG) and thus potentially in financial gain. It is likely that the improved AQ maintained in the AIAO sections of the buildings also reduced the occupational health and safety risks for farm workers (Donham *et al.*, 1995).

Airborne pollutants

There was a marked and consistent improvement in AQ in the AIAO sections throughout the experiment. When comparing the concentrations of different airborne pollutants recorded during this study using one-way ANOVA, it was demonstrated that concentrations of almost all airborne pollutants (including ammonia, total and respirable airborne particles) were significantly reduced

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($P < 0.05$) in both the weaner and grower AIAO sections (results not shown). The percentage-reduction was noticeable for all pollutants in both AIAO sections when compared to their CF equivalents (Table 15.2). However, despite these significant reductions, only a handful of covariates were identified by the statistical models, as having a statistically significant effect on ADG (listed in Table 15.2). These results also highlight the importance of using appropriate statistical methods when analysing the results of studies implemented on commercial farms.

Notably, despite the large and significant reductions achieved in NH_3 , total and respirable particle concentrations, these airborne pollutants were not identified as having significant influence on ADG during the initial analysis. It was thought that the highly variable nature of the independent data points obtained was partially responsible for these results. Thus a percentage of change in ADG improvements were analysed during the second analysis. A more robust statistical model was built during the second analysis that explained approximately 60% of the variation in ADG improvement. The combined AQ improvement was related to ADG improvement during the final analysis and the regression analysis demonstrated a strong correlation between these variables.

An important aspect of the study was to demonstrate the certain level of AQ improvement required to achieve a positive ADG response. Results indicate that ADG response would be expected to peak at approximately 12%. Although these results from this study make a lot of practical sense, further studies will be required to verify these results on other farms.

Stocking rate and density

The SD and SR differences (identified by the GLM analysis as significant) were actually relatively small and statistically non-significant when initially analysed by simple one-way ANOVA. However, according to the analysis, even this relatively small difference in SR and SD had a significant impact on ADG and on the percentage of improvement in ADG. It is still questionable whether the identified effects were a causal effect or simply the identification of a parameter that was consistently better in the AIAO sections. Further experiments are needed to answer these questions. However, based on current results and on the results of previous publications (Cargill and Banhazi, 1996, 1998; Cargill *et al.*, 1996a,b), it appears that improved SR and SD is an important aspect of improved pig management. The reduced stress caused by greater available space and the potentially reduced heat stress due to reduced crowding (and thus better cooling opportunities for individual pig) might have contributed to this observed ADG improvement. In addition, it is also likely that the combined impact of a small SR and SD improvement per pig would add up to a significant improvement when assessed on a pen and/or on building level.

15.5 Conclusions

In summary, the experiment demonstrated the potentially positive effects of improved environmental conditions in piggery buildings. Two separate statistical models identified factors that had an effect on ADG in piggery buildings. These factors included, management (AIAO vs. CF management), SR and SD, concentrations of ammonia, airborne bacteria, airborne fungi, respirable and total particles. The pig in the AIAO sections had significantly higher ADG when compared with pigs housed in their paired CF sections. SR and SD were positively correlated

with ADG while the concentrations of all airborne pollutants were negatively correlated. Careful management of these factors could lead to the improved financial performance of the farm.

It is important to note that during this study a large and significant reduction in the concentration of airborne pollutants was achieved under commercial farming conditions. It would be expected that an ADG improvement would be experienced on other farms as well after reducing the concentrations of these pollutants. However, the extent of AQ improvements might vary between farms, and thus, might not translate to statistically significant ADG increase elsewhere. Especially in piggeries where high levels of building hygiene are maintained, additional improvements in hygiene and reduction in airborne pollutants may be difficult to achieve. Nevertheless, even ADG improvements that are non-significant statistically could result in significant economic gains on commercial farms.

Acknowledgements

We wish to acknowledge the financial support of the Pig Research and Development Corporation (PRDC) and the important contribution of the manager of the study farm and piggery staff who kindly donated their time and facilities. We also would like to thank Dr. C. Cargill (South Australian Research and Development Institute, SARDI), who was instrumental managing and obtaining funding for a larger project that included this experiment. In addition, we sincerely thank Prof. John Black, (J. Black Consulting), Matthew Tschärke and Prof. J. Hartung (Hannover University, Germany) for their professional advice.

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