It was established that improvement in air quality in livestock buildings could produce significant benefits for animals, workers and the environment. In order to achieve a sustained reduction in the concentration of airborne pollutants in livestock building; the different management, environmental and housing factors, which could influence the concentrations within and emissions of airborne pollutants from livestock buildings had to be statistically evaluated. Thus a broad study of air quality in piggery buildings was designed (1) to determine the key piggery design and management factors that affect the internal concentrations and emissions of airborne pollutants and then to (2) model and therefore able to predict the concentrations and emission rates of the main pollutants. This article considers the implications of the main results of this significant research project.

INTRODUCTION

The significant amounts of airborne pollutants, which can be found in the airspace of some piggery buildings could potentially affect the external environment, production efficiency of pigs, human as well as animal health and welfare (Banhazi et al., 2009). In order to achieve the maximum safe concentrations recommended in Australia a broad study of air quality in piggery buildings was designed (1) to determine the key piggery design and management factors that affect the internal concentrations and emissions of airborne pollutants and then to (2) model the concentrations and emission rates of the main pollutants. This article is a summary of the main results of this national research project.

MATERIAL AND METHODS: BRIEF DESCRIPTION OF STUDY DESIGN

To enable this study to be conducted, the sampling methods and instrumentation kit used during the survey was standardised and an “environmental monitoring kit” (EMK) was developed. In the later stage of the study the original EMK was further simplified, so it could be used as an extension tool after the completion of the survey component of the study (Banhazi, 2009). A field survey of airborne pollutant concentrations within and emissions from 160 piggery buildings in four states of Australia was then executed. The measurement techniques chosen proved to be practical, reliable and cost effective (Banhazi et al., 2008b; Banhazi et al., 2008c). Using the collected data, comprehensive statistical modelling was undertaken to explain the variation in the measured concentrations and emission rates. An output from this component of the study was equations to reliably predict concentrations and emission rates of key airborne pollutants (Banhazi et al., 2008b; Banhazi et al., 2008c; Banhazi et al., 2008d; Banhazi et al., 2008a). Later on the models developed were fine-tuned and validated using an innovative statistical approach (Banhazi et al., 2010).

DISCUSSION OF KEY STUDY RESULTS

General comments on concentrations and emissions measured

This study delivered a number important outcome. First of all, the validated model developed can be used as a practical management tool to predict the concentrations and emissions of major pollutants without undertaking costly measurements. Routine use of the combined predictive model is expected to make pig producers aware of potential problems associated with air quality on their farms. In turn, this will facilitate the inclusion of pollutant abatement techniques into routine management procedures on farm, improving the health and welfare of pigs and piggery workers as well as the environmental sustainability of piggery operations. Furthermore, designing piggery buildings to minimize airborne pollution now is a theoretical possibility. Using the predictive equations, mathematical optimization of building and engineering parameters will be possible in order to minimize the concentrations and emissions of different airborne pollutants. The optimization process could calculate the best combination of building features to achieve minimum pollutant loading internally and externally. Such calculation would be very useful for building companies as well as for individual producers contemplating building renovations. These “low-pollution” buildings could improve piggery environment for the
benefits of both pig and piggery staff and could reduce the environmental impact of piggery operations. In addition, if reliable economical data on the effects of airborne pollutants becomes available, the potential financial advantage of one building design over another could be predicted. The range of pollutant concentrations measured in the study buildings are presented and compared to European concentration values in Table 1.

Table 1: Mean concentrations of key airborne pollutants measured in Australian piggery buildings (based on building averages) (Banhazi et al., 2008c)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Concentrations suggested in Australia</th>
<th>Australian study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia (ppm)</td>
<td>10</td>
<td>3.7</td>
</tr>
<tr>
<td>Inhalable particles (mg/m³)</td>
<td>2.4</td>
<td>1.74</td>
</tr>
<tr>
<td>Respirable particles (mg/m³)</td>
<td>0.23</td>
<td>0.26</td>
</tr>
<tr>
<td>Respirable endotoxins (EU/m³)</td>
<td>50</td>
<td>33</td>
</tr>
<tr>
<td>Total airborne bacteria (10⁵ cfu/m³)</td>
<td>1.0</td>
<td>1.17</td>
</tr>
</tbody>
</table>

Recommendations for airborne pollutant concentration targets in livestock buildings in Australia are available and the study demonstrated that the average airborne pollutant concentrations in piggery buildings in Australia are generally below or near the recommended limits. Australian piggery buildings generally have lower or comparable airborne pollutant concentrations compared to published results from Europe (Seedorf et al., 1998; Takai et al., 1998; Groot Koerkamp et al., 1998). Atmospheric NH₃ concentration on average is not a major concern in Australian buildings, as ventilation rates are much higher compared to buildings in colder regions of the world, such as parts of Europe or North America. Only 1% of the buildings surveyed had concentrations measured above recommended levels for CO₂ and approximately 8% of buildings were above the recommended 10 ppm concentrations. The concentrations of airborne particles were high in deep-bedded shelters (DBS); the mean concentration of endotoxin, total bacteria, inhalable and respirable particle concentrations exceeded the recommended limits frequently (Banhazi et al., 2008c). Pigs housed in DBS and workers undertaking manual tasks in those buildings were potentially exposed to high concentrations of these airborne pollutants. In the absence of more specific information, the concentrations measured in DBS do provide a ground for concern.

Factors affecting concentrations and emissions

A number of individual models were developed during the study to explain the variation observed in the concentrations and emission of the airborne pollutants, as well as in environmental variables. Table 2 summarizes all significant main effects identified for the concentrations and emissions of the five major airborne pollutants measured during the study.

Table 2: Significant effects associated with the concentrations and emission rates of the five major airborne pollutants measured.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Ammonia</th>
<th>Airborne Bacteria</th>
<th>Respirable Endotoxin</th>
<th>Respirable Particles</th>
<th>Inhalable Particles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Building type</td>
<td>Building type</td>
<td>Building type</td>
<td>Building type</td>
<td>Building type</td>
</tr>
<tr>
<td></td>
<td>Cleanliness</td>
<td>Cleanliness</td>
<td>Cleanliness</td>
<td>Management</td>
<td>Management</td>
</tr>
<tr>
<td></td>
<td>Seasons</td>
<td>Seasons</td>
<td>Seasons</td>
<td>Ventilation</td>
<td>Ventilation</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>Temperature</td>
<td>Temperature</td>
<td>Humidity</td>
<td>Humidity</td>
</tr>
<tr>
<td></td>
<td>Sow number</td>
<td>Sow number</td>
<td>Sow number</td>
<td>Inlet height</td>
<td>Inlet height</td>
</tr>
<tr>
<td>Emission</td>
<td>Building height</td>
<td>Building height</td>
<td>Building height</td>
<td>Building type</td>
<td>Building type</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>Temperature</td>
<td>Temperature</td>
<td>Humidity</td>
<td>Management</td>
</tr>
<tr>
<td></td>
<td>Seasons</td>
<td>Seasons</td>
<td>Seasons</td>
<td>Building width</td>
<td>Cleanliness</td>
</tr>
<tr>
<td></td>
<td>Sows number</td>
<td>Sows number</td>
<td>Sows number</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The concentrations of four airborne pollutants were affected by the classification of the buildings. Three pollutant concentrations were affected by cleanliness, management and seasons, while the concentrations of two pollutants were affected by temperature, humidity, ventilation, sow numbers and shed size (Table 2). The emission rates of four airborne pollutants were affected by the classification of the ventilation system and the height of the air inlets. Three pollutant emission rates were affected by the type and height of the buildings. The emission rates of two airborne pollutants were affected by temperature, humidity, management and seasons. The
emission rate of one pollutant was affected by building
width, pen hygiene and sow numbers (indication of farm
size) (Table 2). In general, the statistical analysis
accurately identified the important factors affecting the
concentrations and emissions of major airborne pollutants
and therefore improved the understanding of the
behaviour of those pollutants. In the section below, the
primary building and management effects identified during
the study are discussed.

**Type of buildings**

The type of building (dry sow, farrowing, weaner,
grower/finisher buildings and DBS) had a highly significant
effect on total bacteria, respirable endotoxin, inhalable
and respirable particle concentrations and on the
emissions of NH3, inhalable and respirable particles
(Banhazi et al., 2008c; Banhazi et al., 2008a). Overall,
DBS recorded the highest concentrations for all four
pollutants. Inhalable particle emission was the highest
from weaner buildings and from DBS (Banhazi et al.,
2008a). It was hypothesised that the presence of bedding
material used, should be considered in DBS.

- **Ventilation related factors**

Factors related to the operation of ventilation systems
have been demonstrated to have a very significant
influence on emission rates (Banhazi et al., 2008d;
Banhazi et al., 2008a). The emission rates of all
pollutants (with the exemption of NH3 emission) were
influenced by the size of ventilation inlet opening.
Airborne bacteria, respirable endotoxin, inhalable and
respirable particles emission rates are all increased with
increasing size of air inlets. The classification of
ventilation systems also had a very significant influence on
emission rates. Airborne bacteria, respirable endotoxin,
inhalable and respirable particles emission rates were the
highest from tunnel-ventilated buildings, which is a typical
feature of DBS. The high emission rates observed for
these pollutants were partially related to high internal
concentrations measured typically in DBS (Banhazi et al.,
2008c; Banhazi et al., 2008d; Banhazi et al., 2008a).

**Pen hygiene and pig flow management**

The effect of pen floor hygiene (essentially pen
cleanliness) on airborne bacteria, NH3 and respirable
particle concentrations was an important finding of the
study and partially confirmed the results of previous
studies on air quality (Aarnink et al., 1997; Ni et al.,
1999). Dunging patterns need to be controlled in order to
improve pen hygiene. It is interesting to note that while
hygiene was an important factor in concentrations of
airborne pollutants, it only influenced emission of bacteria.
All-in/all-out management proved to be beneficial for
reducing the concentrations of NH3. Management
interacted with seasons for NH3, indicating that summer in
continuous flow (CF) buildings is a risk factor for high NH3
concentrations. These findings confirmed the results of
Dutch researchers, reporting on the strong influence of
temperature on incorrect dunging behaviour in pigs.

**Season**

The effects of season on the concentration of various
airborne pollutants were complex and varied for different
airborne contaminants. In piggery buildings, an increase
in the concentrations of inhalable particles has been
demonstrated in this study for the winter period.
However, for smaller particles, the turbulence associated
with higher air velocities associated with summer
conditions, could increase respirable particle
concentrations under certain conditions. Higher
centrations of NH3 and significantly higher emission
rates were recorded in summer than in winter in CF
management system but not in buildings managed on an
AIAO basis. Therefore, it can be concluded that while
winter is a risk factor for inhalable particles, in summer
greater emphasis needs to be placed on reducing
potentially high NH3 and respirable particle
concentrations.
Temperature and humidity

Generally, temperature had a positive correlation with both inhalable and respirable particles concentrations and emission. As temperature increases, piggery buildings tend to become a drier environment, creating greater opportunities for particle generation (Pedersen et al., 2001). Because of increased temperature, respirable particle concentrations increased significantly in AIAO buildings. Inhalable particle concentrations were also significantly affected by temperatures, but the relationship was more complex due to interaction with the classification of the buildings. The effect of humidity interacted with building type for respirable particles and there was a pronounced reduction effect of increased humidity in DBS. Increased humidity also sharply reduced respirable particle emissions from DBS and NH$_3$ emission generally. However, for other building types the effect of humidity was not simple and in interaction with management type, demonstrated a positive correlation with respirable particle concentrations. This study also found that humidity affected endotoxin concentrations (Banhazi et al., 2008c). This finding could have implications for dust reduction methods, such as spraying of oil/water mixture.

Farm size

The size of farm (as described by the number of sows) had a significant effect on both inhalable and respirable particle concentrations. Inhalable particle concentrations were strongly and positively associated with sow numbers. However, the effect of sow number on respirable dust was more complex. It has been hypothesized that on larger farms, due to work pressures, less time is available for cleaning and general maintenance of the environment of the pigs. Therefore, the reduced hygiene and increased intervals between cleaning episodes creates an ideal environment for higher dust concentrations in buildings on large corporate farms (Banhazi et al., 2008c).

CONCLUSIONS

This study demonstrated that compromised pen hygiene is an important risk factor for elevated concentrations of NH$_3$, viable and non-viable particles. The effect of housing type was greatest on a number of pollutants, however applying improved management of these buildings is more readily applicable. Therefore, this source of airborne pollution could be eliminated to a large extent by controlling dunging patterns and improving the hygienic conditions of pens. The current practice of managing buildings using all-in/all-out strategy with thorough cleaning of the facilities between batches of pigs is advisable. Treatment of bedding materials in DBS is highly advisable to reduce the opportunities for particle generation. The knowledge generated by this study will also enable piggery managers to focus on reducing the concentrations of specific pollutants under different seasonal conditions. Ventilation, humidity and temperature can be theoretically adjusted to minimize airborne pollution emission and concentration in piggery buildings. In terms of emission rates, it appears that ventilation related factors have the most influence on the amount of airborne pollutants emitted from piggery buildings. Although, some of the management methods suggested might be successfully used to reduce the concentration and potentially the emission rates of airborne pollutants, in reality there are limitations associated with managing emission rates via concentration reduction. Therefore, the immediate focus has to be on developing new techniques and evaluating existing ones (such as air scraping and bio-filters), which have the capacity of capturing emitted pollutant plumes from livestock buildings.
REFERENCES


