Australian Government
Rural Industries Research and Development Corporation

RURAL INDUSTRIES
Research & Development Corporation

Control of Odour and Dust from Chicken Sheds

Evaluation of windbreak walls

SEPTEMBER 2013

RIRDC Publication No. 13/001

Australian Government

Rural Industries Research and Development Corporation

Control of Odour and Dust from Chicken Sheds

Evaluation of windbreak walls

by Mark Dunlop and Geordie Galvin

September 2013

RIRDC Publication No. 13/001
RIRDC Project No. DAQ-321A

ISBN 978-1-74254-494-6
ISSN 1440-6845

Control of Odour and Dust from Chicken Sheds – Evaluation of windbreak walls
Publication No. 13/001
Project No. DAQ-321A

Researcher Contact Details

Mark Dunlop
Senior Environmental Engineer
Queensland Department of Agriculture, Fisheries and Forestry
203 Tor Street
TOOWOOMBA QLD 4350

Geordie Galvin (formerly of Department of Primary Industries and Fisheries, Toowoomba, QLD)

Email: mark.dunlop@daff.qld.gov.au

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

RIRDC Contact Details

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

PO Box 4776
KINGSTON ACT 2604

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

Electronically published by RIRDC in September 2013
Print-on-demand by Union Offset Printing, Canberra at www.rirdc.gov.au
or phone 1300 634 313

Foreword

In calendar year 2011 approximately 547 million chickens produced 1,012,542 tonnes of meat. Meat chicken farms are often built close to feed supply and meat processing infrastructure, with associated markets and labour force. This is necessary in order to maximise transport and distribution efficiency and ensure supply of labour. Positioning poultry farms close to essential infrastructure usually means that the farms are located close to urban areas and rural residents. Close proximity of neighbours to poultry farms can result in adverse impacts, primarily due to odour. Odour impacts are recognised as an issue for intensive animal industries worldwide, including the Australian chicken meat industry. Technologies and techniques are being developed to minimise these impacts.

Windbreak walls were identified as a technology that may improve dispersion of odorous air exhausted from tunnel ventilated animal production buildings. They have been promoted as one of a few cost-effective ways to improve dispersion and reduce odour impacts. Unfortunately, the actual performance of windbreak walls to reduce odour impacts from tunnel ventilated broiler sheds has not been properly assessed. For this reason, RIRDC commissioned DPI&F (currently—Department of Agriculture, Fisheries and Forestry, DAFF), Queensland, to investigate the efficacy of windbreak walls for dispersing odour, and the value of windbreak walls as an odour and dust reduction strategy for tunnel ventilated broiler sheds.

Results from this investigation will be useful for poultry producers, the chicken meat industry, environmental regulators, government agencies, consultants and researchers. Information presented in this report will enable better decision making for those considering or recommending use of windbreak walls to reduce odour impacts.

During this investigation, the performance of windbreak walls was assessed using real-life observations and numerical modelling with computational fluid dynamics (CFD). Short stacks were also assessed using CFD modelling. Windbreak walls and short stacks were evaluated under a range of weather and atmospheric conditions. It was found that windbreak walls did not significantly improve dispersion and were therefore unlikely to reduce downwind ground level odour concentrations beyond a very short distance. Based on the results of CFD modelling, short stacks performed better than the windbreak walls, resulting in lower downwind ground level concentrations. Owing to reliance on atmospheric stability and weather conditions to achieve improved dispersion, windbreak walls and short stacks should not be generally viewed as a reliable means for reducing odour impacts. Potential users of windbreak walls, as well as environmental regulators, need to be aware of the limitations associated with using windbreak walls or short stacks to reduce odour impacts. This report provides information that will assist these groups to decide where the use of these devices may be beneficial.

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

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

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

Craig Burns
Managing Director
Rural Industries Research and Development Corporation

Acknowledgments

The project team would like to acknowledge the poultry farm owners and managers who provided access to their farms, allowing the research team to conduct the field studies. These poultry producers dedicated their time, resources and equipment to this project, which contributed to the success of the research.

Thanks also to the consultants, technicians and modellers who developed and tested methodologies and techniques that assisted with the evaluations.

David Duperouzel, John McAlpine and Erin Gallagher, DPI&F Queensland, provided valuable assistance in undertaking the field work. Their dedicated efforts were invaluable to the completion of the project.

Operational funding for this project was provided by RIRDC through the Chicken Meat R&D program. DPI&F, Queensland, provided staff to undertake the research.

Abbreviations

RIRDC	Rural Industries Research and Development Corporation, Australian Government
DPI&F	Department of Primary Industries and Fisheries, Queensland Government (currently Department of Agriculture, Fisheries and Forestry [DAFF])
CFD	Computational fluid dynamics (computer modelling)
GLC	Ground level concentration
SF_6	Sulphur hexafluoride (tracer gas)

Contents

Tables

Figures

Executive Summary

What the report is about

Odour from tunnel ventilated broiler sheds has the potential to cause odour impacts. Meat chicken producers are under pressure to reduce odour impacts and need cost-effective solutions. Windbreak walls have been proposed as an affordable technology that may improve the dispersion of odours from tunnel ventilated broiler sheds, in turn reducing odour impacts. Unfortunately, the actual efficacy of windbreak walls to improve dispersion has not been properly assessed.

This research was important because of a growing need to increase knowledge and improve understanding of windbreak walls for enhancing dispersion from tunnel ventilated sheds. This need was being driven by pressure on the chicken meat industry to adopt odour control technologies/practices, and a lack of evidence to support the theoretical efficacy of windbreak walls.

Who is the report targeted at?

This report was written for:

- poultry producers, who may be considering installation of windbreak walls;
- the chicken meat industry, which is under pressure to reduce odour impacts and needs to know whether or not the use of windbreak walls will be an appropriate odour reduction strategy;
- environmental regulators/government agencies, who require information when making decisions on how to resolve odour impacts;
- consultants, who require additional information on windbreak walls so that they can advise poultry producers, environmental regulators and community groups on appropriate odour reduction strategies; and
- researchers, who might benefit from the methodologies used in this project.

Information presented in this report will enable better decision making for those considering or recommending windbreak walls to reduce odour impacts.

Background

Windbreak walls were first publicised in 2000 as a technology that could potentially improve dispersion of odours from tunnel ventilated livestock buildings (Bottcher *et al.* 2000; Bottcher *et al.* 2001; Bottcher *et al.* 2000). Reported windbreak wall performance was based on theory and a few smoke observations. Even at this early stage, it was identified that dispersal of odour by windbreak walls was unreliable and would probably decrease in calm, stable weather. Later research focussed on the influence of windbreak walls on fan performance (Ford and Riskowski 2003).

Aims/objectives

Due to the lack of existing information pertaining to the efficacy of windbreak walls for improving dispersion, the objectives of this project were:

1. Identify the value of windbreak walls for improving dispersion of exhaust air from tunnel ventilated sheds;
2. Evaluate the use of windbreak walls as an odour reduction strategy for meat chicken sheds.

Methods used

A number of methods were used to meet the project objectives. These methods included:

- *Tracer gas measurements* – A tracer gas, sulphur hexafluoride (SF_6), was released from the poultry shed (or a specially designed stack) and downwind concentrations of the tracer gas were sampled using sorbent tubes and vacuum pumps. The average airborne concentrations of the tracer gas for the measurement period were calculated from the mass of SF_6 trapped in the sorbent tube.

- *Smoke observations* – Smoke, generated using handheld smoke flares, was released from a tunnel ventilated poultry shed and a neighbouring shed fitted with a windbreak wall. Smoke plumes were photographed and assessed for variations in position, size and density. Smoke observations provided a good indication of movement and dispersion close to the shed, which provided an indication of whether downwind concentrations would be reduced.

- *CFD modelling* – Computational fluid dynamics (CFD) was used to model emissions from a conventional tunnel ventilated poultry shed (control) as well as sheds configured with either a windbreak wall or short stacks (the treatments). CFD modelling provided a set of standardised, defined conditions that enabled direct comparison between the three shed configurations under identical conditions. Atmospheric stability class, horizontal wind speed, ambient temperature and number of active fans were identified during the smoke observations as factors that influenced the performance of the windbreak wall. Combinations of these factors were input into the model to assess their influence on dispersion from each of the three shed configurations. The model reported ground level concentrations downwind from the poultry shed, enabling direct comparison between the control, windbreak wall and short stack configurations. Reductions in ground level concentration between the control and treatments indicated when the treatments enhanced dispersion.

Results/key findings

Tracer gas measurements did not provide any clear information regarding the performance of windbreak walls to improve dispersion. Tracer gas measurements were subsequently discontinued.

Smoke observations were very useful for observing dispersion of exhaust plumes over short range. The short duration of smoke releases enabled the windbreak wall to be assessed under a wide range of natural weather conditions. Smoke was released sequentially from the control and windbreak wall sheds, enabling comparison between the two shed configurations under similar conditions.

CFD modelling enabled downwind ground level concentrations (GLCs) to be predicted and compared between the control, windbreak wall and short stack configurations. CFD modelling outputs clearly showed the differences in GLC between the shed configurations for the entire downwind modelling domain.

Results from the smoke observations and CFD modelling showed that the efficacy of the windbreak wall and short stacks to improve dispersion was dependent on conditions such as atmospheric stability, horizontal wind speed, the number of active fans and ambient temperature. In general, windbreak walls provided very little enhancement of dispersion, resulting in only minor reductions in downwind GLCs apart from very close to the windbreak wall (within 150 m downwind). Under some conditions, it was observed that the presence of the windbreak wall actually increased downwind GLCs when compared to the control situation. Efficacy of the windbreak walls to reduce downwind GLCs was particularly poor under stable atmospheric conditions. Short stacks (assessed using CFD only) appeared to improve dispersion slightly more than the windbreak wall, but there were some scenarios where the short stacks increased predicted downwind GLCs over both the control and windbreak wall situations. Overall, this research showed that neither windbreak walls nor short stacks consistently or substantially reduced GLCs.

Windbreak walls and short stacks are not capable of consistently reducing odour emissions from tunnel ventilated poultry sheds. These devices only direct the emission upward to hopefully improve turbulent mixing. Improvements in dispersion are dependent on ambient and shed operating conditions. Therefore, even though short stacks and windbreak walls may improve dispersion under some conditions, they should not be regarded as a reliable means for reducing odour impacts. Potential users of windbreak walls, for the purpose of reducing odour impacts, must thoroughly understand the conditions under which impacts occur in their specific situation, before deciding whether the installation of windbreak walls or short stacks may provide any benefit.

Observations made during field work indicated that windbreak walls could have some benefits unrelated to dispersion enhancement. These benefits included:

- blocking sunlight from entering the shed through open fan shutters;
- altering dust deposition close to the exhaust fans;
- reducing fan noise; and
- maintaining fan performance when strong opposing winds prevail.

These benefits may be sufficient to justify installation of windbreak walls at some poultry farms.

Implications for relevant stakeholders for:

Results from this research indicate that neither windbreak walls nor short stacks reduce poultry odour emissions. Neither device will consistently improve dispersion or reduce downwind GLCs (including odour concentration). Improvement of dispersion is dependent on conditions such as atmospheric stability, weather conditions and shed operating conditions. Therefore, installation of windbreak walls or short stacks should not be considered as the basis of a reliable odour reduction strategy. While there may be some situations where windbreak walls or short stacks will improve dispersion, these need to be balanced against the situations when these devices actually reduce dispersion and increase downwind GLCs.

Recommendations

Project methodology recommendations

Tracer gas measurements did not produce any meaningful results in this project primarily due to a range of technical and weather-related problems. It is recommended that tracer gas measurements not be used for measuring dispersion from poultry sheds unless a dense array of high frequency samplers can be used.

Smoke observations from the windbreak wall were found to be very useful for observing the movement and dispersion of contaminated air exhausted from tunnel ventilated poultry sheds. The smoke observations were correlated against the CFD modelling and were found to support the conclusions derived from CFD for the control and windbreak wall situations. Further smoke observations from short stacks would be useful for confirming the suitability of CFD for modelling short stacks.

Recommendations for the use of windbreak walls and short stacks

It is recommended that neither windbreak walls nor short stack be regarded as the basis of an odour reducing strategy. They do not reduce poultry shed odour emissions and due to external influences, will not reliably improve dispersion or reduce downwind odour concentrations. If they are to be considered as a component of an odour reduction strategy, the situation into which they are being installed must first be completely understood to know when, where and why odour impacts are occurring before installation proceeds.

A number of potential benefits associated with the windbreak wall, not relating to odour dispersion, were observed during field trials. Further investigations should be considered to quantify the value of these to the chicken meat industry.

Introduction

Background

Odour emissions from poultry sheds have the potential to cause odour impacts. Concern about odour impacts may prevent the establishment of new poultry farms or limit the expansion of existing ones. Poultry facilities operate under a regulatory framework that imposes conditions designed to minimise odour nuisance or annoyance. Odour annoyance will occur when a receptor is subjected to odours that are considered offensive. Frequent exposure to offensive odours may encourage an affected receptor to make a formal odour complaint. These complaints invite regulatory attention and may require producers to take remedial action to reduce emissions, with obvious economic consequences.

Windbreak walls have been recognised and promoted as a technology that may reduce odour impacts by improving the dispersion of odour plumes arising from intensive animal housing, including mechanically ventilated poultry sheds. The walls operate by forcing exhausted air upward and improving mixing, which theoretically dilutes the odorous air and reduces impacts at nearby receptors. Figure 1 displays the theoretical operation for a windbreak wall. (Bottcher *et al.* 2001)

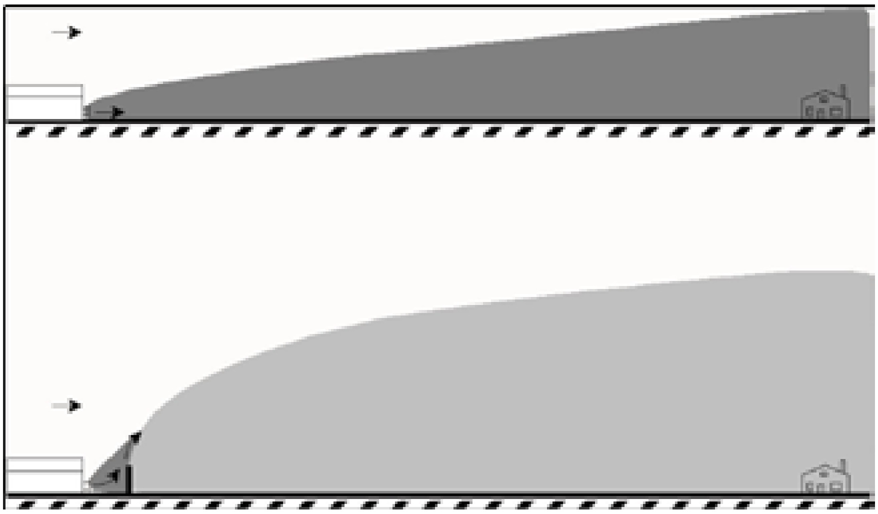


Figure 1. Theory of operation for windbreak walls (Bottcher *et al.* 2000)

Previous research into windbreak walls as a technology for reducing odour impacts failed to provide more than a very simplistic outline of expected performance. The perceived benefits of windbreak walls have been primarily based on theories rather than evaluations of performance under real-life conditions.

When investigating the ability of windbreak walls to reduce odour impacts, it is essential to understand that odour impacts on nearby receptors are a function of:

- rates of odour emission from the production sheds (or manure stockpiles);
- frequency of the receptor being exposed to the odour;
- dispersion of odours prior to reaching a receptor;
- sensitivity of the receptor; and

- the receptor's perception of the odour's offensiveness.

These factors require careful consideration when deciding whether a windbreak wall is an appropriate odour abatement device for a given situation. It is important to recognise that a windbreak wall will not have any influence on the odour emission rate from the poultry shed. A windbreak wall will only have an influence on dispersion of exhaust air immediately after discharge from the building. The amount of dispersion will be dependent on the geometry of the windbreak wall as well as local meteorological and atmospheric conditions (particularly atmospheric stability). A small increase in dispersion by the windbreak wall may be insufficient to prevent odour annoyance.

In Australia, windbreak walls have been presented to the poultry industry as a technology that should be considered for reducing odour impacts (McGahan et al. 2002; Pollock and Anderson, 2004; Robinson and Hulme, 2004).

Promoted benefits of windbreak walls include:

- moderate odour reduction;
- very low capital and operating costs;
- improvement in visual amenity;
- ability to reduce dust emissions; and
- simplicity in installation and operation.

Identified shortcomings of windbreak walls include:

- reliance on atmospheric dispersion; and
- decrease in fan performance if incorrectly designed (Ford and Riskowski 2003).

There is a lack of credible information regarding the performance of windbreak walls. This lack of knowledge highlights the requirement for further research and assessment of windbreak walls and other devices being promoted as dispersion enhancers.

This research was undertaken to improve understanding of the value of windbreak walls when applied to mechanically ventilated meat chicken buildings.

Windbreak walls – general description and theory of operation

A windbreak is a structure that intercepts air movement and increases air turbulence. Windbreaks have been used extensively to reduce ground level wind velocities on the downwind side of a structure. Ground level velocity is reduced for a distance of 13–20 wall heights downwind from the wall. Turbulence in the airflow is greatest from immediately behind the wall to a distance of 10 wall heights downwind. (Bottcher et al. 2000)

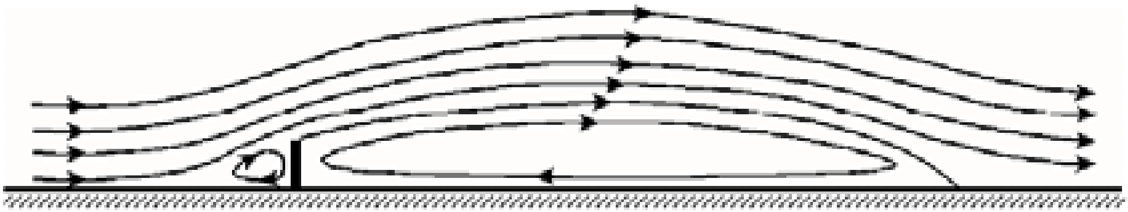


Figure 2. Effect of windbreak wall on wind movements (Bottcher *et al.* 2000)

Windbreaks can be formed using strips of vegetation, or can be constructed from materials such as plywood, steel, roofing iron, supported tarpaulins, hay bales or shade cloth (see Figure 3 for examples). In this report, the term 'windbreak wall' will refer to a constructed wall that is constructed close to the tunnel ventilation fans and intercepts the airflow, redirecting it upward. Bottcher et al. (2000; 2001; 2000) and Ford & Riskowski (2003) provide recommendations regarding the construction and operation of windbreak walls to effectively disperse air exhausted from tunnel ventilated animal buildings.

Figure 3. Examples of windbreaks installed at poultry farms (corrugated iron and tarpaulin material)

Bottcher *et al.* (2000) reported that when the walls were placed within a few fan diameters downwind of the exhaust fans, air from the fans was forced upward over the windbreak. This upward movement forced the exhaust air to mix with the air travelling over the building and windbreak at higher velocity, theoretically creating significant turbulence and improving mixing. It was believed that this increase in turbulence and mixing would improve air quality for downwind receptors, but it was stated that this theory required confirmation.

Windbreak walls can be constructed with or without side walls (Figure 3 and Figure 4). The presence of side walls aids in preventing side wind gusts from interfering with the upward movement of the exhaust air stream. Sidewalls also prevent sideways leakage of exhaust air that would effectively reduce the desired effect of the wall.

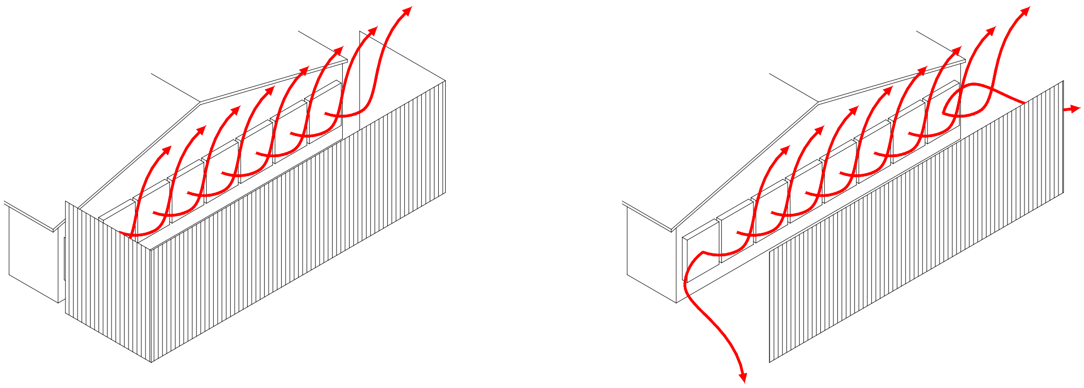


Figure 4. Schematics of windbreak walls with/without side walls showing conceptual air movement

Figure 1, Figure 2 and Figure 4 indicate the likely influence that windbreak walls may have under ideal conditions with a neutrally buoyant, steady wind moving in the same direction as the air being exhausted from the building. No evidence is available to show how windbreak walls will work in less than ideal conditions. Bottcher et al. (2001) used smoke to observe plume movements over a windbreak wall and commented that the effectiveness of windbreak walls would probably be reduced under stable meteorological conditions. Gaussian dispersion modelling performed by these researchers confirmed the initial observation and led to the conclusion that windbreak walls (and short stacks) would not be sufficient for odour control in stable atmospheric conditions. Briggs (2004) added to this by stating that the improved dispersion and dilution provided by windbreak walls becomes less obvious with increasing wind speed, due to increased natural turbulence.

Influence of atmospheric stability on windbreak wall performance

Efficiency of windbreak walls to enhance dispersion is highly dependent on atmospheric stability conditions. Atmospheric stability determines the extent to which a pocket of air will resist vertical mixing. It is most commonly reported using Pasquill-Gifford stability classes (USEPA, 2000).

Stable atmospheric conditions generally occur on clear nights and in the early morning. Stable conditions are generally associated with minimal turbulence and minimal vertical plume dispersion. Exhaust plumes will therefore resist mixing, dispersion and dilution under stable conditions, allowing exhaust plumes to travel significant distances, largely undiluted.

Neutral atmospheric conditions will generally occur during overcast conditions (day and night) as well as during the day when wind speeds are moderately high. Vertical mixing of air is moderate and plumes will tend to neither rise nor descend (neutral buoyancy).

Unstable atmospheric conditions will occur on sunny days when ground temperatures heat low level air, forcing it to rise. Unstable conditions will maximise vertical mixing, leading to high levels of dispersion.

Because of the apparent importance of atmospheric stability on the performance of windbreak walls, atmospheric stability was determined during all phases of fieldwork.

Other potential benefits of windbreak walls

Aside from influencing dispersion of exhaust gases from tunnel ventilated poultry sheds, windbreak walls have several attributes that may make them attractive to poultry producers, including:

- *appearance* – visual amenity may be improved by hiding the tunnel ventilation fans;
- *reduced noise emissions from tunnel ventilation fans* – the windbreak wall may help to limit stray noise caused by slipping belts or fan whirring;
- *control of stray light and heat* – a windbreak wall located at the tunnel ventilation fans will help to block stray light rays being visible through active ventilation fans during the night. If the tunnel ventilation fans are on the western end of the building, excessive heat and light from afternoon sun may be blocked by the wall and prevented from entering through active ventilation fans;
- *improved fan performance during gusty weather* – when prevailing winds are blowing in the opposite direction to that of fan discharge, the windbreak wall can assist the fans by reducing static air pressure on the outlet of the ventilation fans;
- *control of dust deposition* – a proportion of rapidly settling dust will be deposited within the windbreak wall. This should help to reduce dustiness in an area within about 50 m of the ventilation fans. The accumulation of dust in a small area may however require maintenance/cleaning/removal of the dust in order to prevent secondary odour generation from the dust, or messy conditions following rain.

Project Objectives

Reducing impacts from poultry farm emissions has been identified as being important for the future development of the chicken meat industry in Australia. While windbreak walls have been identified as a cost-effective device that could potentially reduce odour impacts from poultry farms, insufficient knowledge, understanding and actual evidence exists to support this claim. Consequently, RIRDC provided funding to address the following research objectives:

1. Identify the value of windbreak walls for improving dispersion of exhaust air from tunnel ventilated meat chicken sheds;
2. Evaluate the use of windbreak walls as an odour reduction strategy for meat chicken sheds.

Introduction to project activities

Three discrete and quite different trials were undertaken during the course of this project. Initially, it was thought that the project objectives could be met using tracer gas methods. Following two unsuccessful attempts to use a tracer gas to measure exhaust plume dispersion, it became apparent that this method was not suited to this purpose. Using smoke visualisation to observe exhaust plume movement was identified as a method that offered a greater chance of success, and was adopted for the final field trial.

Smoke observations did not provide a clear, unambiguous result that fulfilled the project objectives. A desktop study using computational fluid dynamics (CFD) modelling was undertaken to provide additional clarity and to support the smoke visualisations.

The following trials were undertaken during the course of this project.

Trial A – Full scale tracer gas release

Sulphur hexafluoride (SF_6) was chosen as the tracer gas for use in this trial. It was released under stable atmospheric conditions from a tunnel ventilated poultry building fitted with a windbreak wall. An array of sorbent tubes was positioned downwind from the building to collect the tracer gas. The concentration of tracer gas collected in the sorbent tubes was later measured using thermal desorption and gas chromatography techniques. Positioning of the sampling array was predetermined following analysis of local weather information, collected using a dual height weather station (instruments located at 2 m and 4 m). Analysis included atmospheric dispersion modelling and interpretation of wind conditions. Measured tracer gas concentrations were compared with those predicted by Ausplume and Calpuff dispersion modelling.

Trial A was primarily undertaken to confirm that the tracer gas methodology was suitable. Results from this field trial were inconclusive. Some technical and methodological issues were raised. *Trial B* was undertaken to address these issues.

Trial B – Micro-scale tracer gas release

As with *Trial A*, SF_6 gas was used as a tracer to measure plume dispersion. Unlike *Trial A*, this trial was undertaken on a much smaller scale, with the gas emitted from a small stack (height approximately 2.4 m in terrain that was flat and unobstructed. Atmospheric conditions were stable at the time of the release (early morning, 2 December 2004). Weather information was collected using a 10 m weather station located nearby. An array of sorbent tubes was arranged in a location downwind from the release stack. Fluctuating wind conditions during the tracer gas release prevented meaningful results from being obtained.

Review of methodology following Trial A and Trial B

Inconclusive outcomes from *Trial A* and *Trial B* led the project team to change the experimental approach. It was decided to use smoke to compare plume movements and dispersion from a windbreak wall (treatment) and a conventional tunnel ventilated building (control). It was planned to undertake these smoke observations under a range of meteorological and atmospheric stability conditions. It was believed that smoke observations could provide valuable insight and enable an assessment of plume dispersion. This assessment could then be used to determine the value of windbreak walls for enhancing dispersion and reducing odour impacts.

Trial C – Smoke observations

A poultry farm with an extensive cleared area on the exhaust end of the production sheds was chosen for this trial. A 4 m high windbreak wall was constructed 4.5 m downwind of the tunnel ventilation fans. Smoke was delivered evenly to the active fans using a customised distribution manifold. Smoke was released at specified times depending on meteorological and atmospheric stability conditions (from 28 April 2006 to 12 May 2006). Photographs and video footage were collected and analysed to assess plume spread and movement. To assess the improvement in dispersion and mixing attributed to the windbreak wall, smoke releases were also undertaken from an identical, adjacent control shed (no windbreak wall). Weather data was collected using a 10 m weather station.

Computational fluid dynamics (CFD) modelling

A CFD modelling study was undertaken to quantify how much a windbreak wall may improve plume dispersion and reduce ground level odour concentrations. To maximise the information derived from this exercise, the scope was expanded to include modelling of odour dispersion from short stacks.

To maximise the usefulness of the information derived from the CFD modelling, a generic case was established. For this general case, a typical tunnel ventilated poultry building was designed and positioned in the middle of a clear, flat expanse of land. This typical building was designed with a width of 14 m, length of 100 m and roof apex height of 3.1 m. Eight axial fans were fitted to one end of this building. This building formed the *control* situation. To model the *windbreak wall* situation, a windbreak wall 14 m wide, 4 m tall and located 4.5 m from the fans was included in the design. To model the *short-stack* situation, short stacks (the diameter of the fans) were fitted to each of the ventilation fans. The stack formed a 90° discharge tube that was extended to a height of 4 m, the same as for the windbreak wall.

Modelling variables included atmospheric stability class, differential temperature between exhaust and ambient air, horizontal wind speed and the number of active fans. Unstable atmospheric stability conditions were not modelled owing to difficulties accurately modelling unstable conditions. This decision was also based on the assumption that odour annoyance is least likely to occur during unstable conditions due to maximised natural turbulence and dispersion.

CFD modelling provided valuable input to this research project because it provided a standardised virtual environment that enabled direct comparison between the control, windbreak wall and short stack situations. It also enabled comparison of predicted ground level concentrations downwind from the modelled poultry sheds.

Methodology

Description of windbreak walls used in this project

Windbreak wall used during Trial A

A windbreak wall was in existence at the trial site selected for *Trial A* (see Figure 5, Figure 6 and Figure 7). This wall was constructed using a steel tube frame (50x50 mm RHS upright posts and 25x25 mm RHS horizontal batons) and vinyl tarpaulin (similar to the material used on curtain sided trucks). The posts were cemented into the ground and braced back to the shed wall, above the fans. The overall width of the windbreak was 15.4 m, sides 4.4 m and height 3.9 m.

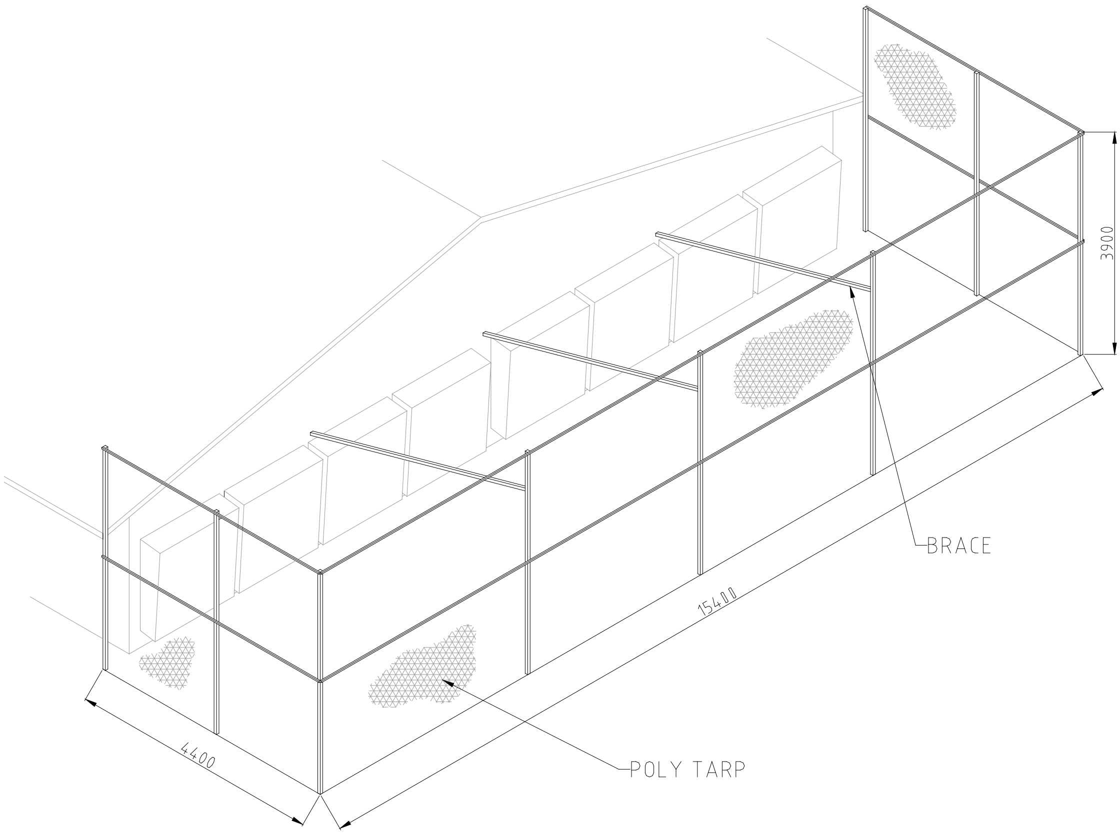


Figure 5. Tarpaulin windbreak used in Trial A

Figure 6. Tarpaulin windbreak wall

Figure 7. Tarpaulin windbreak frame

Construction of chimney for Trial B

A small chimney was constructed from 240 mm diameter PVC tube (225 PVC storm-water pipe) (see Figure 8 and Figure 9). The chimney stood approximately 2.5 m tall. Airflow was generated in the chimney using an axial fan (Fantech® TD-800/200 mixvent series axial fan). Tracer gas was fed into the base of the chimney using 6.35 mm PTFE (polytetrafluoroethylene) tubing. Smoke was supplied intermittently at the inlet of the fan. The chimney was supported using two steel pickets that were secured into the ground.

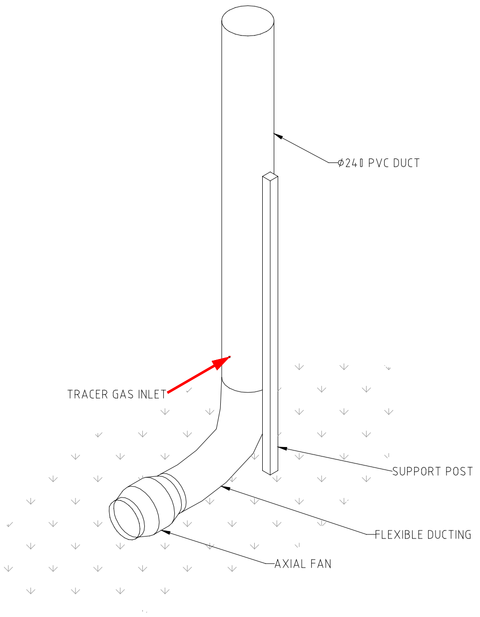


Figure 8. Stack used during Trial B tracer gas release

Figure 9. Stack, fan and tracer gas cylinder as used during Trial B

Construction of a windbreak wall for Trial C

To successfully complete *Trial C*, a windbreak wall was constructed according to the design criteria described in Bottcher et al. (2000) and Ford and Riskowski (2003) (see Figure 10 to Figure 13). These criteria required the wall to be placed approximately three fan diameters downwind of the exhaust fans, and stand at least 3 m tall to ensure that all exhaust air was intercepted and diverted upward. The windbreak wall was constructed 4.5 m from the fans, 4.0 m tall and with sides to prevent sideward air leakage.

The windbreak wall design included two gates to allow the grower access to the building via the main doors located at the fan end of the shed. These were 2250 mm wide, and the full height of the wall. A removable post was positioned between the gates, providing a sturdy latching point for the gates.

The wall was constructed using steel posts (75x50x3 mm RHS) with an 8 mm plate welded to the base. These base plates had four holes, enabling the posts to be bolted down to concrete foundations. Top hat purlins, 61 mm high and 1 mm thick were attached to the vertical steel posts using self-drilling tek-screws. Four evenly distributed rows of these purlins were secured to the posts. Corrugated roofing iron was attached to these purlins using self-drilling tek-screws. Gaps on the corners of the wall, and at the gate hinges were sealed using roof ridge capping, screwed to the corrugated iron.

The gate posts and the side walls were braced using steel tubing (50x50x3 mm RHS). One end of the brace was attached to the posts at approximately 2/3 height. The other end of the brace was bolted to a short stay post, concreted into the ground approximately 3 m from the inside of the wall. Both braces were secured to this stay post.

Materials to construct the wall cost approximately $3000 (plus 10% GST). The wall was erected by two people over a three and a half day period.

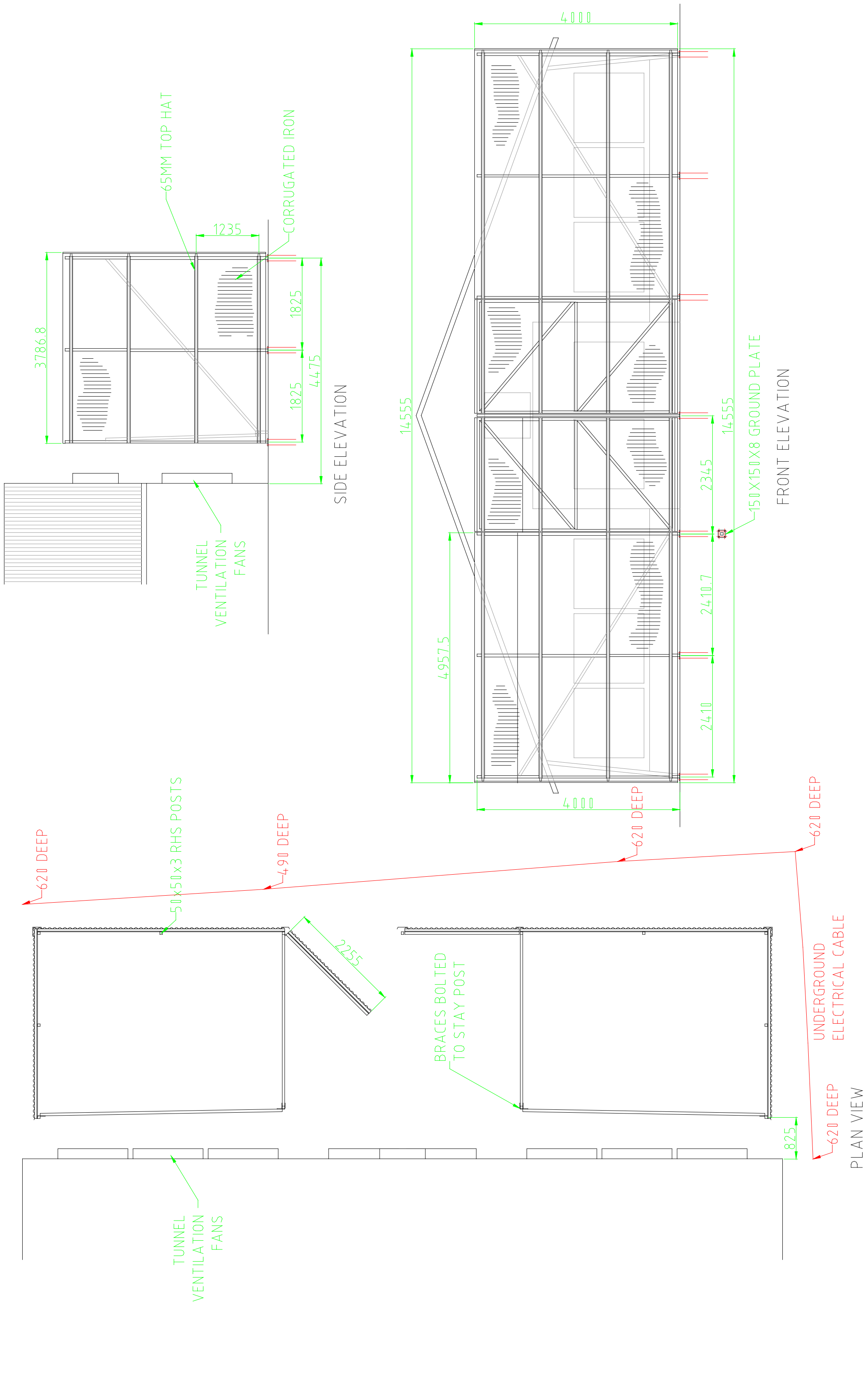


Figure 10. Diagram of the windbreak wall constructed for Trial C

Figure 11. Windbreak wall partially constructed

Figure 12. Completed windbreak wall

Figure 13. Internal view of completed windbreak wall, showing smoke release duct

Tracer gas release and sampling

Tracer gases have previously been used to measure dispersion of gaseous plumes (Abernathy et al. 1999; Kai et al. 2003; Santos et al. 2005; Venkatram et al. 2004a; Venkatram et al. 2004b). An objective of *Trial A* and *Trial B* was to use sulphur hexafluoride (SF_6) as a tracer gas to measure the dispersion caused by a windbreak wall. This tracer gas is not naturally occurring, can be detected at low concentrations and has previously been used to measure atmospheric dispersion of exhaust plumes. Neat SF_6 gas (1 million ppm) was used in the form of a compressed liquid gas.

The release rate of the SF_6 gas was calculated from predictions of downwind ground level concentrations (using atmospheric dispersion modelling) as well as analytical detection limits. The release rate of SF_6 from the gas cylinder was controlled using a stainless steel dual stage gas regulator and measured using a flow meter (TSI® model 4143 thermal mass flow meter). The release rate of SF_6 during *Trial A* was 13 L/min. For *Trial B*, the release rate of SF_6 was 0.2 L/min. For *Trial A*, SF_6 was released directly into the chicken shed approximately 20 m upstream of the fans. For *Trial B,* SF_6 was released directly into the inlet of the stack.

Sorbent tubes were used to collect the SF_6 in ambient air downwind from the source. Sampling and analysis of the sorbent tubes was undertaken using the guidelines recommended by USEPA (1999).

Vacuum pumps (SKC® PocketPump®) were used to draw air through the sorbent tubes at a set flow rate. One vacuum pump was used for each sorbent tube (Figure 14). By recording the flow rate and sampling period, the total volume of air sampled was calculated. The sampling flow rate during *Trial A* was 40 mL/min and for *Trial B* was 100 mL/min. Sampling periods were 240 minutes for *Trial A* and 60 minutes for *Trial B*.

Figure 14. Sorbent tube and vacuum sampling pump

The sorbent tubes contained special packing material (Type 2 Air Toxics tube packed with Carbopack B and Carbosieve SIII) that was able to absorb and retain the SF_6 in the tube. At the completion of the sampling period, the tubes were sealed and sent to a laboratory for analysis. The tubes were analysed using thermal desorption and gas chromatography. During this process, compounds absorbed into the packing material were desorbed by heating the tube and purging with inert gas. The recovered materials were then injected into the gas chromatograph – mass spectrometer for analysis. By interpreting the resulting chromatogram, the mass of SF_6 in the tube could be determined.

By combining the mass of SF_6 in the tube and the volume of sample air drawn through the tube, the average ambient concentration of SF_6 for the sampling period was calculated. The average ambient concentration of tracer gas at the defined points could then be used to determine whether the windbreak wall had improved dispersion of the tracer. If, for example, the ambient concentration at the sampling points was lower for the windbreak wall compared to the control situation, it would have indicated that the windbreak had improved dispersion.

Smoke release and observations

The objective of *Trial C* was to visually assess the dispersion enhancement provided by a windbreak wall. To achieve this, smoke was released into the exhaust air to make it visible. Photographs and video footage were taken during the smoke releases to provide a record of the smoke movement. Weather data was also collected to determine the ambient conditions when the smoke was released.

Smoke was released either from the shed with the windbreak wall or from the control shed. When smoke was released, sequential photographs were taken to record the progressive movement and dispersion of the smoke plume. Dispersion was assessed by measuring the size of the smoke plume and observing its visibility. Increased plume size and reduced visibility were indicators of dispersion. To observe and record smoke movements and dispersion at night, lights were used to illuminate the plume.

Smoke generation

Smoke was used during all field trials to provide a visual representation of wind speed and direction as well as exhaust plume movements and dispersion. Used appropriately, smoke provided valuable insight into valley drainage and buoyant plume rise, and could be used to visualise low-level thermal stratification.

Smoke was produced using two different methods.

1. A smoke generator (Figure 15, Concept Smoke Generators, *Comet Colt-4*™) was occasionally used when small amounts of cool white smoke were required. Smoke was generated by this machine by burning a water based liquid (Concept Smoke Fluid A). Although it was claimed that the smoke produced by this machine was persistent, it quickly dispersed under bright sunlight conditions.

Figure 15. Smoke generator in operation

2. Hand smoke flares were used to provide large volumes of persistent smoke. These hand smoke flares were supplied by Pains Wessex (Victoria, Australia) and were available in a range of colours including white, blue, green and orange. Orange and white smokes were primarily used as these provided the greatest visibility. The smoke produced by hand smoke flares is a pyrotechnic smoke consisting of fine coloured particles. The duration of smoke production was 30–90 seconds.

   The orange hand smokes used in this project are identical to those used as daytime emergency flares commonly available for maritime emergency use. It was therefore necessary to notify emergency and rescue authorities including the Australian Maritime Safety Authority, local Police and nearby military bases prior to the activation of these hand smoke flares.

Smoke delivery system (used in Trial C)

A smoke delivery system was required to ensure uniform distribution of smoke within the windbreak wall, or across the fans on the control shed (see **Error! Reference source not found.**). This distribution system was manufactured using an axial fan (Fantech® TD-500/150 mixvent series axial fan), 100 mm PVC stormwater pipe and metal stands (see Figure 16). Slots (approximately 65x200 mm) were cut into the PVC duct along its length to correspond with the centre of each shed ventilation fan. The size of each slot was made fully adjustable by the installation of a sliding sleeve. Slots were completely closed when the corresponding ventilation fan was inactive. Slots were opened to correspond with active fans. Adjusting the position of the sliding sleeve allowed the flow from each slot to be balanced evenly along the length of the duct.

Figure 16. Uniform smoke delivery using smoke distribution system

Smoke flares were activated using a customised activation system (see Figure 16 and Figure 17). This system could be loaded with up to two flares. These flares could be activated individually or simultaneously by way of string lines. When the string line was pulled, a system of levers ignited the flare by pulling the tab at the end of the flare (see Figure 17). Flares were activated from a distance of 100 m (but this distance could be increased by increasing the length of string).

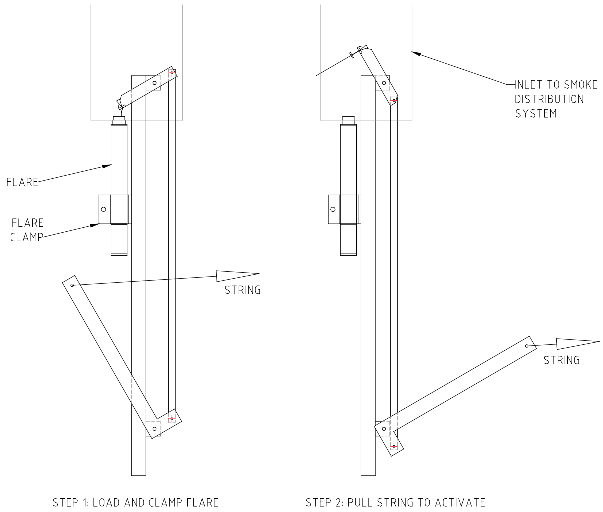


Figure 16. Smoke distribution system showing fan, duct, flare activator, adjustable slots and stands

Figure 17. Illustration of the flare activation system

Photographic equipment and lighting

Digital cameras and a digital video camera were used to capture images of smoke plumes being emitted from the windbreak wall and the control building. Sequential images were taken with the still cameras and then collated to display the progression of smoke plume movement and spread.

The cameras and video camera used to capture the smoke releases were:

- Canon EOS350D, digital SLR camera fitted with either a Canon 18-55 mm lens or Tamron AF Aspherical XR-DiII 18-200 mm lens;
- Olympus C-740 digital camera; and
- Sony HDR-FX1E Digital HD Video Camera Recorder.

Lighting was required for night time smoke observations. To achieve suitable levels of lighting, a self-contained lighting tower was used. This lighting tower comprised four, 1500 W metal-halide flood lights (6000 W total) mounted on an 8 m tall hydraulic tower, powered by a diesel generator. The tower was located approximately 80 m from the windbreak wall, with the lights directed to shine light onto the poultry buildings, the ground directly in front of the buildings and into the sky above the buildings.

Figure 19. The light tower being used to illuminate smoke plumes during the night

Scaffolding, 3.5 m high, was used during most of the photography to provide a better view and better perspective of the smoke release (see **Error! Reference source not found.**).

Figure 20. 3.5m-tall scaffold used to improve photographic perspective

Field trial site descriptions and location of sampling points

Trial A – Full scale tracer gas release

Trial A was undertaken at a commercial broiler farm located south of Brisbane, Queensland. The broiler buildings were located on the top of a low hill (**Error! Reference source not found.**). The farm was surrounded by undulating country that had mostly been cleared of trees (Figure 18). A creek was located approximately 750 metres to the east of the sheds.

Figure 21. View of the Trial A farm (camera situated 600 m to the south of the sheds, facing north, see point X in Figure 18)

Figure 18. Aerial photo of Trial A site

An array of sampling points was positioned to the northeast of the tracer release point (see Figure 19). The location of the sampling array was estimated using atmospheric dispersion modelling (described later in section *Atmospheric dispersion modelling*). The specific orientation of this array relative to the source was determined by the prevailing wind direction at the time of the release. Figure 20 is a photo from one of the sampling points looking back toward the tracer gas release point.

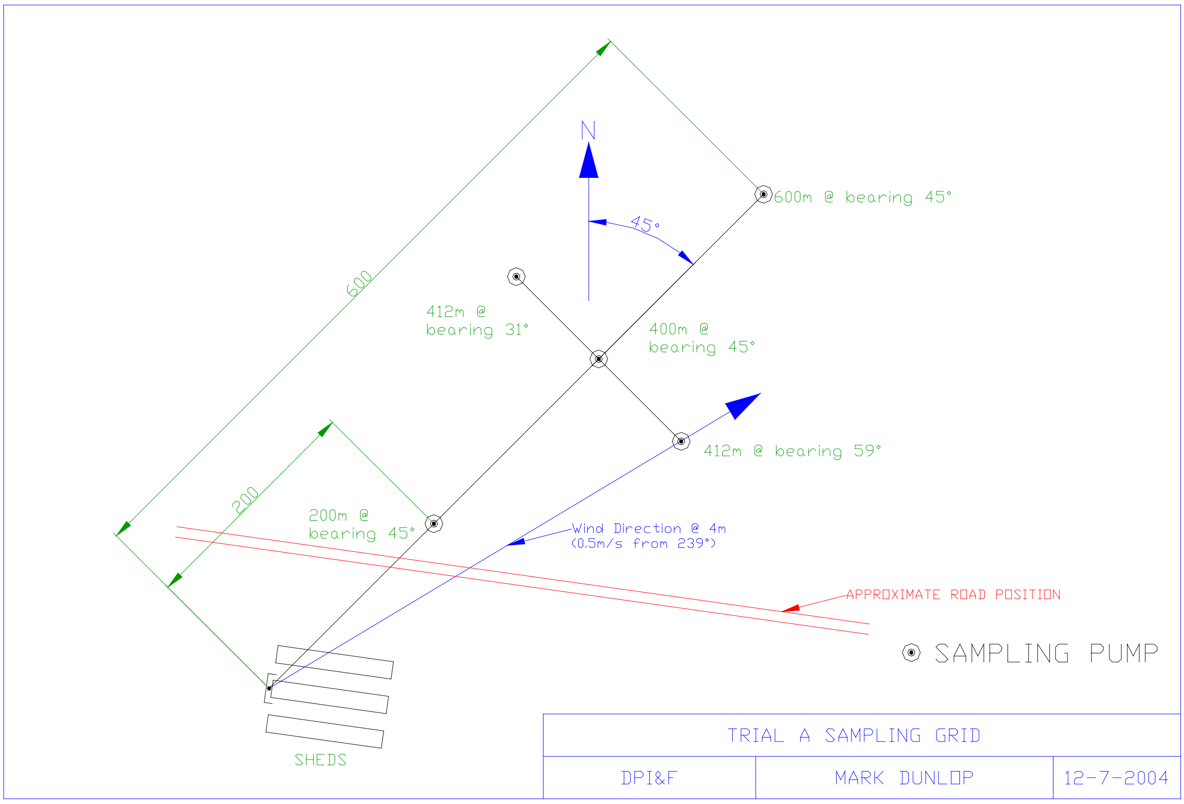


Figure 19. Position of sampling array in relation to the tracer gas release point

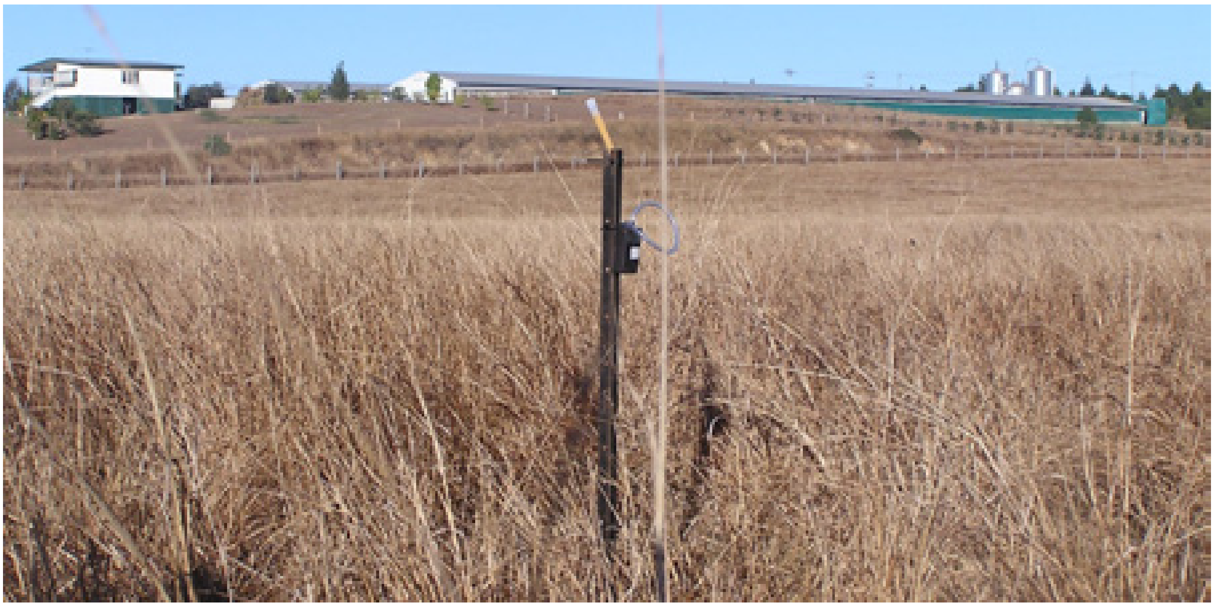


Figure 20. View from sampling point back to the tracer gas release point (400m to NE, looking SSW)

Trial B – Micro-scale tracer gas release

Trial B was undertaken in a flat, unobstructed area south of Toowoomba, Queensland. This trial was undertaken to test the tracer gas methodology. A flat, unobstructed area was required to minimise interference with the tracer gas plume. A short release stack and sampling array of eight sorbent tubes was established in the trial site according to the planned configuration shown in Figure 21. Figure 22 is a photo of the trial site with stack and sampling array established.

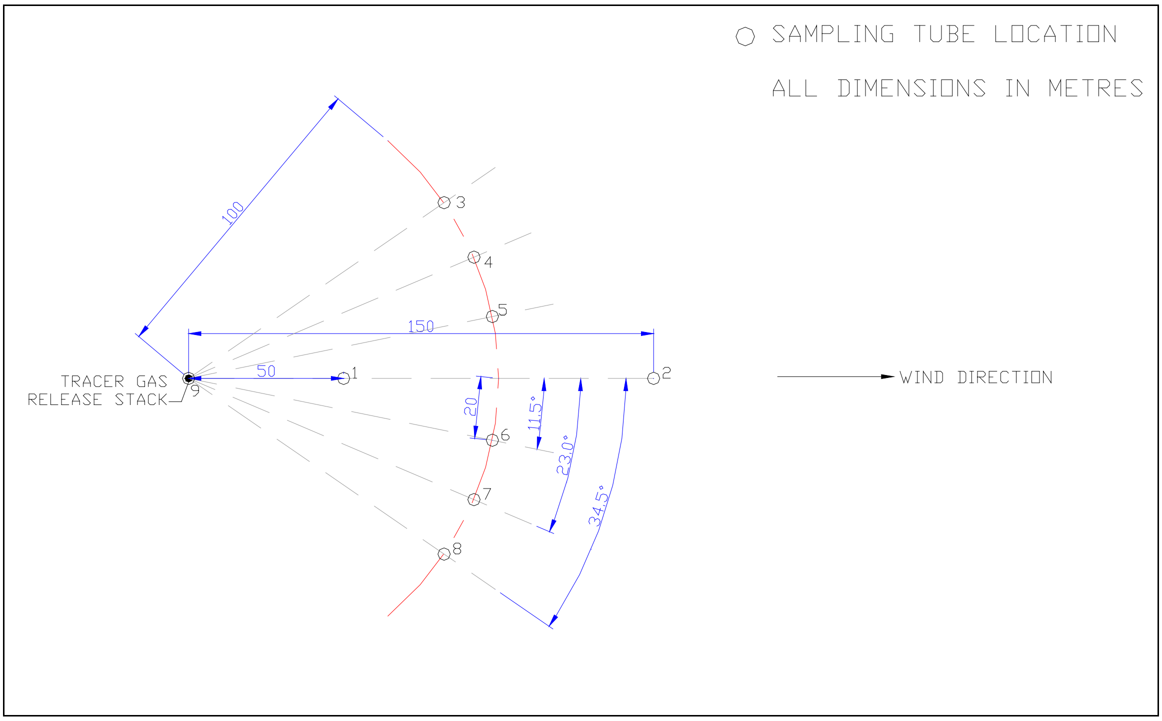


Figure 21. Planned layout of sampling array

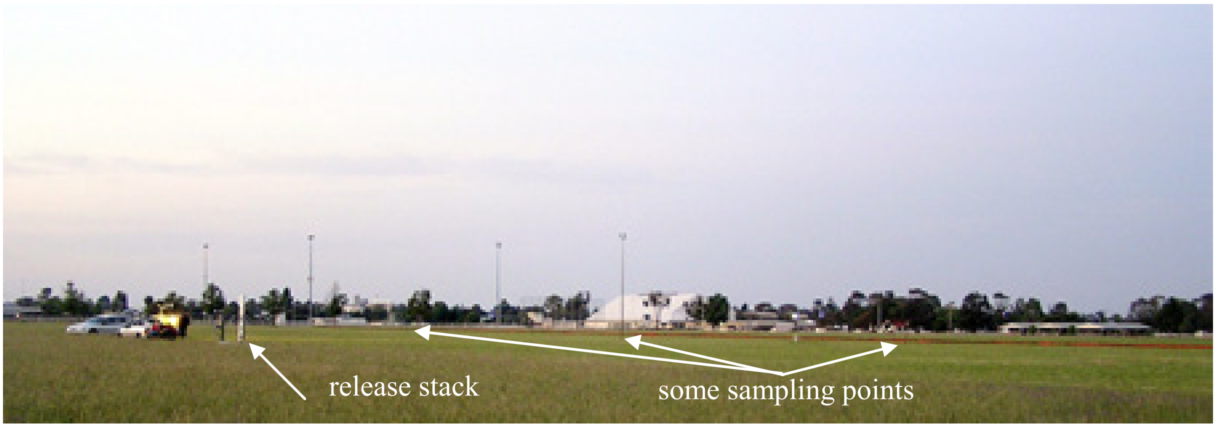


Figure 22. *Trial B* tracer gas release site (release stack B (see Figure 48) and sample points 7, 6 & 5 visible)

Tracer gas was released from the small stack (see Figure 8 and Figure 9). It was necessary to move this stack during the tracer gas release due to significant changes in wind direction (see Figure 48). At the time when the sampling grid and release stack (stack A) were positioned, the wind was blowing in an east-northeast to northeast direction (the centre line of the sampling array). Unfortunately, just as the tracer gas release began, the wind swung around, directing the tracer gas plume away from the sampling array. In an attempt to salvage some useful information from this trial, the release stack was repositioned (stack B).

Trial C – Smoke observations

Trial C was undertaken at a commercial broiler farm in an area southwest of Brisbane, Queensland. This farm was selected because it was situated in a flat, mostly cleared area (Figure 23 and Figure 24). Another feature of this farm was the availability of two identical growing sheds (in terms of overall dimension, design and fans). This feature provided an ideal opportunity to make realistic comparisons between the performance of the windbreak wall (treatment) and a standard tunnel ventilated growing building (control).

Figure 23. ***Trial C*** **aerial photograph with approximate scale**

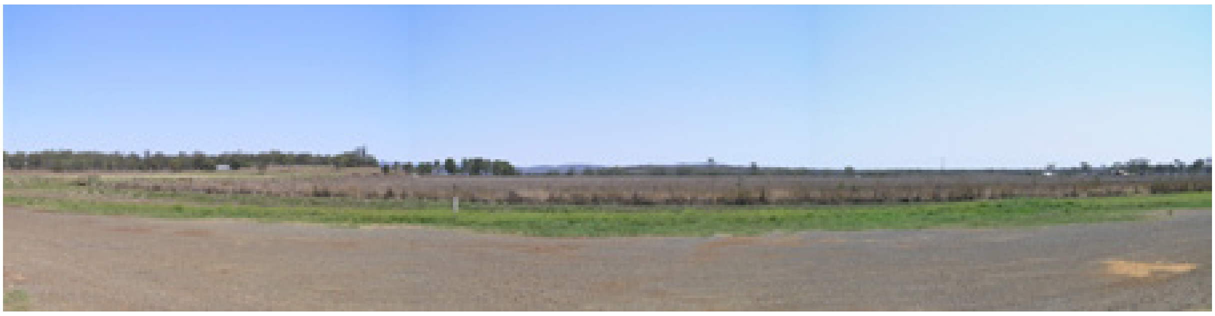


Figure 24. View looking directly out from windbreak wall over extensive cleared area

An array of steel pickets was established in the cleared area downwind from the windbreak wall and control buildings (see Figure 25 and Figure 26). These pickets provided reference points to compare plume spread and movement. The pickets extended 60 m out from the windbreak wall and control buildings. Approximately 40 m directly out from the windbreak wall was a barbed wire fence. Starting at this fence and extending away from the buildings was a paddock of 1.2 to 1.5 m tall grass (see Figure 26).

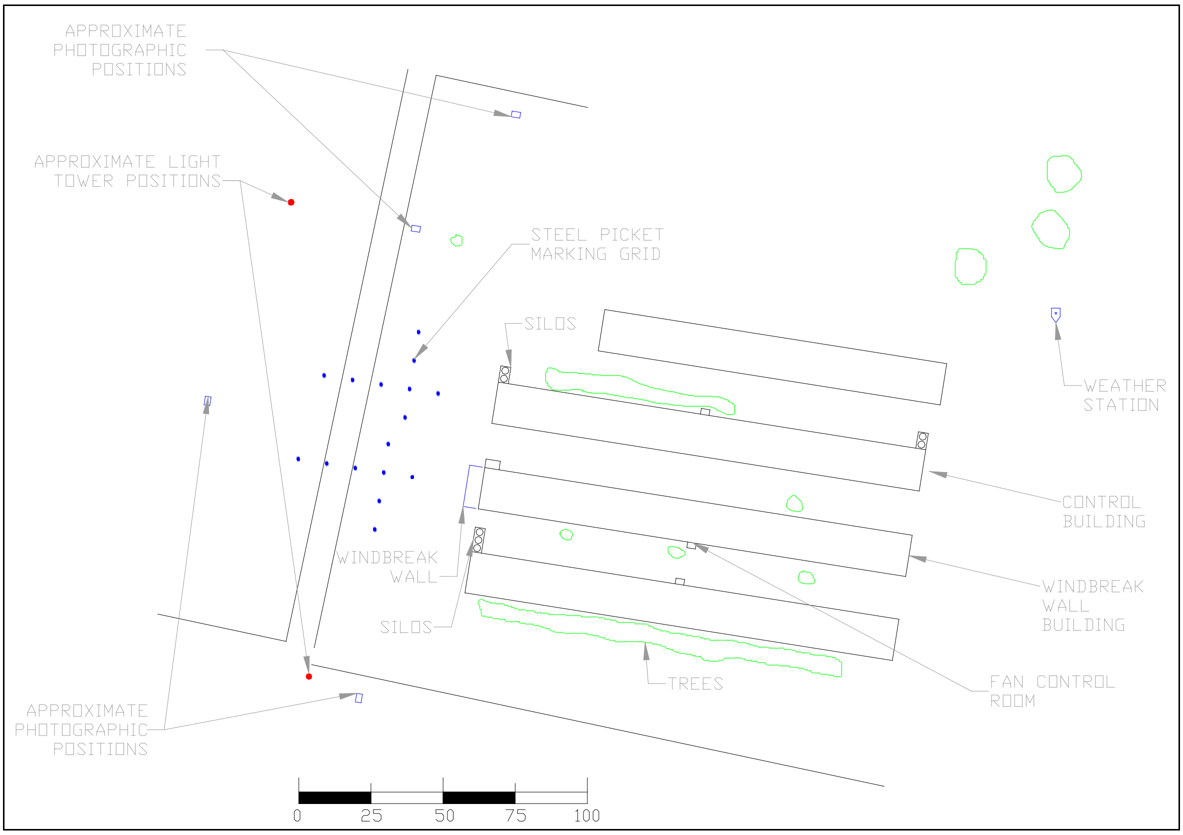


Figure 25. Layout of *Trial C* site

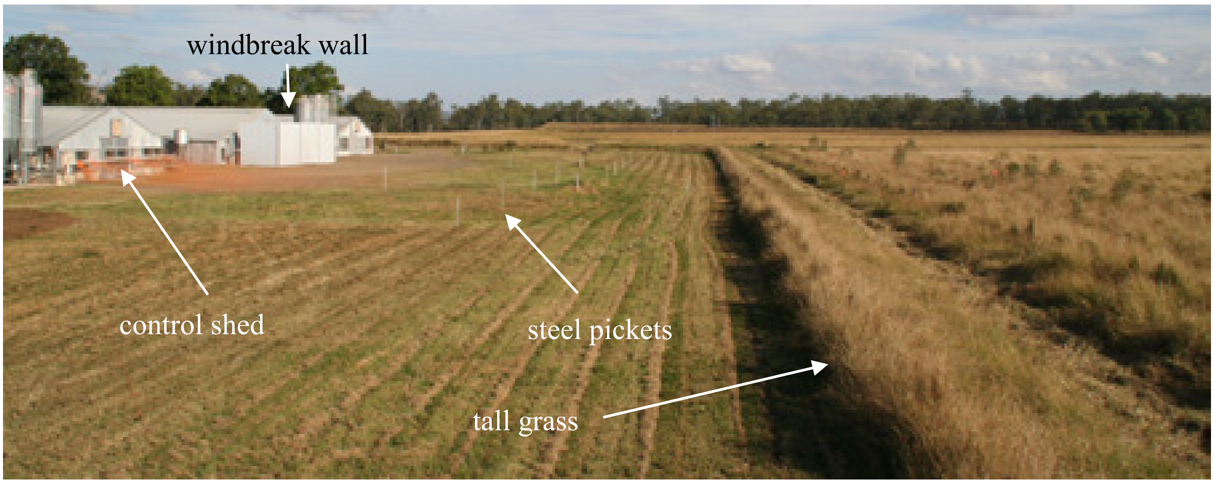


Figure 26. *Trial C* site showing steel picket array, windbreak wall, control and tall grass

Collection and analysis of weather information

Weather data was collected during all field trials. Customised on-site weather stations were used for each of the trials.

Weather information collected during the trials is displayed in Table 1. All data (except rainfall) was collected every second then averaged and reported every six minutes. Hourly and daily averages (and totals) were calculated during post processing. Specific information for the weather station sensors is displayed in **Appendix 1**.

Table 1. Weather information collected during the trials

Trial A	Trial B	Trial C
2 m wind speed	2 m wind speed	2 m wind speed
2 m wind direction		2 m wind direction
4 m wind speed	10 m wind speed	10 m wind speed
4 m wind direction	10 m wind direction	10 m wind direction
2 m wind direction SD[1]		2 m wind direction SD
4 m wind direction SD	10 m wind direction SD	10 m wind direction SD
	2 m wind speed SD	2 m wind speed SD
	10 m wind speed SD	10 m wind speed SD
2 m temperature	2 m temperature	2 m temperature (2 sensors)
2 m relative humidity	2 m relative humidity	2 m relative humidity
4 m temperature	10 m temperature	10 m temperature
4 m relative humidity		
total radiation	total radiation	total radiation
	barometric pressure	barometric pressure
	rainfall	rainfall

A different weather station was used for each of the three trials (Figure 27). During *Trial A*, a 4 m portable weather station was used. During *Trial B*, a 10 m permanent weather station located approximately 1 km from the trial site was used. For *Trial C*, a 10 m portable weather station was used. Weather stations were owned by DPI&F and were located and managed according to AS 2923-1987 (Standards Australia, 1987) (the Standard) wherever possible. It was not possible to locate the weather stations in strict accordance with the Standard at some of the sites due to vegetation or geographical landforms. It was considered more important to get the weather station as close as

[1] SD = Standard deviation

possible to the trial site, which occasionally meant small compromises with weather station placement in relation to these obstacles.

Figure 27. Weather stations used for this project (*Trial A* – left, T*rial B* – centre, *Trial C* – right)

Wind and stability class information was used to predict optimal times for undertaking field activities.

Wind speed and direction information was presented using *Wind Rose* (Advanced Technology Systems, Inc, 1999). This program presents wind data as a wind rose (see Figure 28 for a typical example). To interpret a wind rose, the thickness of the line indicates the wind speed (see the scale bar at the bottom of the wind rose), the location of the line indicates the wind direction, and the length of each line indicates what percentage of the time the wind blew from that direction. The number in the middle of the wind rose indicates the percentage of time the wind speed was less than the minimum value on the scale bar. The example wind rose in Figure 28 shows that winds most commonly blow in the quadrant from south to east, and most of the time wind speeds range from 1 m/s to 5 m/s.

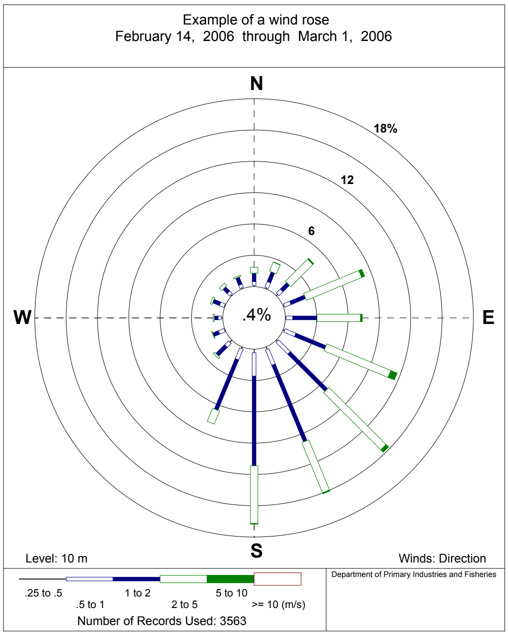


Figure 28. Example of a typical wind rose

Atmospheric stability class was determined using a spreadsheet program. This spreadsheet calculated the stability class using both the 'sigma-A' (σ_A) and 'solar radiation-delta temperature' (SRDT) techniques (USEPA, 2000). The σ_A technique is a turbulence-based method that uses the standard deviation of wind direction in combination with mean horizontal wind speed. The SRDT method uses horizontal wind speed in conjunction with solar radiation during the day and air temperature at two heights during the night. Stability class estimations by each of these methods were calculated simultaneously for comparison. Figure 29 displays the typical output from the stability class spreadsheet as a time-series graph. This chart displayed the stability class at specific times of the day. Historical stability class information was used to predict optimal times for field activities. Actual stability class information (calculated after conducting field work) was used to interpret results obtained during field activities.

The stability class spreadsheet calculated stability classes on an hourly basis (as displayed in Figure 29) using the six minute averaged weather data collected by the weather stations. A modified version of this spreadsheet calculated the stability classes at six minute intervals to correspond with the weather data. This modified spreadsheet was occasionally referred to for short duration stability class information. Six minute atmospheric stability information was used as a guide only because the recommended frequency for calculating stability class is one hour (USEPA, 2000).

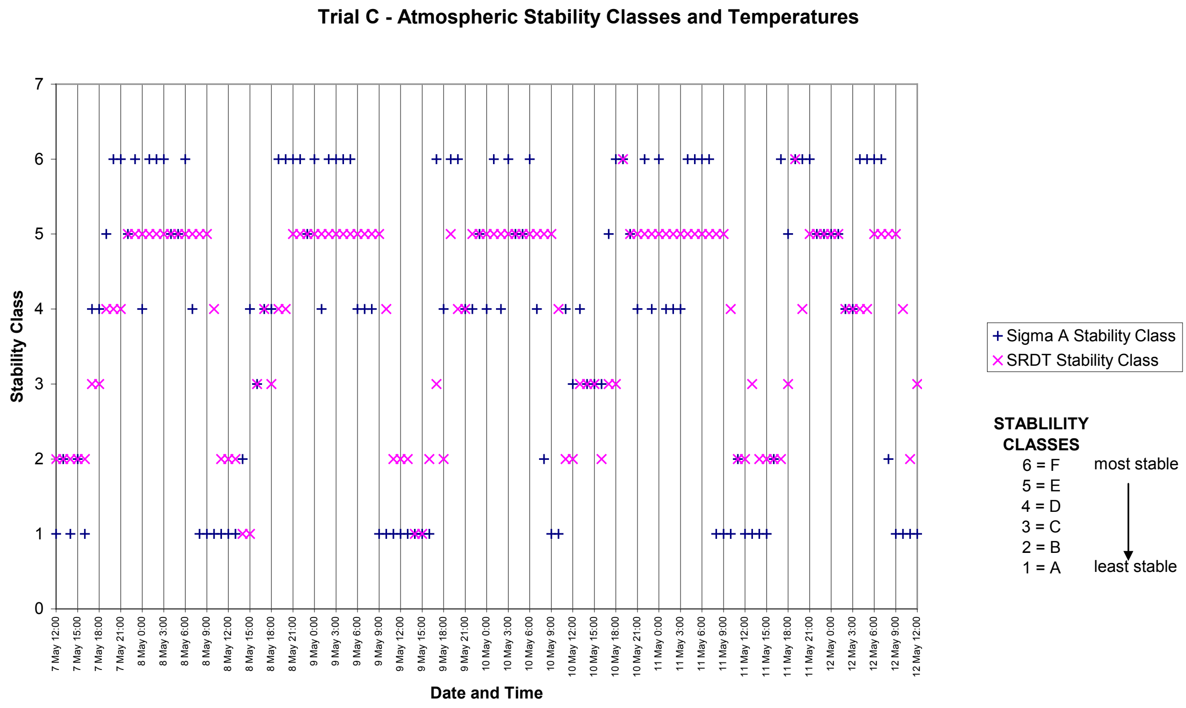


Figure 29. Example output from the stability class spreadsheet

Obtaining accurate and relevant weather information was crucial to the success of this project. Therefore, significant effort was dedicated to ensuring that this information was correct and reliable. Accurate local weather information was used to interpret the results of field activities and provided an essential input for atmospheric dispersion modelling.

Atmospheric dispersion modelling

Measurement of plume dispersion is extremely complex. Several atmospheric dispersion models have been developed to provide a means of simulating and estimating plume movement and dispersion. Ausplume (EPA Victoria and CAMM, version 5.4) and Calpuff (Earth Tech, Inc., version 5.7) are two models commonly used in Australia. Ausplume is a Gaussian dispersion model and was used in this project to predict likely ground level concentrations of tracer gas for the purpose of predicting optimal sampling locations for tracer gas samplers. Concentrations predicted by the models were compared to the measured tracer gas concentrations. Calpuff is a puff model, and like Ausplume, was used following the tracer gas releases to compare predicted gas concentrations with measured tracer gas concentrations.

Weather data is an essential input into dispersion models. Ausplume accepts hourly averaged data while Calpuff can accept six minute averaged data.

Screening modelling to determine sampling locations for Trial A

Prior to the tracer gas field work undertaken for *Trial A*, Ausplume was used to predict ground level concentrations of tracer gas in the areas surrounding the release point. Local weather data collected by the weather station (displayed in Figure 27) was used as an input into the model. Plume emission temperatures of 16 °C and 24 °C were used as these represented the range of ‘typical’ conditions of a plume exiting a tunnel ventilated poultry building. Some terrain features were also included to improve accuracy of the model output. Emission rate of the tracer gas was assumed to be 2.53 g/s.

Ausplume predicted that maximum ground level concentrations of tracer gas would occur 270 –400 m from the source if the emission temperature was 16 °C (Figure 30), and 500–1600 m if the emission temperature was 24 °C (Figure 31). The modelling, which was undertaken using on-site weather data, indicated that the tracer gas would move toward the northeast.

The tracer gas release occurred when no birds were present in the building, leading to cooler emission temperatures. Taking this into account, tracer gas sampling points were located 200–600 m from the source.

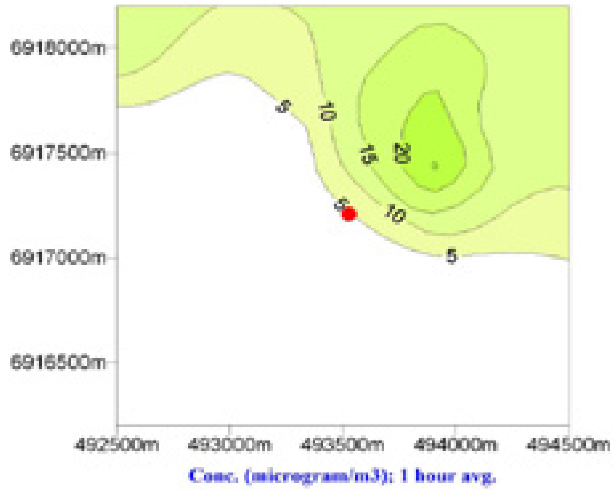


Figure 30. Ground level concentration of tracer gas predicted using Ausplume with source temperature 16 °C (1 hour average, red dot indicates source)

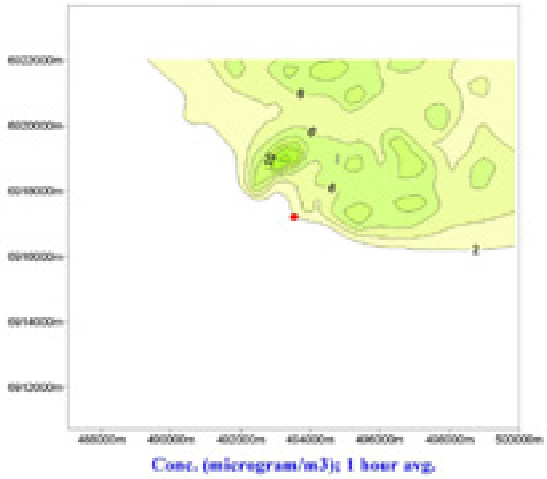


Figure 31. Ground level concentration of tracer gas predicted using Ausplume with source temperature 24 °C (1 hour average, red dot indicates source)

Screening modelling to determine sampling locations for Trial B

Ausplume was used to predict likely sampling sites for the micro-scale tracer gas stack release for *Trial B.* The actual tracer gas release was planned to be undertaken between 0200 and 0500 on the morning of 2 December 2004. Weather data for the three days prior to the tracer release date was loaded into the model. The stack geometry and vertical velocity was accurately described. Weather data suggested that, at the expected time for the release, the ambient air temperature would be approximately 18 °C. Since terrain was flat and unobstructed, terrain effects were ignored.

Output from the model suggested that average ground level concentrations would be in a suitable range (for the sorbent tube samplers) at a distance of 50–150 m downwind from the stack (Figure 32). Analysis of the wind data collected by the weather station indicated that winds at the test site were predominately from the northeast and west-northwest during the expected tracer gas release times (0200–0500) (see Figure 33).

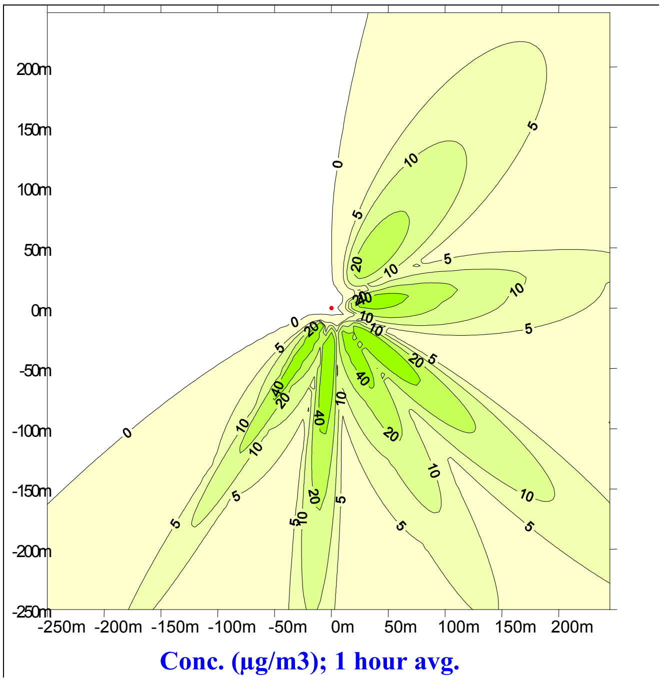


Figure 32. Ausplume prediction of ground level concentration (1 hour average, red dot indicates source)

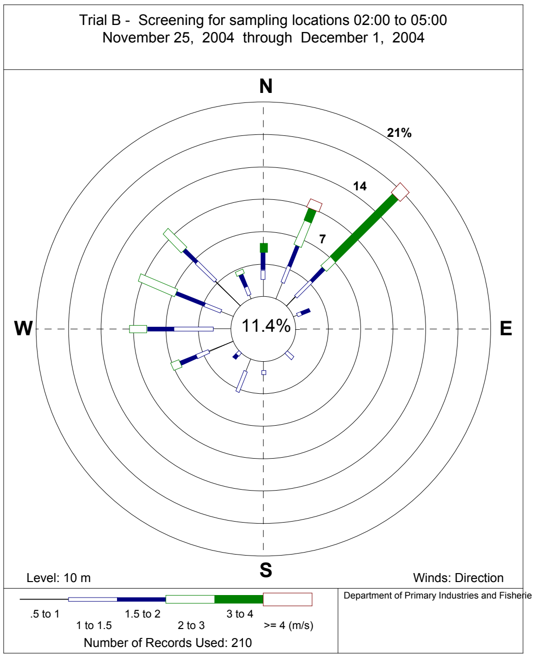


Figure 33. Wind rose displaying the 0200–0500 wind conditions at the test site for 7 days prior to the tracer gas release.

Dispersion modelling comparison to tracer gas measurements

Following the tracer gas release, Ausplume and Calpuff were used to predict the average ground level concentration at the sampling points. On-site information collected at the time of the release including weather data, emission temperature and tracer gas release rate were input into the models. Model predictions were compared against the actual tracer gas concentrations measured using the sorbent tube samplers.

Computational fluid dynamics modelling

Computational fluid dynamics (CFD) modelling, using Fluent (version 6.2), was used to assess whether windbreak walls could significantly improve the dispersion of odour being emitted from tunnel ventilated poultry buildings. To maximise the information derived from this exercise, the scope of the modelling was expanded to include modelling of short-stacks.

To maximise the usefulness of the information derived from the modelling, a generic case was established. For this general case, a typical tunnel ventilated poultry building was designed and positioned in the middle of a clear, flat expanse of land covered with 0.3 m tall grass cover. This typical building was designed with a width of 14 m, length of 100 m and apex height of 3.1 m. Eight axial fans were fitted to one end of this building. This building formed the *control* situation (see Figure 34). To model the *windbreak wall* situation, a windbreak wall 14 m wide, 4 m tall and located 4.5 m from the fans was included in the design and fitted to the control building (see Figure 35). To model the *short-stack* situation, short stacks the diameter of the axial fans were fitted to each of the axial fans (see Figure 36). The stack formed a 90° discharge tube that was lengthened to a height of 4 m, the same as for the windbreak wall.

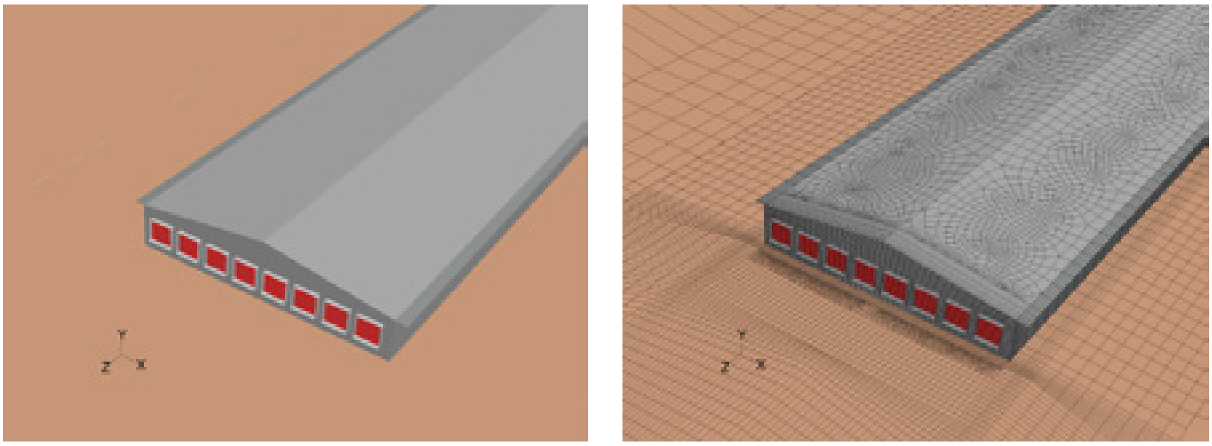


Figure 34. Visual representation of the control situation used in CFD modelling (a) without computational mesh and (b) with computational mesh

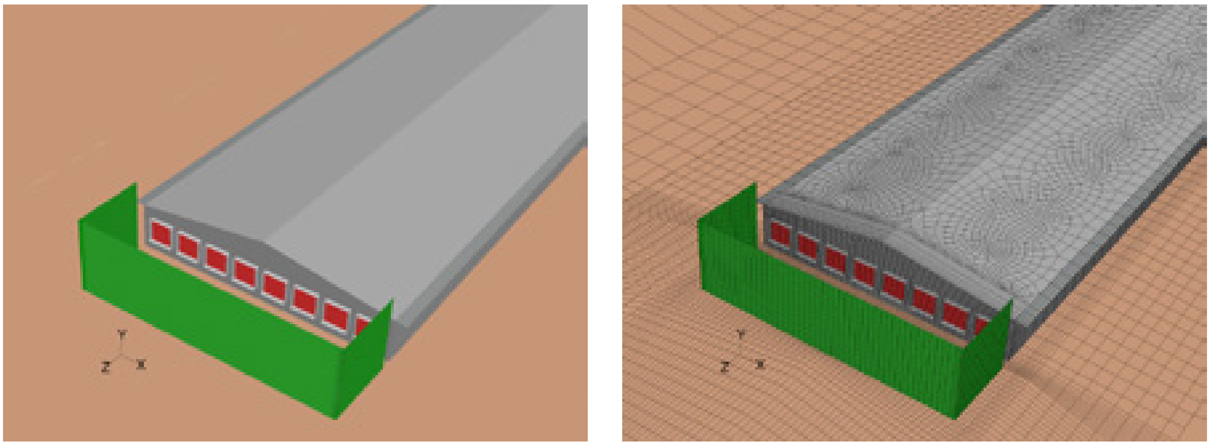


Figure 35. Visual representation of the windbreak wall situation used in CFD modelling (a) without computational mesh and (b) with computational mesh

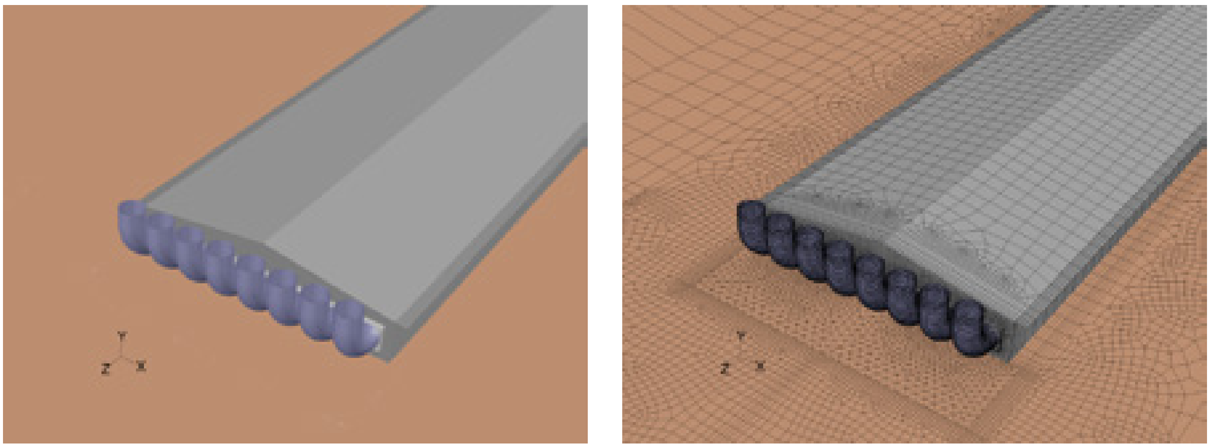


Figure 36. Visual representation of the short stack situation used in CFD modelling (a) without computational mesh and (b) with computational mesh

A modelling domain was established that extended 200 m upwind, 1500 m downwind, 500 above ground level and 500 m either side of the shed. Sheds were modelled individually to prevent interference by neighbouring buildings.

Following the smoke observations in *Trial C*, it was apparent that the ability of a windbreak wall to improve odour dispersion was influenced by atmospheric stability class, differential temperature between exhaust and ambient air, horizontal wind speed and the number of active fans. A high and low value was selected for each of these variables, forming a range of scenarios to test the influence of windbreak wall and short stacks on plume dispersion. Following consultation with experienced CFD modellers, the unstable atmospheric stability case was not modelled owing to difficulties accurately modelling unstable conditions. This decision was also based on the assumption that odour annoyance was least likely during unstable conditions due to maximised natural turbulence and dispersion.

Table 2 is the list of scenarios modelled using CFD. To remain within budget, stable conditions were not modelled with 4.5 m/s wind speeds. This scenario was excluded from the study because it was considered to be the least likely condition to occur in real life and would contribute the least value to the modelling exercise.

The following assumptions were used while undertaking the CFD modelling (Featherstone, 2006):

- Temperature of the shed exhaust was 20 °C.
- Wind was steady and in the direction along the axis of the sheds, going with the direction of the ventilation fans.
- Terrain beyond the shed was flat, unobstructed pasture with grass height of 0.3 m.
- Nominal wind speeds were as at 10 m above ground level. Nominal temperatures were at ground level.
- Neutral and stable atmospheric conditions were modelled as “D” and “F” Pasquill/Gifford stability classes respectively. Boundary layer parameters were set appropriately.
- Thermal plume rise was explicitly modelled using variable air density with respect to temperature with minimal assumptions. An incompressible ideal gas assumption was used to model plume rise.
- Operational fan configuration was symmetrical. This was relevant for the two (2) fan scenarios, where these were not adjacent. The fans second from the outside of the building were assumed to be operational for the two (2) fan conditions.
- Building, windbreak and short stacks were also considered to be symmetrical.
- The rotational direction was clockwise when viewed from the rear (fan end) of the shed. Thus, the fans spiralled air downward on the outside of the building.
- Each individual fan extracted 11.1 m^3/s of air from the shed. No flow correction was made for back-pressure associated with the wall and short stack options.
- Pollutants were not depleted or removed from the system.
- Results were not time dependent (from time of release) because the system reached steady-state.

Table 2. CFD modelling configurations

Building configuration	Stability class	Active fans	Wind speed (m/s)	External ground temperature (°C)	Run ID number
Control	Neutral	2	1.0	5	R01
				20	R02
			4.5	5	R03
				20	R04
		8	1.0	5	R05
				20	R06
			4.5	5	R07
				20	R08
	Stable	2	1.0	5	R09
				20	R10
		8	1.0	5	R11
				20	R12
Windbreak Wall	Neutral	2	1.0	5	R21
				20	R22
			4.5	5	R23
				20	R24
		8	1.0	5	R25
				20	R26
			4.5	5	R27
				20	R28
	Stable	2	1.0	5	R29
				20	R30
		8	1.0	5	R31
				20	R32
Short Stacks	Neutral	2	1.0	5	R41
				20	R42
			4.5	5	R43
				20	R44
		8	1.0	5	R45
				20	R46
			4.5	5	R47
				20	R48
	Stable	2	1.0	5	R49
				20	R50
		8	1.0	5	R51
				20	R52

Ground level concentrations (GLCs) reported in the modelling results should be considered higher than those expected in real life. This was primarily due to the assumptions that there was no pollutant depletion and wind movements were steady (no fluctuation in wind speed or direction which would naturally improve dispersion). These assumptions were deemed acceptable because the purpose of this study was to compare the three scenarios, not predict actual downwind concentrations.

Emissions from the poultry building were modelled in three dimensions within the modelling domain.

Figure 37, Figure 38 and Figure 39 show visualisations of the three dimensional plumes being emitted from the control, windbreak wall and short stacks respectively.

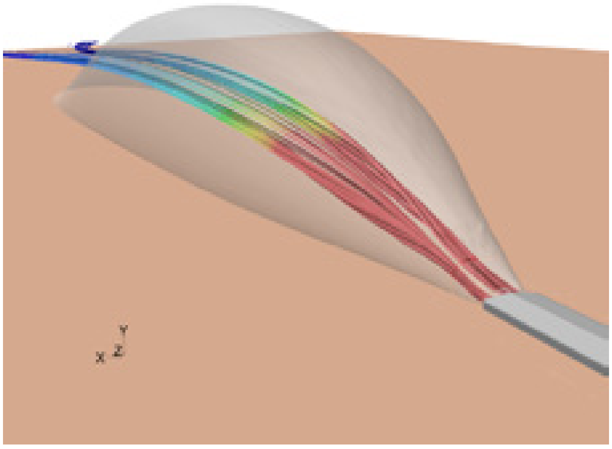


Figure 37. 3-D plume dispersion plot from the control (run 09)

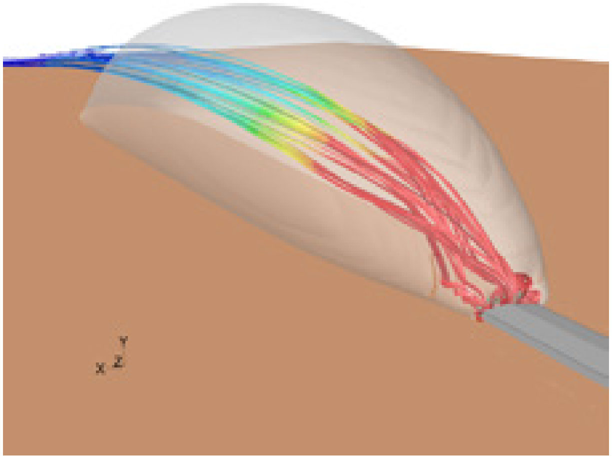


Figure 38. 3-D plume dispersion plot from the windbreak wall (run 29)

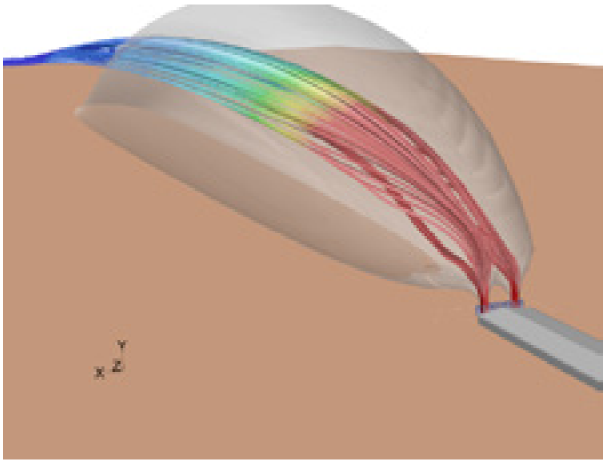


Figure 39. **3-D plume dispersion plot from the short stacks (run 49)**

Ground level concentration results from this modelling were reported in percentage (%) of emission. Results were plotted for each of the modelling scenarios using GLC contour plots and centreline GLC charts. Examples of these plots are given in Figure 40 and Figure 41 respectively.

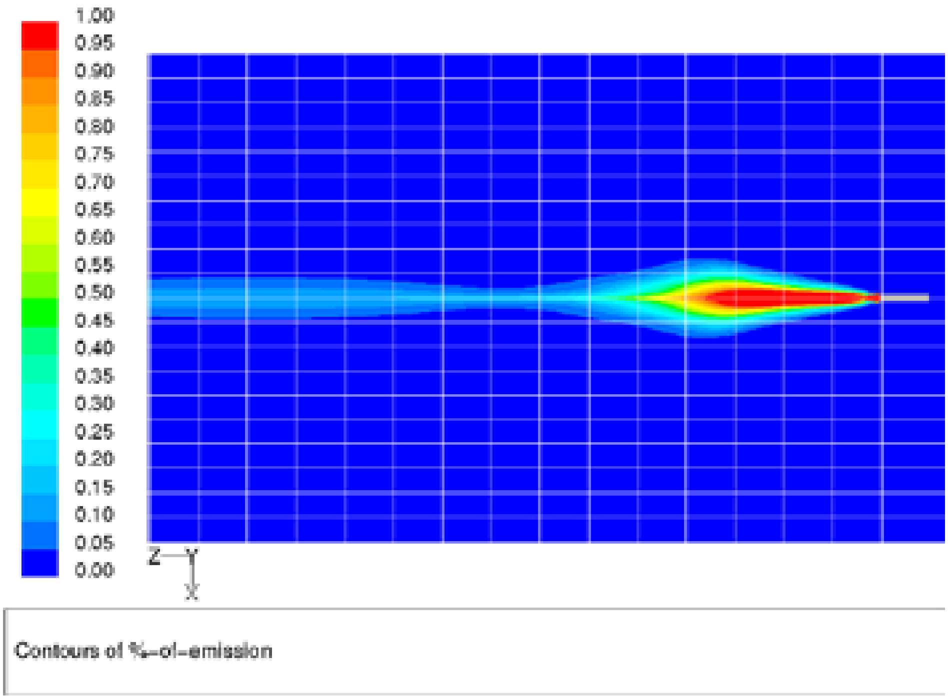


Figure 40. **Example of GLC contour plot (run 29) (horizontal grid lines (in the direction of wind movement) every 100m and vertical grid lines (perpendicular to wind movement) every 50 m)**

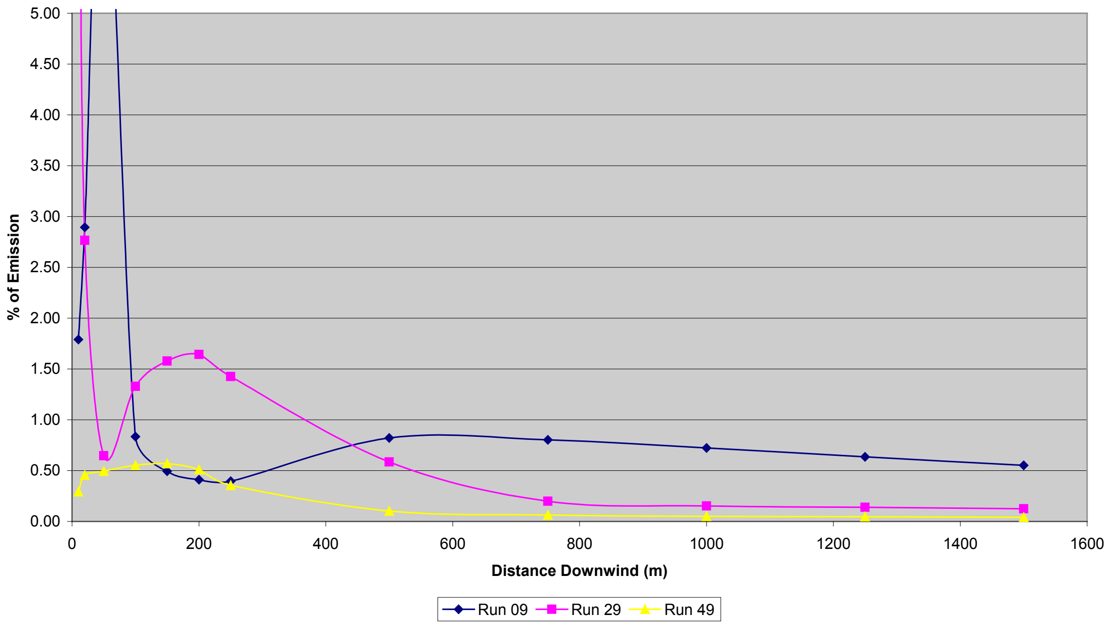


Figure 41. Examples of centreline GLC chart (runs 9, 29 & 49)

Results

Trial A – Tracer gas release from a windbreak wall

Tracer gas concentration in the sorbent tubes

A tracer gas was released from a windbreak wall. An array comprising five sets of sampling equipment (sorbent tubes and vacuum sampling pumps) was established downwind in a neighbouring property to sample tracer gas in the air. Unfortunately, this sampling event was plagued by numerous equipment malfunctions and failures. Of the five vacuum pumps being used:

- two operated continuously for the entire sampling period (240 minutes);
- two stopped on several occasions, leading to a reduced sampling duration and uncertainty regarding the sampling period; and
- one pump operated for most of the sampling period but was found to have stopped due to a flat battery some time before the end of the sampling period. It was believed that the pump operated to within about 15 minutes of the complete sampling period (225 minutes total instead of 240 minutes).

No explanation was identified for why the pumps failed to operate continuously throughout the trial. Prior to the gas release, all of the pumps were fitted with a flow calibration tube (a sorbent tube similar to the ones used in the trial but not used for analysis) and operated for the same period of time as was expected during the tracer gas release (four hours). All pumps functioned perfectly during this pre-trial test and calibration. The pump batteries were then recharged for use during the trial. The provider of the pumps could not explain why the pumps had failed either. It was suggested that the pumps may have stopped due to interference by radio waves (eg. from hand held UHF radios used during the trial), condensation on the pumps, or by condensation that accumulated in the sorbent tubes causing them to become blocked.

The sorbent tubes corresponding to the two pumps that continuously stopped throughout the sampling period were excluded from further analysis due to uncertainty of the amount of air drawn through the tube. The remaining sorbent tubes were sent to a laboratory for analysis. The quantity of SF_6 detected in the tubes was below the detection limit of the analysis technique and analysing equipment.

Atmospheric dispersion modelling

Calpuff was used to model the tracer gas release. This modelling was undertaken in an attempt to explain why no SF_6 was detected in the sorbent tubes. Figure 42 is the Calpuff output for the tracer gas release period. It is evident from this output that the majority of the tracer gas plume did not move directly toward the sampling array, instead moving south of it. The average concentration of tracer gas at the sampling points (indicated by purple triangles) should, however, have been sufficient to allow detection in the sampling tubes. It is unclear as to why the analytical method failed to detect any SF_6.

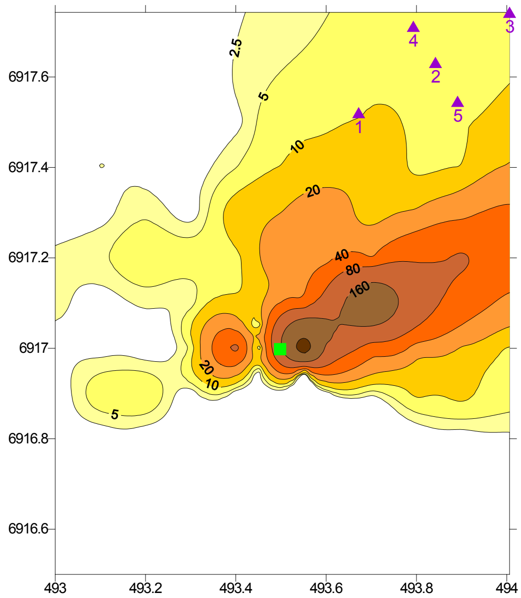


Figure 42. Calpuff prediction of ground level concentration of SF_6 during *Trial A* tracer release

Post-release analysis of wind conditions

Wind data was analysed following the tracer gas release to explain why tracer gas was not detected on the tubes. Historical data for the sampling period (0300–07:00) for the seven days prior to the tracer release (Figure 43) showed that the prevailing wind blew from the west-southwest (heading toward east-northeast). The wind continued to blow in this direction on the sampling day (Figure 44) indicating that the sampling array was positioned too far to the north (in a direction to the north-east from the release point).

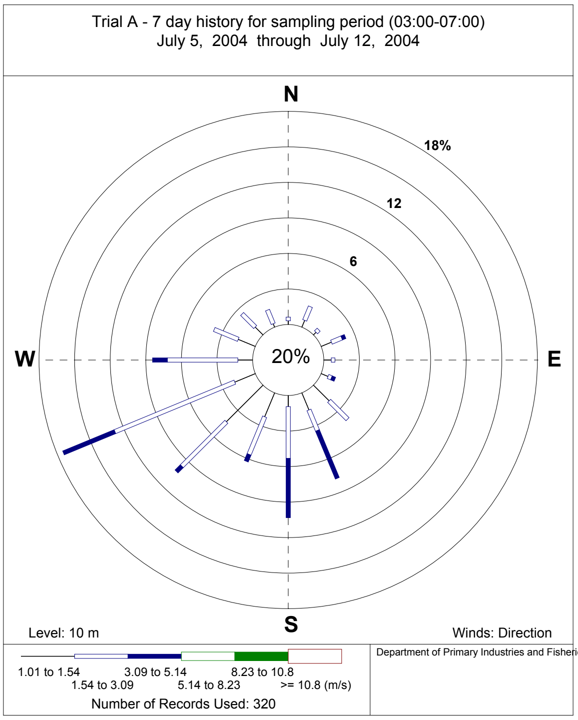


Figure 43. Seven day history of wind conditions prior to the sampling period

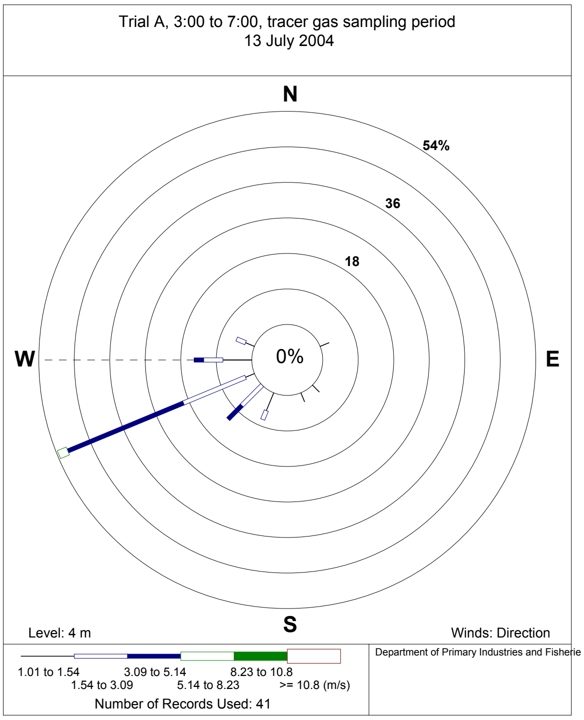


Figure 44. Wind rose during the actual tracer gas release period

Smoke release during the trial

At approximately 0615 on the morning of the tracer gas release, an orange hand smoke flare was activated within the windbreak wall to enable visualisation of the tracer gas plume (see Figure 45, Figure 46 and Figure 47). This smoke plume indicated that atmospheric conditions were stable (neutral to stable as calculated by the stability class spreadsheet program) and therefore resisted vertical mixing. It is important to highlight that the temperature of the air exiting the building was equal to the ambient air temperature and therefore was not subject to buoyant plume rise. Figure 46 shows that the smoke plume returned to the ground approximately 30 m to 50 m from the windbreak wall, only rising to go over the neighbouring poultry building. In Figure 47, the smoke returned to the ground and continued to travel in an east-northeast direction. Whilst observing the smoke move into the distance, it was obvious that horizontal dispersion of the plume was also extremely limited, and for the time that the smoke was visible, completely missed the sampling array.

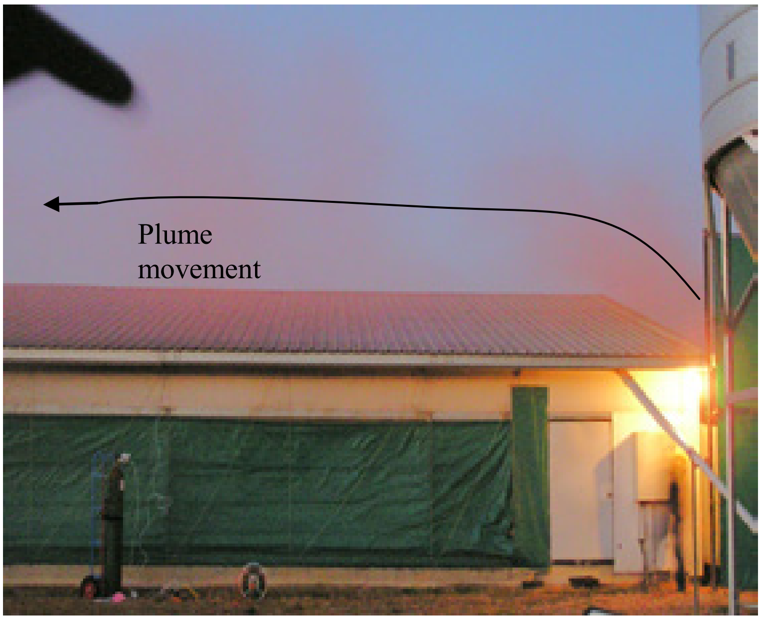


Figure 45. Smoke release from windbreak wall at daylight looking toward the poultry building fitted with the windbreak wall

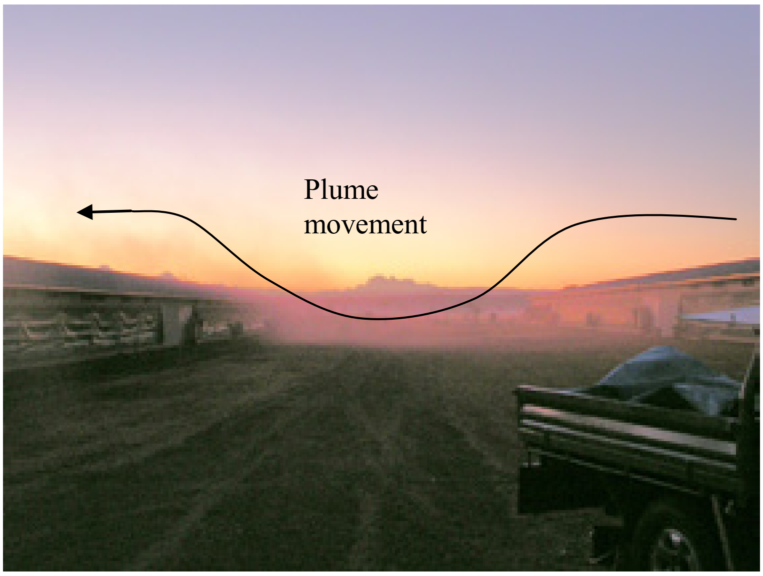


Figure 46. Smoke release from windbreak wall at daylight looking between two of the poultry buildings

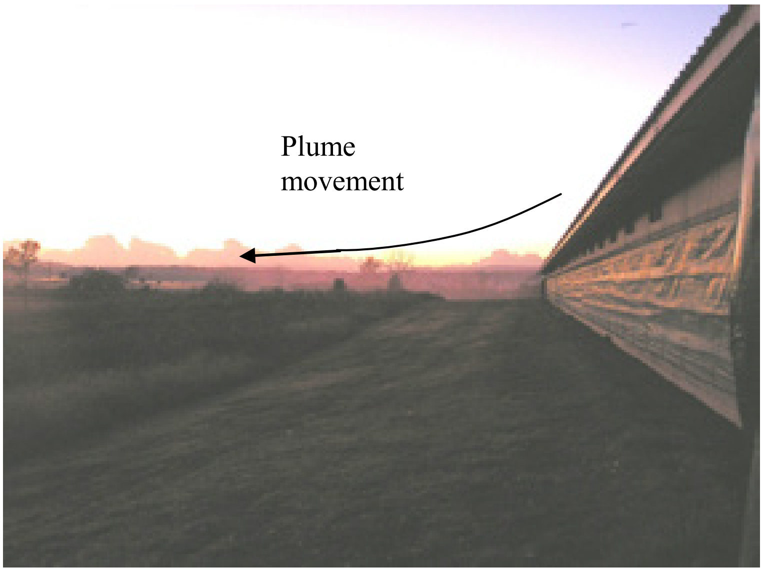


Figure 47. Smoke release from windbreak wall at daylight looking toward ENE of the windbreak wall

Summary of results for Trial A

From the post trial analysis of wind conditions and atmospheric dispersion (using Calpuff) it appeared that the sampling array was not in the correct position to sample the tracer gas. The sampling array was located according to preliminary atmospheric dispersion modelling (using historical weather data) rather than weather information at the time of the release. The incorrect placement of the sampling array was compounded by the limited horizontal dispersion exhibited during the smoke release. This meant that the sampling array would need to be placed in the direct path of the plume to be effective. A recommendation from this field trial was that the project team should make on-site weather observations at the time of the tracer release as a basis for locating the sampling grid.

Trial B – Micro scale tracer gas release from a small stack

Trial B was primarily undertaken to confirm that the tracer gas methodology could be successfully used to measure dispersion of an odorous plume. As such, it was undertaken in a flat, unobstructed area (to eliminate terrain influences). The tracer gas was released from a small stack (because Ausplume is most suited to modelling stack releases). A sampling array comprising eight sampling points (Figure 48), each with a sorbent tube and vacuum sampling pump, was positioned according to dispersion modelling (Figure 32), up to date weather observations (Figure 49) and onsite observations using a windvane and smoke (Figure 50).

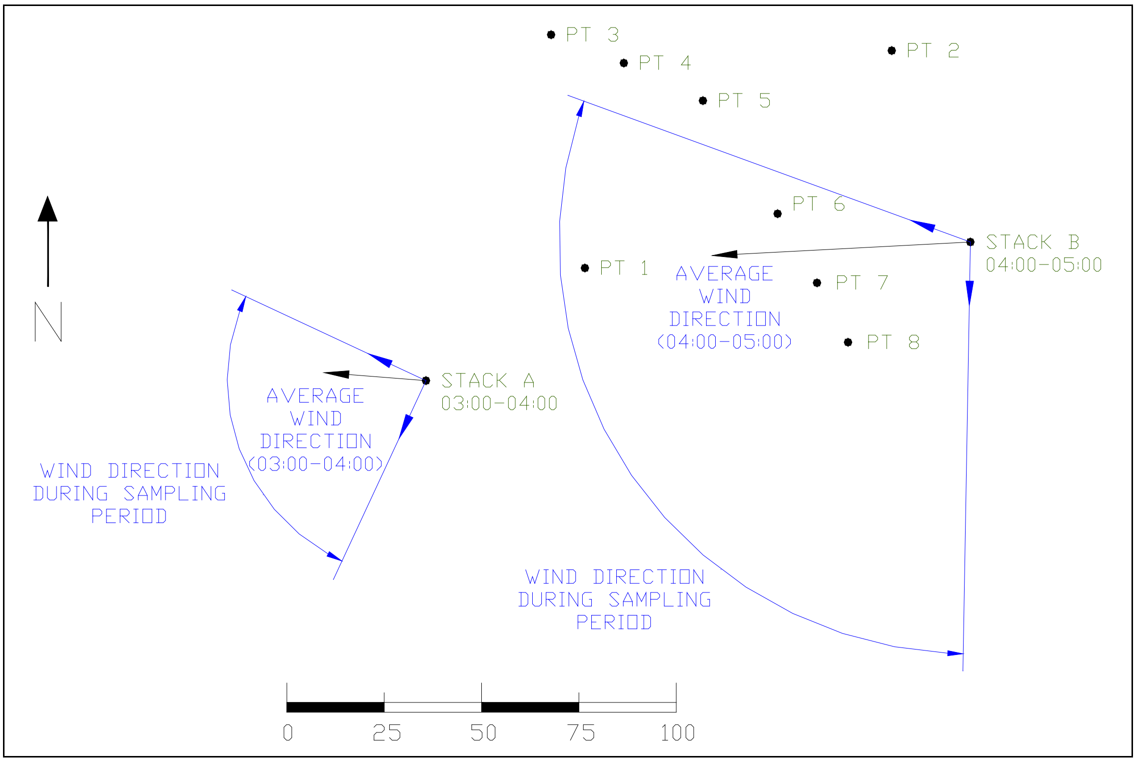


Figure 48. Location of release stacks and sampling locations for *Trial B*

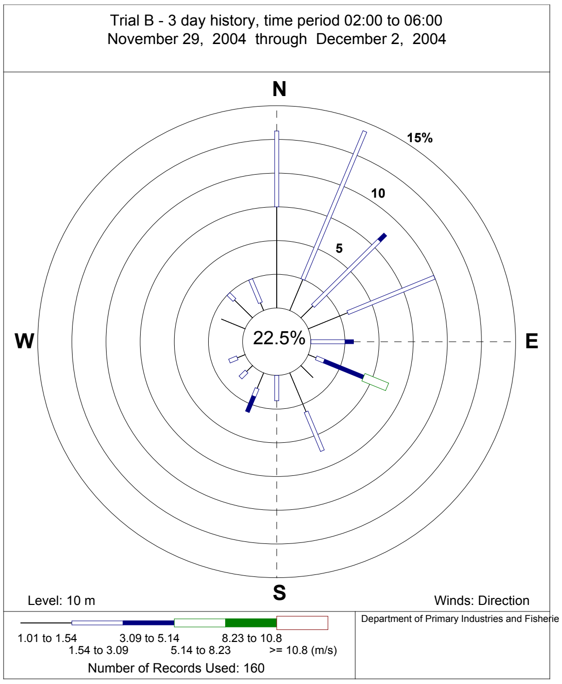


Figure 49. Three day history of wind conditions prior to the sampling period

Figure 50. Wind vane used to determine on-site wind direction

During *Trial B*, the sampling pumps operated flawlessly throughout the trial. None of the problems experienced with the sampling pumps during *Trial A* occurred during *Trial B*.

Unfortunately, despite extra precautions being taken, local wind conditions fluctuated wildly throughout the tracer release period. These fluctuations caused significant complications during the tracer gas release and reduced the effectiveness of this trial.

Post analysis of wind conditions

(Note: see Figure 48 for stack and sampling array positioning and Figure 51 for wind recordings by the weather station during *Trial B* tracer gas release.)

On arrival at the sampling site (approximately 0105–0110), the project team assessed that the wind was blowing from the southwest. The stack was erected (*stack A*) at 0115–0130 and smoke was released in order to confirm the wind direction. The sampling array was then organised to suit the wind direction and the vacuum sampling pumps and sorbent tubes were calibrated to ensure the correct sampling rate. The tracer gas release was planned to begin at 0300.

Just prior to the tracer gas being released, the wind eased and the direction shifted toward the east. It was decided by the project team to begin the tracer release (using a SF_6 flow rate of 100 mL/min), hoping that the wind direction would return to the southwest. A shift in the wind direction did not occur! At 03:30, after 30 minutes of the wind blowing the tracer gas in the opposite direction from the sampling tubes, it was decided to move the release stack (to *stack B*) so that the tracer gas plume would make contact with at least some of the sample tubes. Changing the position of the release stack would not affect the measured concentration because the SF_6 plume from *stack A* was nowhere near the sampling tubes. Due to the shortened exposure time (now only 1 hour), the tracer gas release rate was doubled to 200 mL/minute. Tracer gas was released from stack B (Figure 48) between 0400 and 0500. The wind direction remained reasonably constant during this period of time.

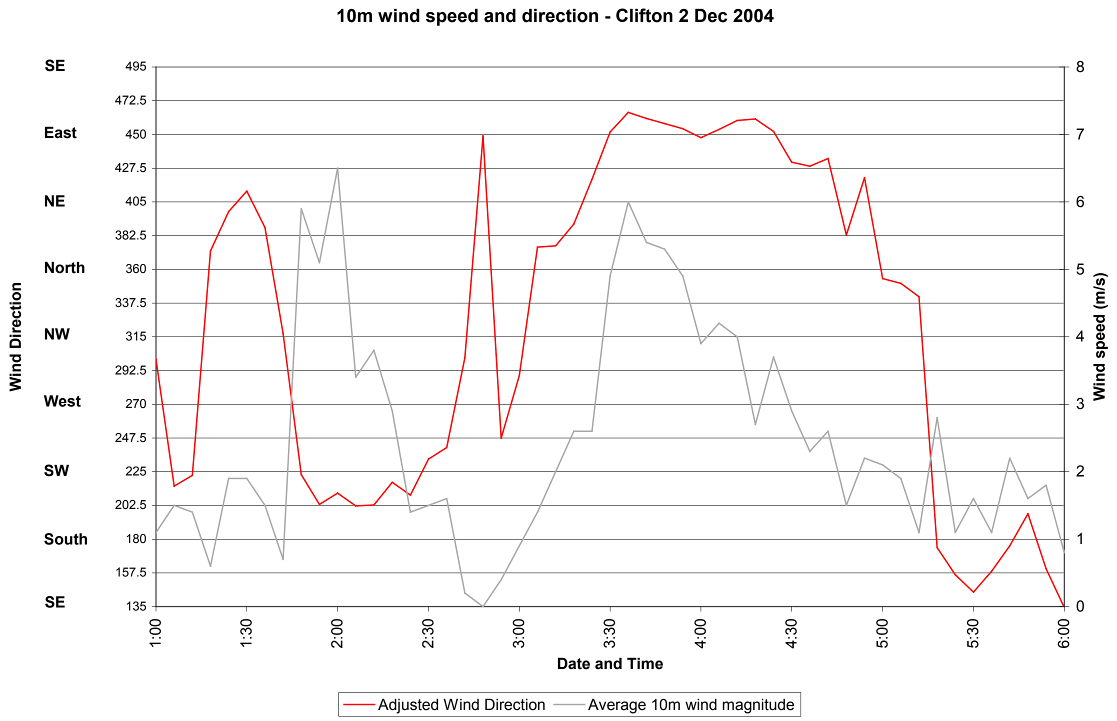
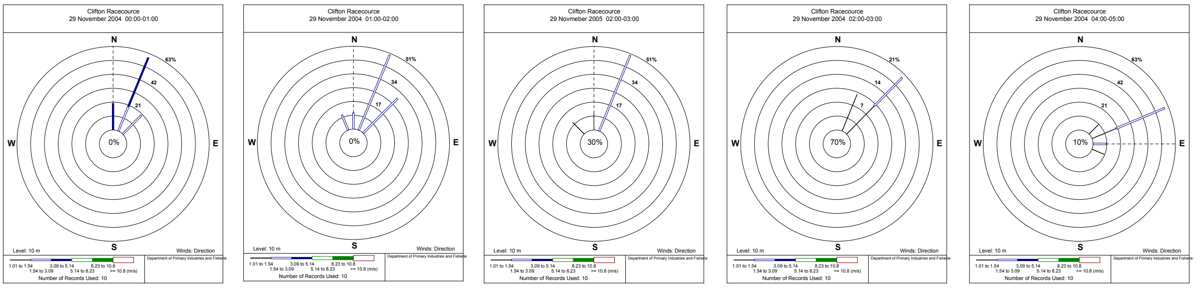


Figure 51.Wind speed and direction measured by 10 m onsite weather station

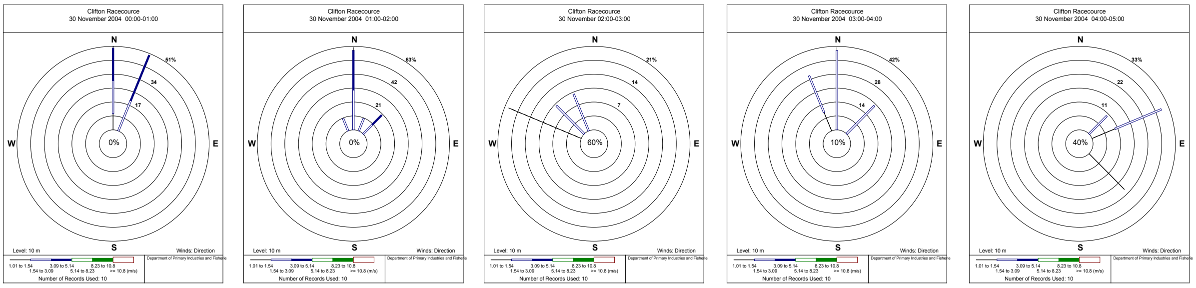
Figure 48 displays the position of the tracer gas release, and the range of wind directions recorded during the release period (arrows show the direction of wind movement, not the origin of the wind as is the usual convention). For *stack B*, the wind blew from north to east-southeast, with a vector averaged wind direction of 88° (east).

Extreme changes in wind direction experienced during the sampling period (as indicated in Figure 51), were not expected at the Clifton site. For the three days prior to the tracer gas sampling day, wind direction remained fairly constant for the period between 0000 (midnight) and 0500 (see Figure 52). Some natural fluctuation did occur, but no dramatic changes in wind direction were evident. This contrasts strongly with the sampling day (2 December 2004, Figure 52), when two distinct changes in wind direction occurred.

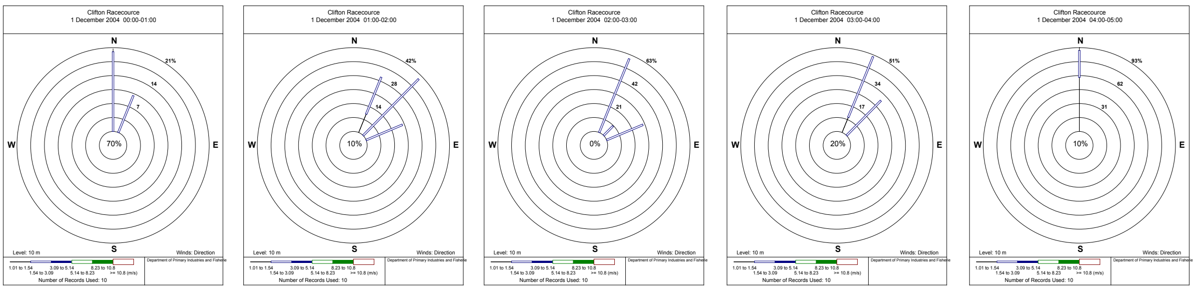
29 November 2004



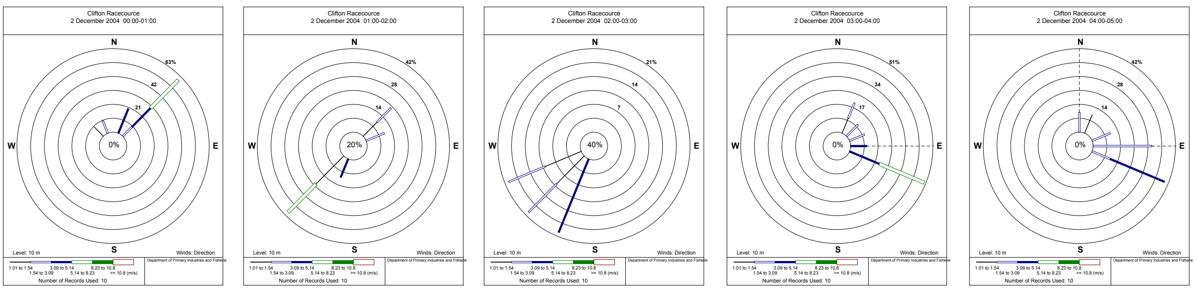
30 November 2004



1 December 2004



2 December 2004 (sample day)



0000–0100 **0100–0200** **0200–0300** **0300–0400** **0400–0500**

Figure 52. One hourly wind roses for 0000–0500 time period on the sampling day and three days prior

Atmospheric dispersion modelling

Ausplume was used to model the dispersion of tracer gas from *stack B* (Figure 48). Dispersion of tracer gas from *stack A* was not undertaken because the wind blew the tracer gas away from the sampling tubes. The Ausplume output for the tracer gas release from *stack B* is displayed in Figure 53. It can be seen that three of these tubes should have trapped a measurable amount of tracer gas.

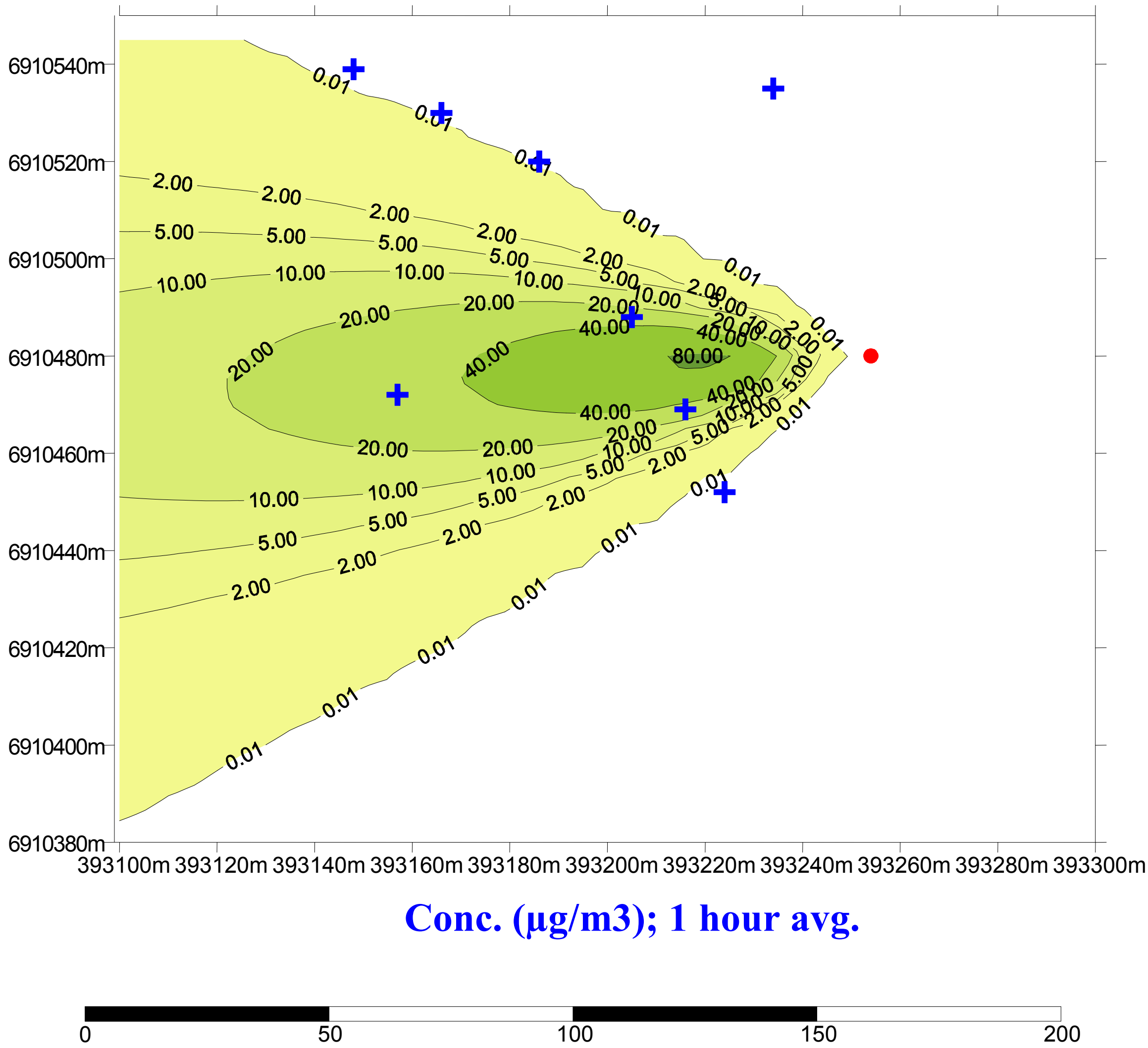


Figure 53. Ausplume output for tracer gas release from *stack B, Trial B*. Red dot indicates the stack and the blue crosses indicate sampling positions.

Tracer gas concentration in the sorbent tubes

Ten sorbent tubes were used to collect tracer gas during *Trial B*. Eight of these were arranged in the sampling array. The ninth was used to measure the SF_6 concentration in the stack (short duration sample). The tenth tube was used as a travel blank. The analysis results and corresponding ambient average concentration of SF_6 gas are shown in Table 3.

Table 3 Results from sampling tubes

Sampling location (see Figure 48)	Mass of SF_6 per tube (ng)	Average SF_6 concentration (µg/m³)
1	1 ng/tube	0.083
2	3 ng/tube	0.25
3	1 ng/tube	0.083
4	below limit of detection	-
5	below limit of detection	-
6	below limit of detection	-
7	below limit of detection	-
8	below limit of detection	-
9 – Stack B (200 mL/min SF_6)	> 6100 ng/tube	> 506
10 – blank	below limit of detection	-

Comparison between dispersion modelling prediction and measured tracer gas concentration

The ambient concentrations predicted by Ausplume were compared with the tracer gas concentrations measured using the sorbent tubes. The results of this comparison are displayed in Table 4. There are substantial differences between the predicted and measured concentrations of tracer gas.

Table 4 Comparison of measured and modelled airborne concentration values of SF_6

Sampling location (see Figure 48)	Tracer gas (µg/m³)	Ausplume output (µg/m³)
1	0.083	31.8
2	0.25	0
3	0.083	0
4	0	0
5	0	0
6	0	0.297
7	0	30.7
8	0	0

The measured tracer gas concentration for sampling location two (Table 4) was unexpected. According to the six minute averaged weather data, the wind never blew in the direction of the sampler (Figure 48). The Ausplume output (based on this weather data) likewise suggested that sample location two should not have been exposed to the tracer gas. Reasons for the difference between the predicted concentrations (using modelling) and the measured concentrations (from the sorbent tubes) were unclear.

Smoke release to visualise plume movements

Smoke was used on several occasions during *Trial B* to observe the direction and shape of the tracer gas plume. Figure 54 shows the shape and direction of the exhaust gas plume at 0410. The locations of the sorbent tubes were marked using green cyalume sticks. It can be seen (using the visible portion of the plume) that the exhaust air kept low and only slightly dispersed in both horizontal and vertical directions.

Figure 54. Image of smoke plume size and direction (from stack B), time 0410

A smoke flare was used at daybreak (0450) to demonstrate the dispersion of the exhaust plume exiting the stack. This smoke release is shown in Figure 55. It can be seen that the plume kept low and resisted dispersion. The smoke made contact with the ground within twenty metres of the stack. The stability class spreadsheet indicated that atmospheric stability was neutral when the smoke was released.

Figure 55. Time sequence showing the smoke plume downwind from stack B (0450)

Summary of results for Trial B

Trial B was plagued with fluctuating wind directions and speeds that required the tracer gas release stack to be repositioned half way through the release period. The tracer sampling was restarted once the stack was repositioned. Ausplume predictions of tracer gas concentrations indicated that tracer gas should have been detected in some of the sorbent tubes when they were analysed. Some of the sorbent tubes had trapped some tracer gas, but the quantity of tracer gas was low and was detected on tubes that should have been free of the tracer gas.

The intricacies of actual plume movement appeared too great for either Ausplume of Calpuff due to their long averaging periods (1 hour resolution for weather data inputs). Neither model was able to predict real air movements and plume dispersion with precision on a fine time scale.

Smoke observations confirmed the shape and direction of the tracer gas plume. The narrowness of the plume confirmed that accurate placement of the sampling array and steady wind conditions were required for the tracer gas method to be successful.

Combined with the findings from *Trial A*, it was clear that fluctuating winds, malfunctioning equipment and incorrect placement of the sampling array prevented success with the tracer gas methods. Smoke observations appeared to provide some useful information with relation to the movement and spread of the exhaust plumes. For these reasons, tracer gas methods were discontinued in favour of undertaking smoke releases.

Trial C – Smoke observations from a constructed windbreak wall

Smoke releases were undertaken during *Trial C* to provide visual evidence of windbreak wall performance. Smoke observations (using photography and video footage) were combined with weather information to provide an understanding of how windbreak walls influence dispersion under a range of conditions. Smoke observations were carried out on a poultry building fitted with a windbreak wall (will be referred to as the ‘windbreak wall’) as well as an identical building without a windbreak wall (will be referred to as the ‘control’).

Behaviour of poultry building exhaust plumes

The poultry buildings were fitted with eight fans on the end of the building. The number of active fans could be manually controlled, however ambient temperatures and bird age determined the number of active fans in order to prevent chilling or over-heating of the birds. During the period of the smoke releases, bird age was 25–40 days and ambient temperatures were 2.7–25.3 °C (average 13 °C). During most of the smoke releases, one or two fans were active. The low number of active fans enabled dense, concentrated smoke to be released at these fans. If more fans were active, dilution of the smoke (by sharing the same amount of smoke across more active fans) reduced visibility of the plume as it moved downwind.

The windbreak wall formed a barrier to the natural movement of the exhausted air as it was designed to do. When low numbers of fans were active, exhausted air tended to swirl and mix within the windbreak wall prior to being emitted (see Figure 58). This mixing may be insignificant for a continual process such as odour emission (compared to the short, intermittent release of smoke) because the mixing air within the windbreak wall will be odorous and will not significantly dilute the odours being emitted from the building. It was important to be aware of this mixing because the smoke often appeared less dense when exiting the windbreak compared to the control, potentially leading to an incorrect assumption that the air exiting the windbreak wall was already significantly diluted.

Air was exhausted horizontally from the control (see Figure 57) at 6–10 m/s depending on the fan specifications and wind influences. Conversely, air was exhausted vertically from a windbreak wall, it moved in a vertical direction (see Figure 56) and appeared to have a lower velocity (resulting from friction, turbulence, mixing of the air and a larger cross-sectional area).

Windbreak wall and control exhaust plumes were often intercepted by cross winds. As cross wind speeds increased, there was a decrease in the amount of vertical rise from the windbreak wall or horizontal travel from the control. Increasing crosswind speed appeared to reduce the effectiveness of the windbreak wall in forcing the exhaust plume to rise.

Figure 56. Vertical smoke movement from the windbreak wall (low crosswind speed)

Figure 57. Horizontal smoke movement from the control (low crosswind speed)

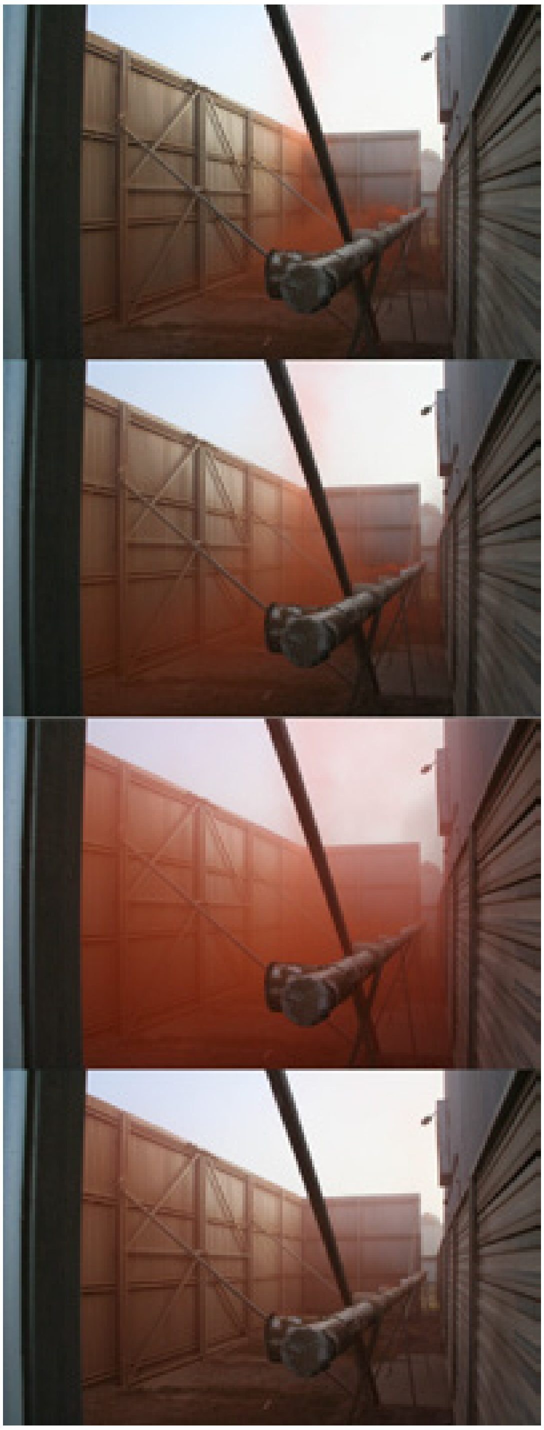


Figure 58. Mixing of smoke within the windbreak wall

In order to photograph poultry exhaust plumes under stable conditions, smoke observations were undertaken at night. Weather conditions at night are generally different to those during the day, with calmer winds and lower temperatures. Cooler ambient temperatures created a larger temperature difference between the poultry building exhaust air and the outside air, with the exhausted air being warmer (see Figure 59). This warmth causes the exhaust plume to naturally rise once outside the building. Significant plume rise was often observed during the smoke releases. Plume rise was most obvious during very calm conditions.

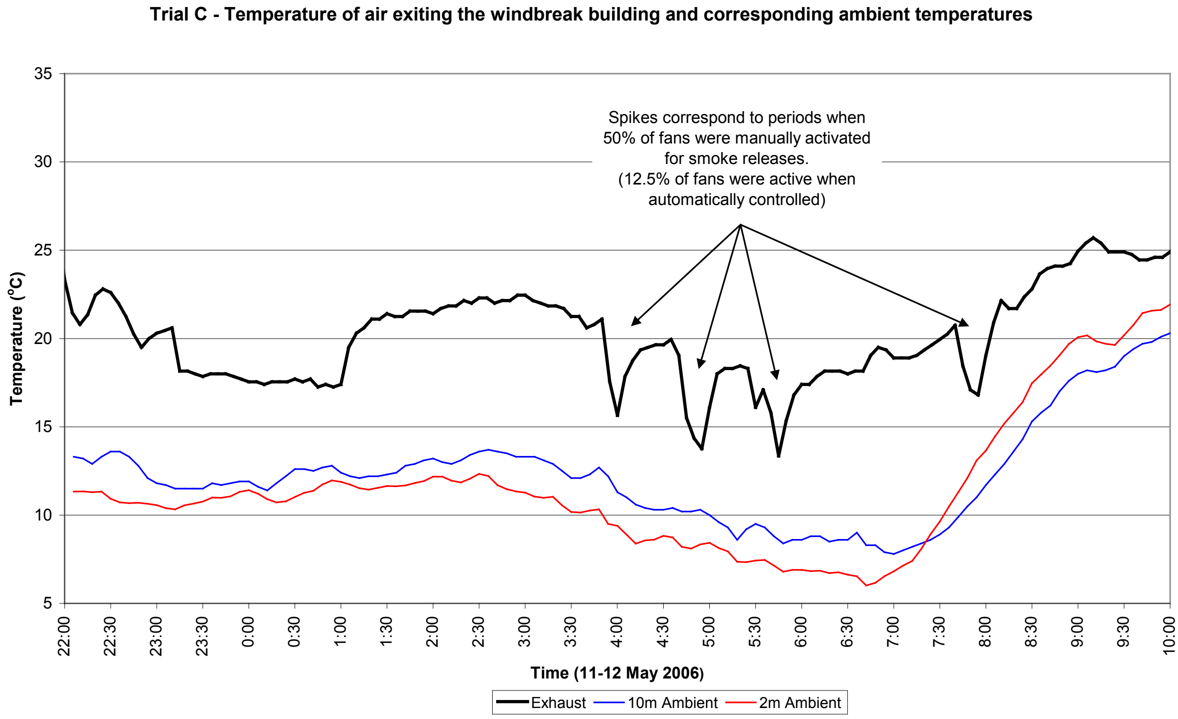


Figure 59. Temperature of air exiting the windbreak wall (measured at the exhaust fans) compared to ambient temperatures

Smoke observations during stable atmospheric conditions

Stable atmospheric conditions occur mostly at night (an hour before sunset to an hour after sunrise) and are characterised by limited dispersion. Under these conditions, plumes will resist vertical mixing and dispersion and may travel significant distances in a largely undiluted state. Figure 62 to Figure 69 show a series of photographs depicting the movement of smoke plumes from the control and windbreak wall. These figures have been paired to provide a comparison between the control and windbreak wall.

Weather data recorded at the time of the smoke releases is noted in the captions for these figures. These weather recordings are six minute averaged data and therefore do not accurately describe fluctuations in wind speed or direction at the exact time of the smoke release.

Description for Figure 60 and Figure 61

The smoke releases shown in Figure 60 and Figure 61 took place during stable atmospheric conditions. The temperature of the exhaust air was not measured on this occasion but was expected to be between 15 °C and 23 °C because there were approximately 35,000 (34 day old) birds in each of the growing buildings. Cool ambient temperatures (approximately 4.5 °C) created a significant temperature difference between the exhausted air and outside air. Consequently, the smoke plumes demonstrated vertical rise (to approximately 16 m in height) from both the windbreak wall and the control due to thermal buoyancy. The smoke plume emitted from the control appeared to remain in contact with the ground and demonstrated vertical mixing for a short period of time . On the other hand, the smoke plume emitted from the windbreak wall appeared to be higher off the ground and denser at the top of the plume. The windbreak wall therefore demonstrated greater dispersion compared to the control, which may result in lower ground level concentrations downwind of the windbreak wall.

Figure 60. Smoke release from control (0203 4/5/06, stable conditions, 1.7 m/s wind speed, ambient temp 4.7 °C, 1 fan active)

Figure 61. Smoke release from windbreak wall (0159 4/5/06, stable conditions, 1.7 m/s wind speed, ambient temp 4.5 °C, 1 fan active)

Description for Figure 62 and Figure 63

The smoke releases shown in Figure 62 and Figure 63 took place during stable atmospheric conditions. The temperature of the exhaust air was not measured on this occasion but was expected to be between 15 °C and 23 °C because there were approximately 35,000 (34 day old) birds in each of the growing buildings. As with Figure 60 and Figure 61, significant vertical mixing and movement was observed and was most likely due to thermal buoyancy of the exhausted plume. When the smoke flare was activated at the control (Figure 62), the wind momentarily eased, allowing significant vertical rise very close to the poultry building. Wind speed was more constant when the smoke was released from the windbreak wall. It can be seen that the smoke plume exiting the windbreak is less dense. This could be due to the mixing of the smoke within the windbreak wall (previously explained and shown in Figure 58) or the flare used on the windbreak wall may have been faulty and produced less smoke. The similarity in size, shape and position of the smoke plumes at the bottom of both Figure 62 and Figure 63 indicate that the windbreak wall did not significantly improve dispersion of the exhaust plumes. Vertical rise due to buoyancy appeared to mix and disperse the control plume to such an extent that the effect of the windbreak wall was insignificant.

Figure 62. Smoke release from control (0424 4/5/06, slightly stable conditions, 1.8 m/s wind, ambient temp 2.8 °C, 1 fan active)

Figure 63. Smoke release from windbreak wall (0426 4/5/06, slightly stable conditions, 1.9 m/s wind, ambient temp 2.6 °C, 1 fan active)

Description for Figure 64 and Figure 65

The smoke releases shown in Figure 64 and Figure 65 took place during stable atmospheric conditions. The wind speed at the time of the windbreak wall smoke release (Figure 65) was higher than for the control smoke release (Figure 64) which caused slightly greater horizontal spread of the plume. Downwash was exhibited during the windbreak wall smoke release, drawing the smoke immediately down to ground level. Despite the differences in wind speed, other conditions were similar for these two smoke releases and therefore the two situations were compared. Figure 64 and Figure 65 show that as the smoke plumes moved away from the poultry buildings, they were similar in size and shape and therefore it is unlikely that the windbreak wall significantly improved dispersion of the exhaust air.

Figure 64. Smoke release from control (0052 12/5/06, stable conditions, 1.2 m/s wind, ambient temp 12.2 °C, 2 fans active, exhaust temp 17 °C)

Figure 65. Smoke release from windbreak wall (0048 12/5/06, stable conditions, 2.5 m/s wind, ambient temp 12.4 °C, 2 fans active, exhaust temp 17 °C)

Description for Figure 66 and Figure 67

The smoke releases shown in Figure 66 and Figure 67 took place during stable atmospheric conditions. Wind speed eased at the start of the windbreak wall smoke release, allowing the plume to initially rise. When the wind speed increased, the plume moved horizontally and downwash was apparent at the windbreak wall. Due to the slight initial rise, the windbreak smoke plume appeared to have more vertical movement than the control. As the smoke continued to travel away from the poultry buildings (bottom of Figure 66 and Figure 67), the size, shape and position of the plumes appear similar. This indicated that the windbreak wall did not significantly increase the dispersion of the exhaust plume compared to the control.

Figure 66. Smoke release from control (0115 12/5/06, stable conditions, 1.5 m/s wind, ambient temp 11.9 °C, 1 fan active, exhaust temp 20 °C)

Figure 67. Smoke release from windbreak wall (0132 12/5/06, stable conditions, 1.8 m/s wind, ambient temp 12.0 °C, 2 fans active, exhaust temp 22 °C)

Description for Figure 68 and Figure 69

The smoke releases shown in Figure 68 and Figure 69 took place during very stable conditions. Wind conditions were very still during the control smoke release. For the windbreak smoke release, the wind was still to begin with (indicated by initial rise) then increased. Consequently, the windbreak smoke plume rose vertically to a greater extent than the control smoke plume. As the smoke plumes moved away from the poultry buildings, they flattened out and dispersed horizontally. The vertical depth of the windbreak wall plume was greater than that of the control due to the greater initial vertical mixing. During this instance, there may have been greater mixing and dispersion of the windbreak wall smoke plume, however, this may be solely due to the initial vertical smoke movement. It is difficult to conclude in this case whether or not the windbreak wall would have improved dispersion to such an extent as to prevent downwind odour nuisance (assuming that odour nuisance would occur without the windbreak wall).

Figure 68. Smoke release from control (0332 12/5/06, very stable conditions, 0.2 m/s wind, ambient temp 11.2 °C, 1 fan active, exhaust temp 21.1 °C)

Figure 69. Smoke release from windbreak wall (0322 12/5/06, very stable conditions, 0.9 m/s wind, ambient temp 11.5 °C, 1 fan active, exhaust temp 21.7 °C)

Smoke releases at dawn

Smoke releases were undertaken during stable conditions at dawn and are shown in Figure 70 and Figure 71. The smoke released from the control indicated that buoyancy created substantial mixing. The smoke plume remained in contact with the ground and spread horizontally over a large area. The wind speed eased at this point and the smoke plume lingered for several minutes. It is possible that the smoke plume was trapped below a temperature inversion layer that prevented it from mixing vertically. The smoke released from the windbreak wall rose and travelled as an intact plume well above the ground for some distance, possibly indicating that the plume was forced above a temperature inversion layer that prevented it from returning to ground level. It remained visible for a significant distance downwind (visible in the tree line at the bottom of Figure 71).

From the smoke releases in Figure 70 and Figure 71, it is evident that, the windbreak wall had a significant influence on the movement of the plume. The windbreak smoke plume remained intact and resisted dispersion whereas the control smoke plume spread widely and dispersed. For a very close receptor, the windbreak wall may have reduced odour nuisance in this situation by propelling the odour plume upward. It did however seem to resist dispersion, which may result in the odour plume being higher in concentration than if it had been in contact with the ground and subjected to turbulent mixing due to surface friction and landscape features. It is therefore unclear whether the windbreak wall would have prevented a situation of odour nuisance, or simply transferred the potential for odour nuisance further away.

Figure 70. **Smoke release from control at dawn (0626 4/5/06, stable atmospheric conditions, 0.22 m/s wind speed, 2.2 °C ambient temp)**

Figure 71. **Smoke release from windbreak wall at dawn (0634 4/5/06, stable atmospheric conditions, 0.5 m/s wind speed, 2.2 °C ambient temp)**

Summary of smoke releases during stable atmospheric conditions

Several smoke releases were conducted during stable atmospheric conditions from the windbreak wall and the control. These smoke releases were carried out under a variety of wind and temperature conditions. For the majority of situations when smoke was released and photographed, there was no discernable difference in the dispersion, density or movement of the smoke plumes exhausted from the windbreak wall or the control.

The smoke releases displayed in Figure 64 to Figure 69 appeared less buoyant compared to the smoke releases shown in Figure 60 to Figure 63. This was due to slightly warmer ambient temperatures and lower exhaust temperatures due to lower bird numbers (10,000 birds per building compared to 35,000, aged 34–42 days). It appeared that buoyancy of the exhaust plume was important for improving mixing and dispersion of poultry building exhaust under cool, stable conditions.

When the atmosphere was stable, it is unlikely that the windbreak wall would have enhanced dispersion of the exhausted plume to such an extent that it would significantly reduce the concentration of the plume downwind. In other words, if a nearby receptor was experiencing odour nuisance from a broiler farm during stable conditions, it is unlikely that the installation of a windbreak wall would reduce the frequency or level of annoyance.

Smoke observations during neutral atmospheric conditions

Neutral atmospheric conditions most commonly occur during the day when solar radiation is low to moderate (such as on cloudy days, early morning and late afternoon) or at night when the wind speed is moderately high. Under these conditions, plumes will tend to travel horizontally and the rate of dispersion will be moderate.

Average (6 minute) weather data recorded at the time of the smoke releases by the weather station are noted in the captions for these figures. Atmospheric stability during the smoke releases was calculated using the stability class spreadsheet.

Only a few smoke releases were undertaken during absolutely neutral atmospheric conditions. Some smoke releases were undertaken when the atmosphere was neutral tending to stable, or neutral tending to unstable.

Description for Figure 72 and Figure 73– neutral tending to stable conditions

The smoke releases shown in Figure 72 and Figure 73 were undertaken when the atmospheric stability was neutral tending to stable. The smoke release from the control showed that the smoke tended to stay low with limited vertical mixing. Thermal buoyancy of the exhaust plume would have been negligible due to warm ambient temperatures. As a result, the plume did not demonstrate much vertical movement. On the other hand, the smoke released from the windbreak wall was forced to rise due to upward momentum imparted by the wall. This upward movement as well as turbulence within the wall (explained earlier and shown in Figure 58) assisted the plume to move and disperse vertically above the wall. As the plume travelled away from the windbreak wall, it resisted further dispersion and further plume rise, with the smoke plume remaining visible for some distance. Visibility of the orange smoke was reduced against the late afternoon sky.

Under the conditions observed for these smoke releases, the windbreak wall assisted the smoke plume to mix and disperse vertically, which should have the effect of reducing the ground level concentration. This reduction in ground level concentration would likely exist for a reasonable distance (hundreds of metres) from the windbreak wall.

Figure 72. Smoke release from control (1716 3/5/06, neutral to stable atmospheric conditions, 2.0 m/s wind speed, 22.5 °C ambient temp, 3 active fans)

Figure 73. Smoke release from windbreak wall (1725 3/5/06, neutral to stable conditions, 2.1 m/s wind speed, 21.5 °C ambient temp, 4 active fans)

Description for Figure 74 and Figure 75 - neutral tending to stable conditions

The smoke releases shown in Figure 74 and Figure 75 were undertaken during neutral tending to stable atmospheric conditions. Lower ambient temperatures created greater thermal buoyancy compared with the other neutral stability smoke releases. Unfortunately, due to darkness, it was not possible to photograph these plumes as they travelled away from the poultry buildings. The smoke release from the control exhibited some vertical dispersion but remained in contact with the ground. The smoke release from the windbreak wall, however, displayed a similar amount of vertical mixing but tended to remain elevated off the ground. Higher and more consistent wind speed during the windbreak smoke release tended to extend the smoke plume horizontally.

As with the smoke releases shown in Figure 72 and Figure 73, it appeared that a similar amount of mixing and dispersion occurred with both the windbreak wall and control, but the windbreak wall smoke plume was elevated above the ground. This elevation would probably reduce ground level concentration for some distance down wind.

Figure 74. Smoke release from control (2140 3/5/06, neutral to stable atmospheric conditions, 1.5 m/s wind speed, 9.1 °C ambient temp, 1 active fan) (bottom image from opposing angle)

Figure 75. Smoke release from windbreak wall (2155 3/5/06, neutral to stable conditions, 1.8 m/s wind speed, 8.9 °C ambient temp, 1 active fan)

Description for Figure 76 and Figure 77 – neutral tending to unstable conditions

The smoke releases shown in Figure 76 and Figure 77 were undertaken when atmospheric stability was neutral tending to unstable. When smoke was released at the control, the smoke plume displayed some dispersion, but remained at ground height. When smoke was released from the windbreak wall, the plume initially rose due to upward momentum imparted by the windbreak wall. It then dispersed slightly but did not demonstrate significant vertical mixing. The plume remained elevated from the ground.

The size and shape of the plumes emitted from the control and the windbreak wall appeared similar, however, the plume from the windbreak wall appeared to remain elevated from the ground. This elevation would likely reduce ground level impacts very close to the wall, and then would reduce the ground level concentration downwind. It is unclear whether this would reduce odour impacts downwind because the control plume may experience additional mixing and dispersion (when compared to the windbreak wall plume) attributed to ground surface roughness.

Figure 76. Smoke release from control (0810 2/5/06, neutral atmospheric conditions, 1.4 m/s wind speed, 16.2 °C ambient temp, 2 active fans)

Figure 77. Smoke release from windbreak wall (0821 2/5/06, neutral to unstable atmospheric conditions, 1.5 m/s wind speed, 17.4 °C ambient temp, 2 active fans)

Summary of smoke observations during neutral atmospheric conditions

A limited number of smoke releases were undertaken during neutral atmospheric conditions. From these observations, it appeared that a similar amount of mixing and dispersion occurred with both the windbreak wall and control. A consistent difference between the two situations appeared to be elevation of the smoke plume being emitted from the windbreak wall. Elevation of the smoke plume would likely reduce ground level concentration close to the windbreak wall (compared with the control) and may reduce ground level concentrations further downwind.

Under neutral conditions, it appeared that the windbreak wall may reduce downwind concentrations of emitted odours. This observation was based on visual smoke observations, so it is unclear whether the predicted reduction in ground level concentration of odours would be sufficient to reduce potential odour impacts.

Smoke observations during unstable atmospheric conditions

Unstable atmospheric conditions most commonly occur on warm, fine, sunny days. These conditions are associated with strong atmospheric turbulence and maximum vertical mixing that rapidly disperse plumes. During unstable conditions, odours emitted from poultry buildings will rapidly disperse, typically reducing downwind ground level odour concentrations.

Numerous smoke releases were undertaken during unstable conditions. Visibility of the smoke decreased markedly as it travelled downwind from the poultry buildings due to increased dispersion. It was therefore difficult to see the size or position of the exhaust plumes as they travelled downwind from the sheds.

Description for Figure 78 and Figure 79

The smoke releases shown in Figure 78 and Figure 79 were undertaken during unstable atmospheric conditions. When smoke was released at the control building, the plume travelled along the ground for sixty to seventy metres before rising and dispersing. When smoke was released from the windbreak wall, the plume rose and rapidly dispersed.

In this situation, it appeared that the windbreak wall assisted the exhaust plume to rise quickly, where it then dispersed. Therefore, addition of a windbreak wall may reduce potential odour impacts at downwind receptors under these conditions. Due to the limitations of smoke visibility at long range, it was unclear if any improvement would be experienced at long distances downwind.

Figure 78. Smoke release from control (1525 28/4/06, unstable atmospheric conditions, 0.7 m/s wind speed, 25.2 °C ambient temp, 5 active fans). In the bottom two images, the zoom remained the same but the camera was panned to the right

Figure 79. Smoke release from windbreak wall (1516 28/4/06, unstable conditions, 0.9 m/s wind speed, 25.6 °C ambient temp, 5 active fans)

Description for Figure 80 and Figure 81

The smoke releases shown in Figure 80 and Figure 81 were undertaken during unstable atmospheric conditions. The smoke plume released from the control began to disperse in the immediate vicinity of the building before rising and continuing to disperse at a distance approximately 50 m away. When smoke was released from the windbreak wall, a strong crosswind and building downwash forced the smoke to the ground before travelling approximately 50 m. The smoke then rose and rapidly dispersed.

The movement of the smoke plume shown in Figure 81 suggests that the windbreak wall did not offer any benefit when there was a strong crosswind. The smoke plume effectively travelled along the ground in much the same way as the smoke plume from the control (compare the second bottom images in Figure 81 and Figure 80). Therefore, in the situation presented in these figures, the windbreak wall appeared to provide no additional benefit from the control. Having made this statement, it is unlikely that a nearby receptor (at a distance of 100–150 m) would experience odour impact from either the control or windbreak wall because of plume rise and vertical mixing.

Figure 80. Smoke release from control (1035 2/5/06, unstable atmospheric conditions, 3.1 m/s wind speed, 22.9 °C ambient temp, 5 active fans)

Figure 81. Smoke release from windbreak wall (10:03 2/5/06, unstable conditions, 3.7 m/s wind speed, 22.7 °C ambient temp, 5 active fans)

Description for Figure 82 and Figure 83

The smoke releases shown in Figure 82 and Figure 83 were undertaken during unstable atmospheric stability conditions. Smoke released from the control travelled along the ground for approximately 80 m before rising and dispersing. Within these 80 m, the plume started to move and disperse vertically but remained in contact with the ground. Smoke released from the windbreak wall rose vertically before dispersing.

In the comparison displayed in Figure 82 and Figure 83, it would appear that the plume emitted from the windbreak wall dispersed much closer to the poultry building than it did for the control. With regard to odour impacts, the windbreak wall may assist in dispersing odours vertically. This vertical dispersion may reduce ground level odour concentrations, particularly close to the poultry buildings (within 150 m).

Figure 82. Smoke release from control (0803 10/5/06, unstable atmospheric conditions, 0.6 m/s wind speed, 8.8 °C ambient temp, 1 active fan)

Figure 83. Smoke release from windbreak wall (0912 10/5/06, unstable conditions, 1.8 m/s wind speed, 16.8 °C ambient temp, 2 active fans)

Description for Figure 84 and Figure 85

The smoke releases shown in Figure 84 and Figure 85 were undertaken under unstable atmospheric conditions. Smoke released from the control building was forced along the ground and then started to disperse and rise vertically after approximately 60 m. The plume then rapidly rose and dispersed. Smoke released from the windbreak wall rose vertically and dispersed.

Comparing the smoke releases pictured in Figure 84 and Figure 85, both smoke plumes rose and mixed vertically within a short distance from the poultry building. The plume emitted from the windbreak wall appeared to rise more quickly when compared to the control. This rapid rise may lead to lower ground level concentrations very close to the poultry buildings.

Figure 84. Smoke release from control (0755 12/5/06, unstable atmospheric conditions, 0.6 m/s wind speed, 12.7 °C ambient temp, 1 active fan)

Figure 85. Smoke release from windbreak wall (0800 12/5/06, unstable conditions, 0.7 m/s wind speed, 13.4 °C ambient temp, 4 active fans)

Summary of smoke observations during unstable atmospheric conditions

Numerous smoke releases were undertaken under unstable atmospheric conditions. Some of these are presented in Figure 78 to Figure 85. Observing and photographing smoke plumes during unstable conditions was challenging because the unstable conditions dispersed the smoke quickly and made it difficult to see. The maximum range for visualising smoke during unstable conditions was approximately 200 m.

With the exception of strong crosswind conditions (Figure 80 and Figure 81), the windbreak wall enhanced plume rise and plumes displayed immediate vertical mixing. On the other hand, smoke emitted from the control initially travelled along the ground for 60–80 m before rising and dispersing. When there were strong crosswinds, there was no appreciable difference in the dispersion of the smoke plumes emitted from either the windbreak wall or control.

In terms of reducing odour impacts from poultry buildings, it appears that windbreak walls could assist in reducing ground level odour concentrations under unstable conditions. However, significant atmospheric dispersion will occur under these atmospheric conditions from both the windbreak wall and control, and will tend to dominate the initial increase in dispersion that may be attributed to the windbreak wall.

Additional observations made during field trials

During the course of the field trials, observations indicated that there may be several potential benefits of using windbreak walls in addition to improving the dispersion of exhausted ventilation air. These observations included:

- dust accumulation within the windbreak wall;
- reduction in dustiness in the area in front of the ventilation fans;
- improved fan performance when strong winds were blowing into the ventilation fans (opposing the direction of normal fan flow); and
- preventing early morning or late afternoon sun from entering the shed through open fan shutters.

Dust accumulation within the windbreak wall

A layer of dust accumulated on the corrugated iron windbreak wall that was used during *Trial C*. Construction of this wall was completed on 27 April 2006, at which time the birds in the poultry building were approximately 28 days old. Five days following installation of the windbreak wall, a thin layer of dust was visible on the inside surface of the wall, with most of the dust concentrated directly in front of the minimum ventilation fan (see Figure 86). Fifteen days following installation of the windbreak wall, substantially more dust was attached to the inside surface of the windbreak wall (see Figure 87).

Accumulation of dust appeared greatest on the corrugated iron directly above each of the horizontal purlins. It is assumed that turbulent eddies and lower velocities in these areas allowed dust particles to become detached from the general airflow and settle on the wall.

A greater quantity of dust appeared to be deposited on the corrugated iron windbreak wall compared to the tarpaulin windbreak wall (see Figure 7). Dust might be less likely to remain attached to the tarpaulin wall due to flapping and movement of the tarpaulin material with wind action.

Figure 86. Dust on the windbreak wall after 5 days (photo taken on 2/5/06, birds aged 28 to 33 days during this period)

Figure 87. Dust on the windbreak wall after 15 days (photo taken on 12/5/06, birds aged 28 to 43 days during this period)

Reduction in dustiness in the area in front of the ventilation fans

Dust accumulated in the area in front of the ventilation fans on the control building (see Figure 88). This dusty area extended approximately 40 m from the fans. Dustiness was experienced when walking on the grass in this area because foot action disturbed the dust and make it airborne.

The area directly in front of the windbreak wall appeared to be considerably less dusty than the area in front of the control. One possible explanation for the reduction in dustiness is that larger dust particles accumulated within the windbreak wall (see Figure 87) while finer particles remained airborne and settled further away. This is in contrast with the control situation where the larger dust particles settled in front of the poultry building with the finer particles transported away with the exhaust air.

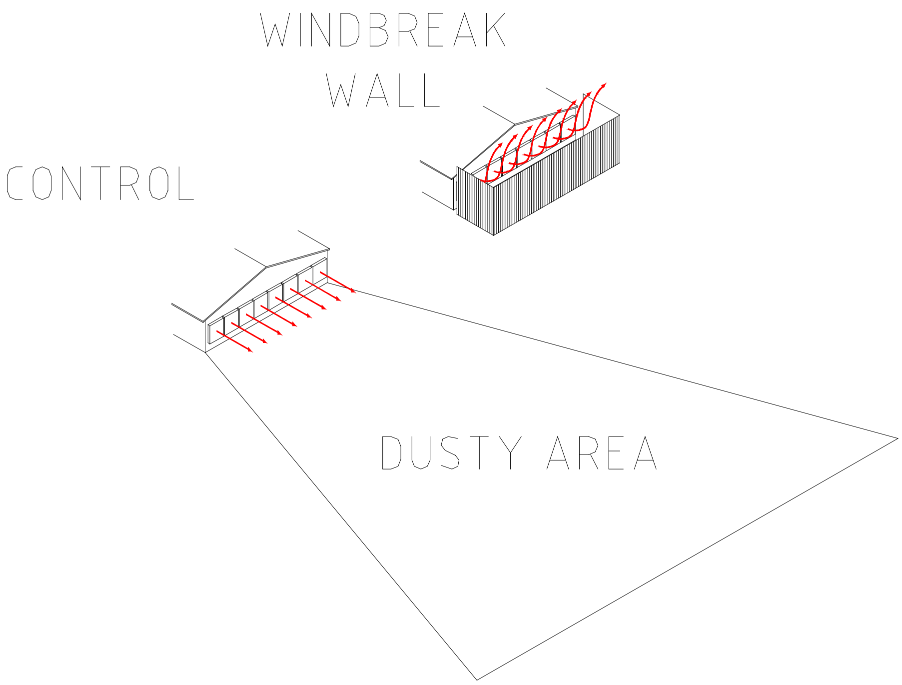


Figure 88. Illustration of the dusty area in front of the ventilation fans on the control building

Improving fan performance during gusty winds

During *Trial C*, there were numerous occasions when the wind blew toward the ventilation fans (opposing the normal direction of ventilation, see Figure 89). Without the windbreak wall, the rate of air emitted from the ventilation fans appeared to decrease. This was observed when walking across the front of the fans. When there were no strong winds, air exhausted from the fans could be clearly felt 10–15 m from the fans. When strong gusts of wind blew into the fans, air exhausted from the fan could barely be felt 1–2 m from the fans.

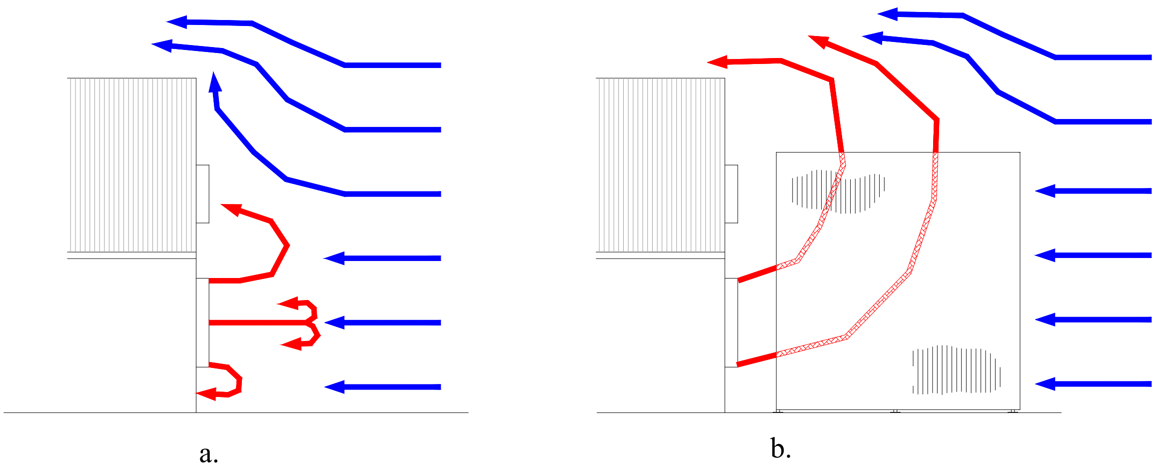


Figure 89. Theoretical change in air currents when gusty winds blow into the ventilation fans: a. without a windbreak wall; and b. with a windbreak wall (red arrows represent exhausted ventilation air, blue arrows represent wind movement)

During an extended period when a moderate wind continuously blew into the ventilation fans, it was observed that eight fans were active on the control building whereas only five fans were active on the windbreak wall building. Taking into account that the sheds were of identical design, with identical fans, housing similar numbers of similar aged birds, it appeared that the presence of the windbreak wall helped to maintain the performance of the fans at times when the wind was blowing toward them.

Intercepting sunlight in the late afternoon (or morning)

Tunnel ventilation fans were positioned on the western end of the sheds at the smoke release site. The windbreak wall intercepted sunlight and prevented the sun from shining directly into the chicken shed during the mid to late afternoon (see Figure 90). Interception of sunlight may help to reduce solar heating at the fan end of the shed by preventing the sun from shining through the open back-draft shutters on active fans. Reducing the amount of direct sunlight shining into the shed would also help to control lighting within the shed.

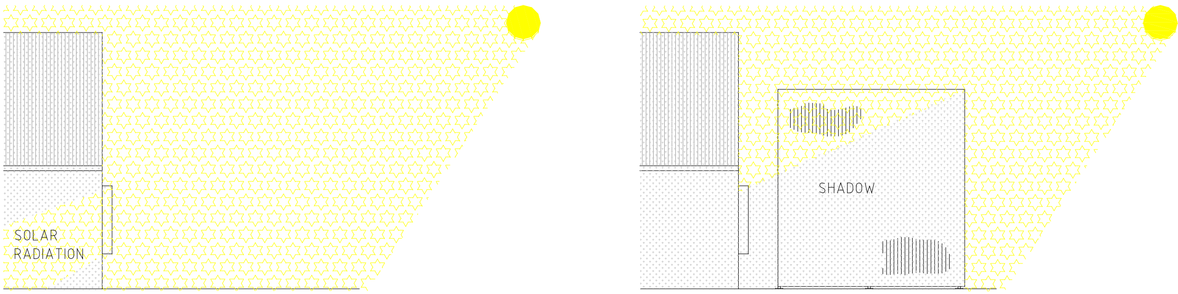


Figure 90. Interception of sunlight by the windbreak wall

Computational Fluid Dynamics Modelling

Results from the CFD modelling were presented using ground level concentration (GLC) contour plots and as centreline GLCs. GLC plots are displayed in Appendix 2 (0– 0.2% of emission scale) and Appendix 3 (0–1.0% of emission scale). Centreline GLC data is provided in Appendix 4. Centreline GLC plots are provided in Appendix 5.

To correctly assess the downwind influence of the treatments (windbreak wall and short stacks) and other factors (wind speed, external temperature etc.) on GLCs, centreline GLC charts (Appendix 5) and GLC contour plots in Appendix 2 and Appendix 3 were compared to get an overall appreciation of both centreline concentrations and horizontal plume spread.

Centreline GLC results provided a means to directly compare all of the modelling scenarios. Centreline GLC results are presented for the control in Figure 91, for windbreak wall in Figure 92 and for short stacks in Figure 93. Inspection of these charts indicated that for most of the modelling scenarios, the windbreak wall reduced GLC compared to the control. Even greater reduction in GLC was evident from the short stacks centreline GLC results.

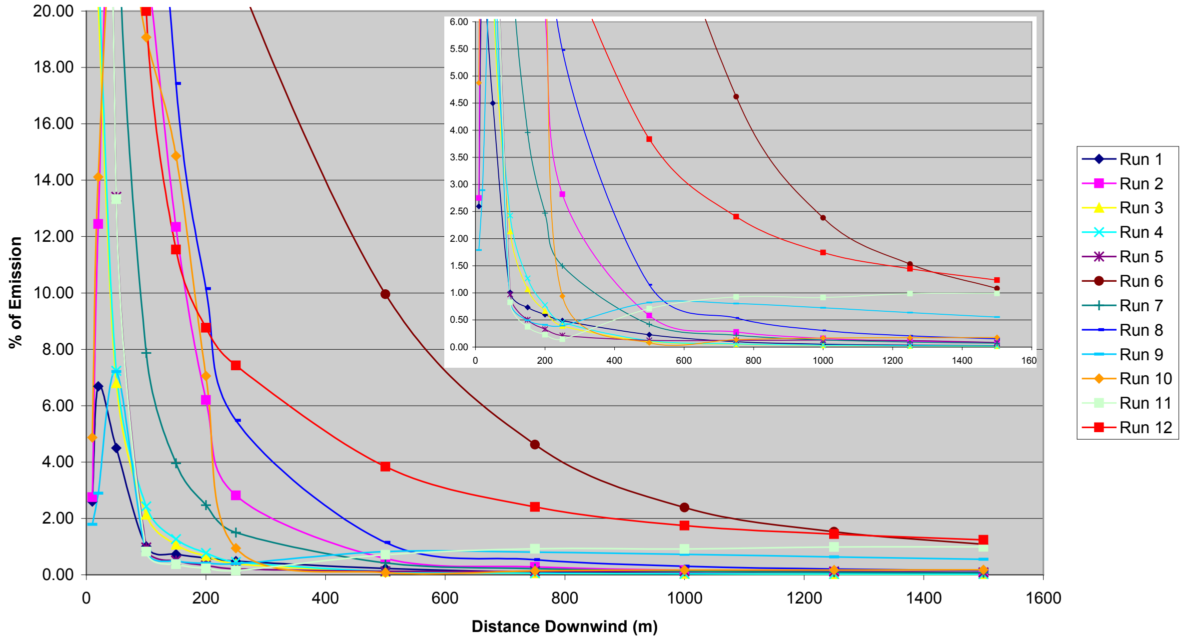


Figure 91. Centreline GLC from the control (Inset chart has vertical axis from 0 to 6)

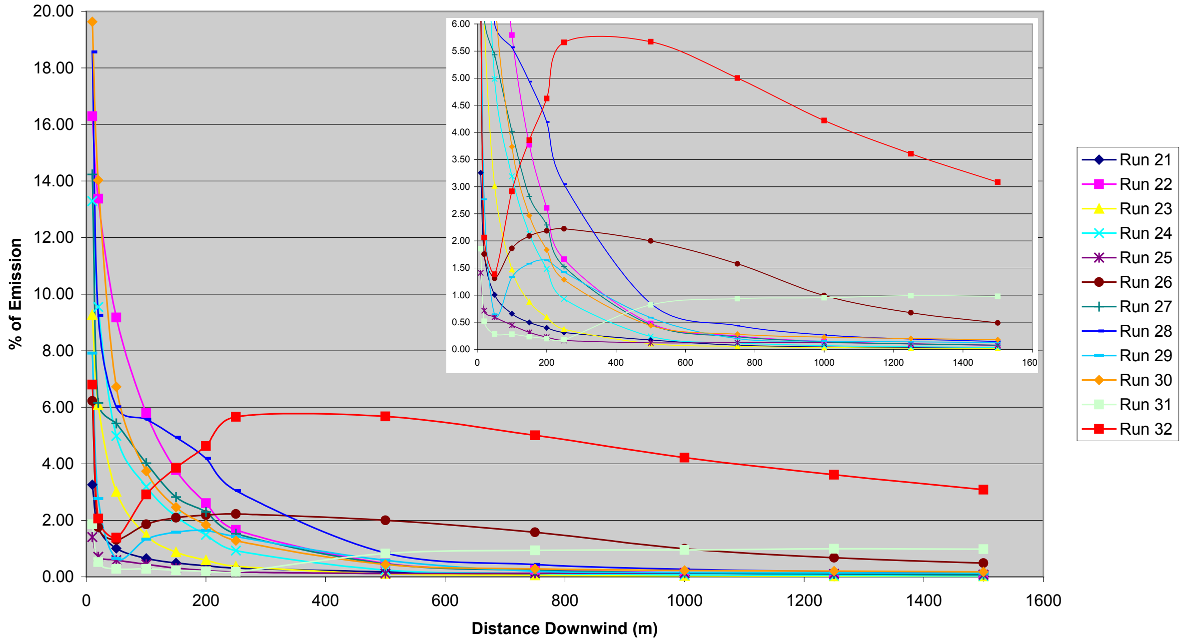


Figure 92. Centreline GLC from the windbreak wall (Inset chart has vertical axis from 0 to 6)

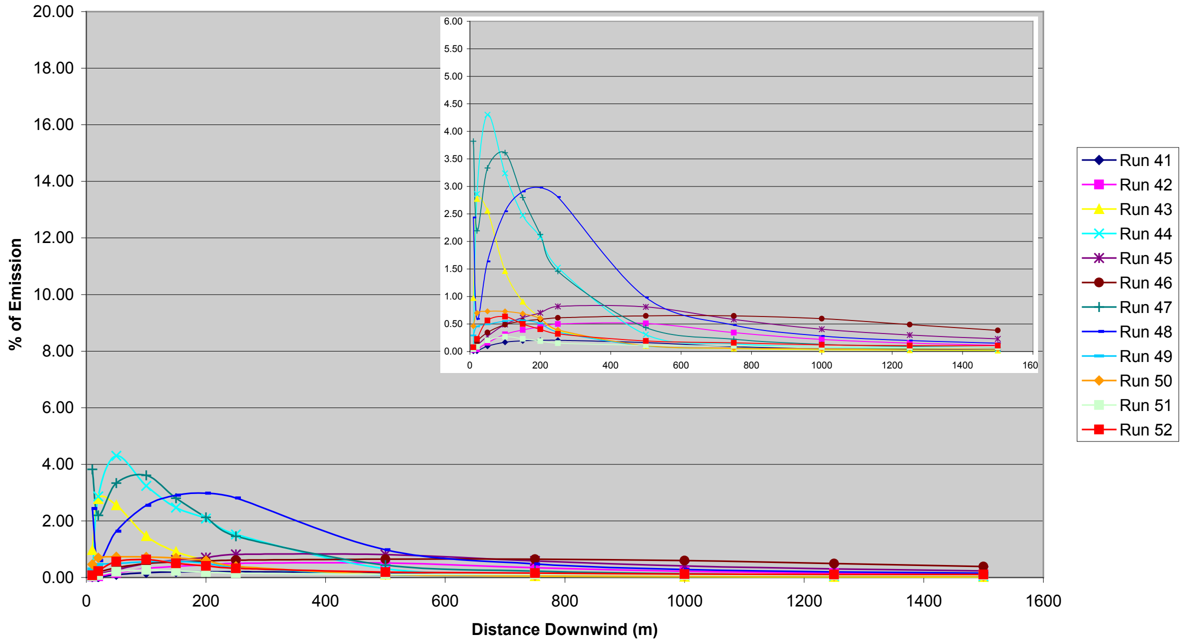


Figure 93. Centreline GLC from the short stacks (Inset chart has vertical axis from 0 to 6)

Comparison of individual modelling scenarios

Individual comparisons between the control, windbreak wall and short stacks for each of the modelling scenarios are provided in Appendix 5. These charts indicate the scenarios for which the windbreak wall and short stacks reduced the GLC downwind from the shed. Analysis of the scenarios when the windbreak walls and short stacks did not significantly reduce the downwind GLC compared to the control indicated which external factors (eg. wind speed and ambient temperature) were most influential on the performance of these devices.

The windbreak wall's ability to reduce GLCs was strongly influenced by stability class. Under all but one of the stable scenarios, the windbreak wall failed to substantially reduce the downwind GLC, and in several cases actually increased the downwind GLC. Reduction in GLC by the windbreak wall was most evident very close to the wall (within 100–400 m from the wall). This reduction in GLC diminished further downwind.

Short stacks appeared to reduce GLCs under stable conditions. On the flip side, increasing wind speed impaired the efficacy of short stacks in reducing GLCs. When the wind speed increased to 4.5 m/s, GLCs increased, particularly close to the shed (within 600 m from the shed) but was often still better than or similar to the control. There was one scenario when the short stacks made the GLC higher than the control for most of the distance downwind (comparison of runs 5 & 45: neutral stability, 8 active fans, 1 m/s wind speed and 5 °C ambient temperature). However, the apparent reduction in performance in this case is most likely related to an improvement in dispersion by the control, rather than a reduction in performance by the short stacks.

Reduction in GLC due to the windbreak wall and short stacks

Summarising the overall benefit of the windbreak wall and short stacks relative to the control was challenging because of variability in performance due to external factors, and the scale of the ground level concentrations. Average centreline GLC data for the three shed configurations is shown in

Figure 94. To demonstrate the sensitivity of the average centreline data to a single high GLC value, Figure 95 displays the average of all GLC data excluding runs 12, 32 and 52 (identical conditions for the control, windbreak wall and short stacks). A marked difference in the average performance of the windbreak wall is evident from these two figures and could lead to very different conclusions, particularly for downwind distances greater than 900 m.

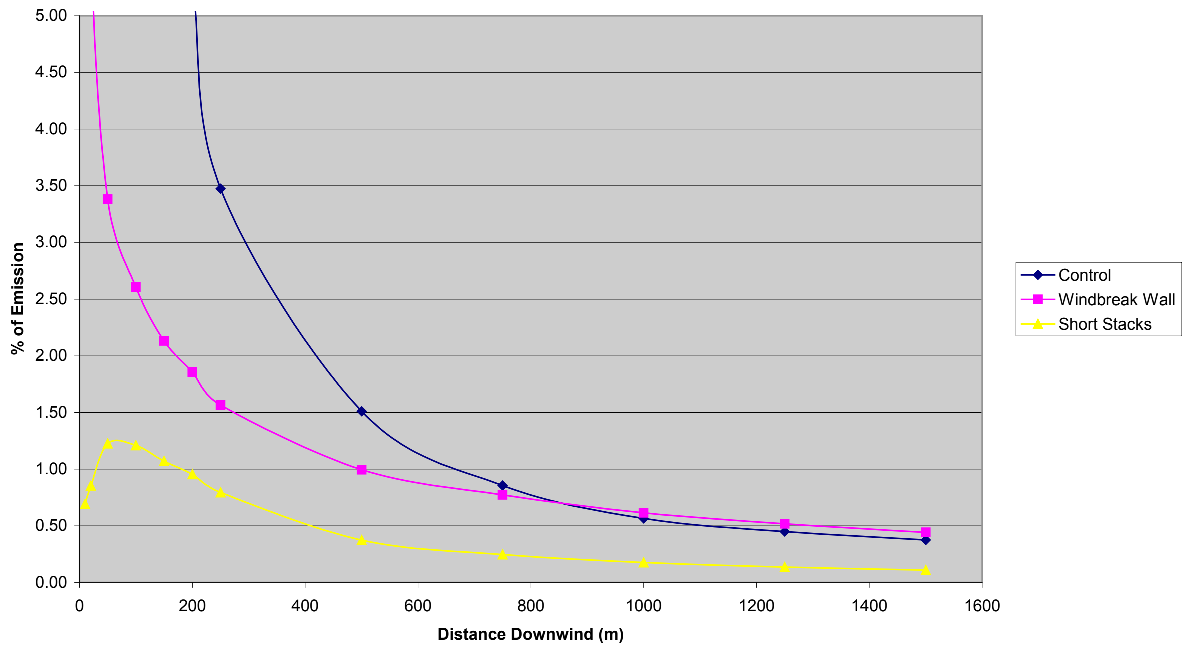


Figure 94. Average of all centreline GLC data

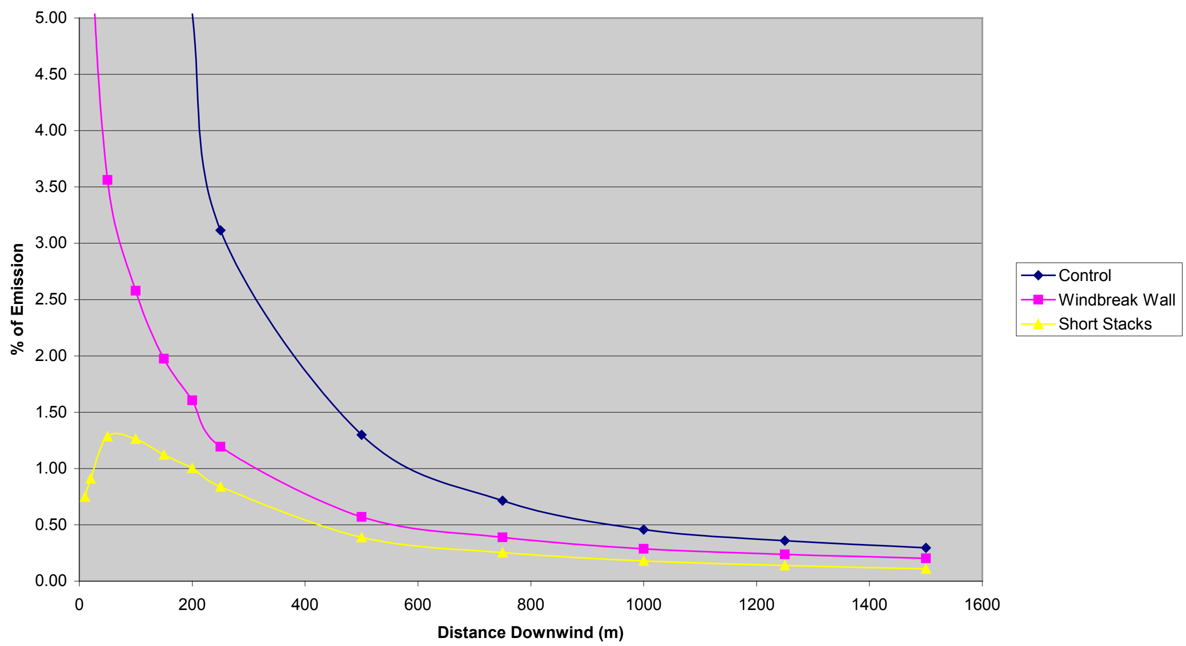


Figure 95. Average of all centreline GLC data excluding runs 12, 32 & 52

An alternative way to represent the average performance of the windbreak wall and short stacks relative to the control, across all of the modelling scenarios, is to report the percentage of modelling scenarios when the treatments produced lower GLCs. Adopting this approach effectively normalises the GLC concentrations and enables comparison between the treatments to the control on a case-by-case basis. Summaries of this data are presented in Figure 96 for the windbreak wall and Figure 97 for short stacks.

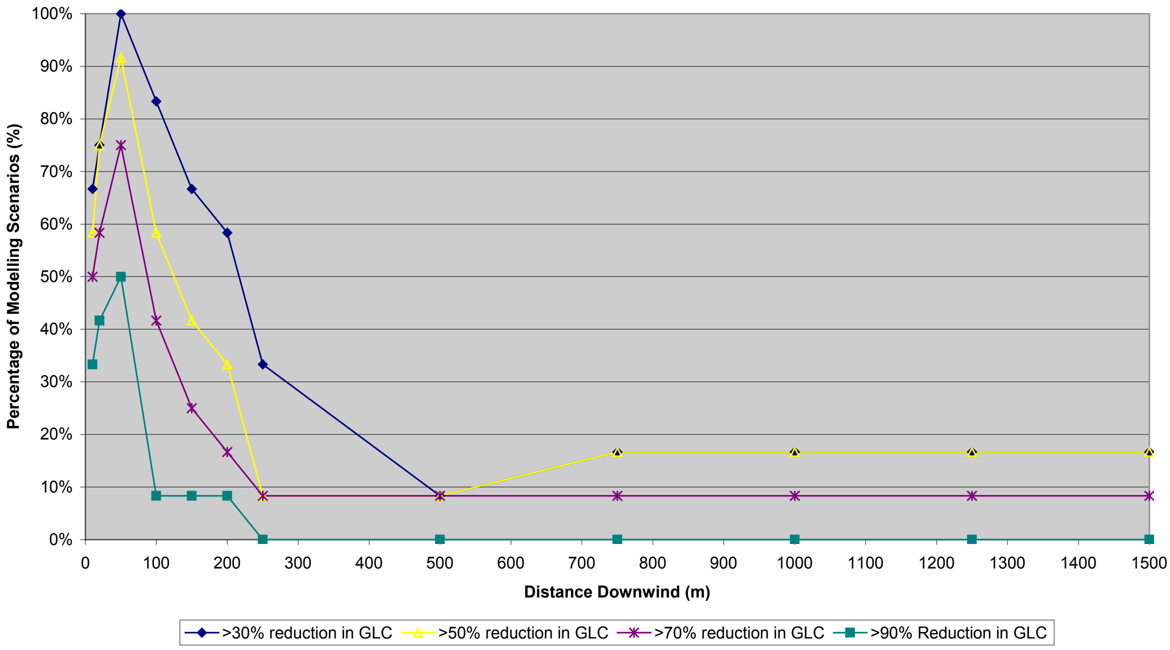


Figure 96. Percentage of modelling scenarios when the *windbreak wall* reduced the GLC compared to the control by greater than 30%, 50%, 70% and 90%

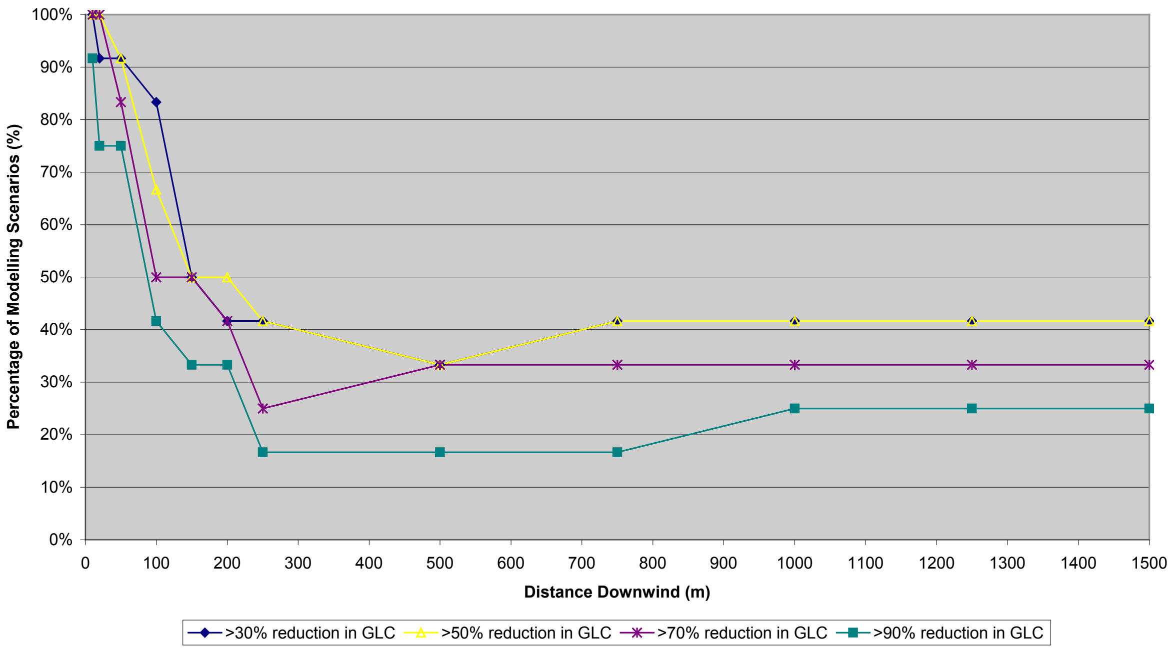


Figure 97. Percentage of modelling scenarios when the *short stacks* reduced the GLC compared to the control by greater than 30%, 50%, 70% and 90%

As an example of how to interpret these charts, examine the “>70% reduction in GLC” line in Figure 96. It shows that a greater than 70% reduction in the GLC by the windbreak wall compared to the control occurred in about 40% of the modelling scenarios 100 m downwind, and reduced to about 8% of the modelling scenarios at 250 m (and beyond).

The charts in Figure 96 and Figure 97 show that the windbreak wall was less effective than the short stacks in reducing the GLCs downwind from the model chicken shed. The short stacks reduced the centreline GLC by greater amounts for more of the modelled scenarios compared to the windbreak wall. At distances beyond 500 m downwind from the shed, the windbreak wall reduced the centreline GLC by 50% for less than 17% of the modelling scenarios. In comparison, the short stacks reduced the GLC by more than 90% for 17% (and sometimes 24%) of the modelling scenarios at the same range.

Influence of external temperature on GLCs

The influence of thermal buoyancy on dispersion was evident in the CFD modelling results. Throughout the modelling, the exhaust temperature was set at 20 °C while the ambient temperature alternated between 5 °C and 20 °C. At the 5 °C ambient temperature, thermal buoyancy of the exhaust plume would be expected, causing the exhaust plume to rise and disperse vertically. At 20 °C, the exhaust would be neutrally buoyant and neither rise nor fall.

Figure 98 displays the average centreline GLC for all of the modelling scenarios. The data was divided according to shed configuration and ambient temperature. This chart demonstrates that the GLC was much lower when the ambient temperature was 5 °C (solid lines) compared to when the ambient temperature was 20 °C (dotted lines). For the control and windbreak wall situations, the positive influence of thermally buoyancy on reducing GLC was most obvious close to the shed but extended for the entire downwind range (1500 m). For the short stacks situation, the influence of thermal buoyancy was less obvious, but still tended to reduce the GLC.

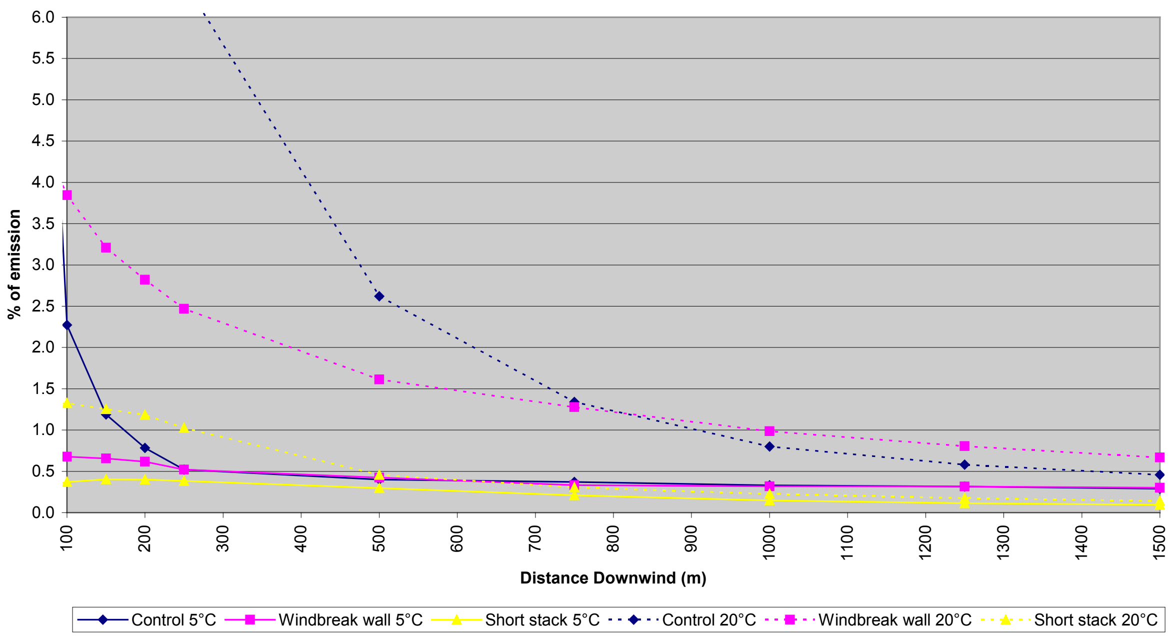


Figure 98. Influence of external temperature on GLCs (exhaust air temperature 20 °C)

The influence of thermal buoyancy and subsequent increase in dispersion (resulting in lower GLCs) appeared less for the windbreak wall and short stacks compared to the control. This is most likely due to the tendency of these devices to exhaust air vertically instead of horizontally. Figure 99 and Figure 100 illustrate how thermal buoyancy directly influenced the horizontal dispersion of the plume emitted from the shed. Figure 99 displays the GLC contour plots for one modelling scenario at 5 °C and Figure 100 displays the GLC contour plots at 20 °C (all other factors constant). Downwind centreline GLC was obviously less at 5 °C than at 20 °C for the control situation (top images), but the plume displays more horizontal dispersion. For the windbreak wall cases (middle images), centreline GLC at 5 °C was significantly reduced close to the shed, but extended at higher concentration for further downwind and had increased horizontal dispersion (compared to the 20 °C case). For the short stack cases (bottom), external temperature did not appear to significantly reduce the downwind GLC.

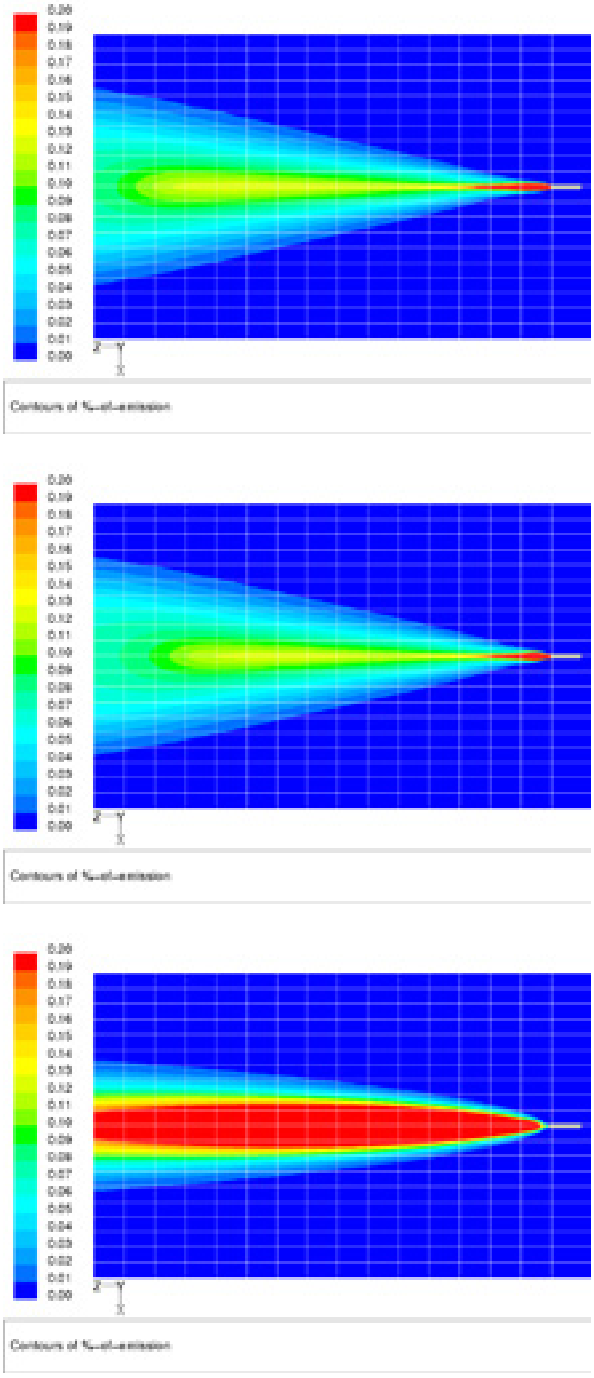


Figure 99. Control (top), windbreak (middle) and short stacks (bottom) Runs 5, 25 & 45: neutral stability, 8 fans, 1 m/s, 5 °C

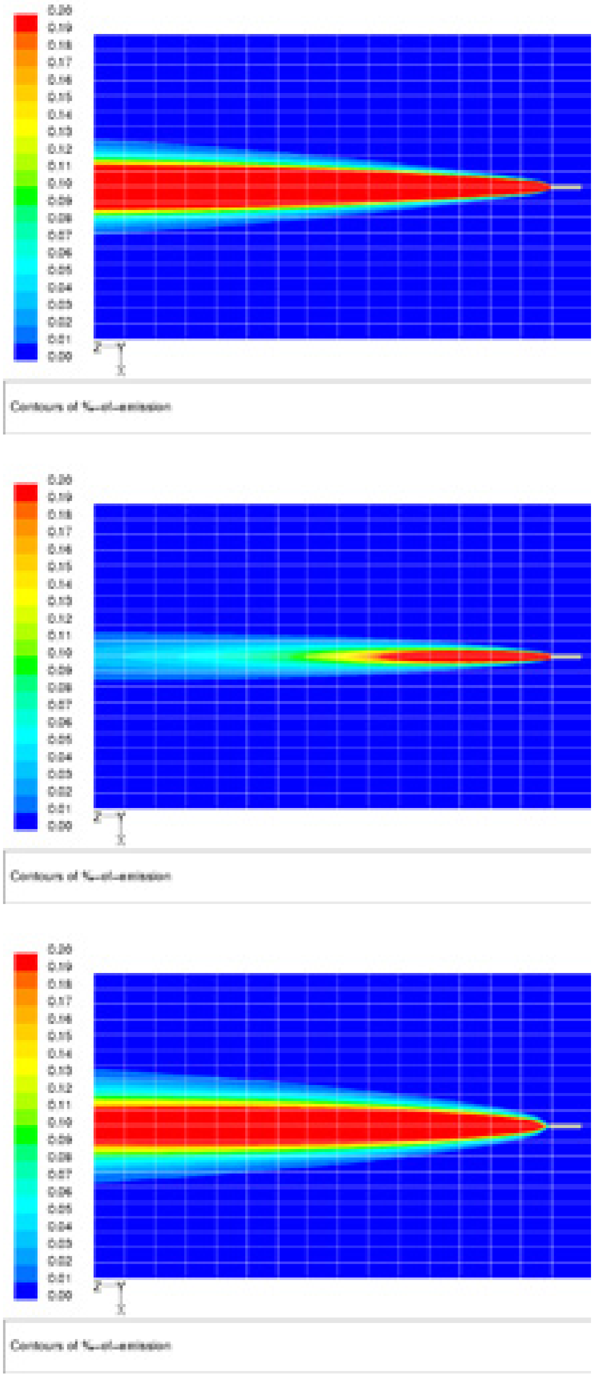


Figure 100. Control (top), windbreak (middle) and short stacks (bottom) Runs 6, 26 & 46: neutral stability, 8 fans, 1 m/s, 20 °C

Close examination of the modelling results displayed in Appendix 2, Appendix 3 and Appendix 5 suggests that the tendency of thermal buoyancy to improve dispersion and reduce GLC diminished as the wind speed increased from 1 m/s to 4.5 m/s. Intuitively, this result is logical because the higher wind speed would reduce the amount of vertical movement (per unit of horizontal movement) imparted on a plume by thermal buoyancy.

The influence of thermal buoyancy on dispersion of exhausted plumes was observed during the smoke work undertaken during *Trial C* (see Figure 60 and Figure 62) as well as the CFD modelling.

Impact of short stacks on fan performance

The CFD model indicated that installation of the short stacks would increase the static pressure acting on the fan. This static pressure was reported to be 12 Pa for the given stack geometry. When combined with the negative pressure inside the poultry shed, this additional 12 Pa could become quite a significant factor on fan performance and energy efficiency. Reducing fan efficiency following installation of short stacks would increase power consumption and reduce the amount of air exhausted from the shed.

Summary of the CFD modelling results

Examination of the CFD modelling results indicates that, compared to the control, the windbreak wall was reasonably effective in reducing the GLCs very close to the windbreak wall (less than 150 m), had some ability to reduce GLCs at mid range (to 500 m) but was fairly ineffective at reducing GLCs beyond 500 m. This was particularly obvious during stable atmospheric conditions when the downwind GLCs from the windbreak wall often exceeded that of the control.

Results for the short stacks indicate that, compared to the control, the stacks were effective at reducing the GLC close to the shed, and were reasonably effective at reducing the GLC further downwind. It appeared that only higher wind speeds (4.5 m/s) reduced the effectiveness of short stacks to reduce GLCs when compared to the control.

When considering the results predicted by the CFD model, it is important to be mindful of the limitations of the modelling. Only a few artificial scenarios (but still representative of real-life conditions) were selected for the modelling exercise to try to improve overall understanding of the conditions under which windbreak walls and short stacks can be used beneficially to reduce ground level concentrations. Differences in the level of performance by the two treatments across the range of modelling scenarios were observed. Neither the windbreak wall nor short stacks significantly reduced the ground level concentration consistently across all of the modelled scenarios for the entire downwind range. In some instances, the treatments actually increased the GLCs. It is therefore crucial to understand the conditions under which a proposed windbreak or short stacks will be operated to determine whether they will provide air quality enhancements.

The use of CFD modelling to predict dispersion of tunnel ventilated poultry exhaust was supported by the smoke observations made during *Trial C*. The smoke work suggested that windbreak walls would be unlikely to significantly reduce ground level odour concentrations under stable atmospheric conditions. Another conclusion drawn from the smoke observations in *Trial C,* and supported by the CFD modelling, was that any reduction in GLC attributed the windbreak wall would most likely occur close to the chicken shed and would diminish further downwind.

Based on the similarities of the conclusions drawn from the smoke observations and CFD modelling, and on the similarities in observed thermal buoyancy, there is sufficient evidence to support the suitability of CFD for modelling exhaust plumes from tunnel ventilated poultry buildings and windbreak walls.

Discussion and Recommendations

Tracer gas measurements

Tracer gas methods were used in this study because they were expected to quantify the dispersion of tunnel ventilated poultry exhaust following installation of a windbreak wall. Unfortunately, despite the best efforts of the project team, field trials using the tracer gas methods failed to provide meaningful results. The lack of success experienced during these tracer gas field trials was attributed to a range of technical difficulties and unexpected complications with local weather conditions. In addition to these problems, a number of other issues were identified that highlighted the unsuitability of this method to adequately quantify the dispersion of air exhausted from tunnel ventilated poultry sheds.

Only one tracer gas, SF_6, was identified as suitable for the tracer gas field trials in this study. In order to compare the differences in GLC between the control and windbreak wall situations, it would have been necessary to repeat the trial for each scenario on separate occasions. It is highly unlikely that identical weather conditions would occur on separate occasions. Outputs from the CFD modelling showed how small variations in weather conditions significantly influenced dispersion, causing distinct changes in downwind GLCs.

The number of tracer gas sampling points used during the field trials (5 points for *Trial A* and 8 points for *Trial B*) was insufficient to adequately describe differences in the downwind concentration profiles between the windbreak wall and control situations. The number of samples was restricted due to cost, equipment and practical limitations. Many more points would be required to describe the downwind GLC profile. This issue is best demonstrated using an example of a GLC contour plot generated during CFD modelling (see Figure 101 and other plots in Appendix 2 and Appendix 3). It would be practically impossible to predict where to position five to ten sampling locations in the area downwind from the shed in Figure 101 in order to properly describe the shape, size and position of the plume. Addressing this dilemma becomes even more complicated when considering that this GLC contour plot is based on a simplified case with a steady wind moving in a single direction and from a lone source unaffected by external influences, a situation that is unlikely to occur. With fluctuating winds and interference from other buildings and vegetation, the plume could move or disperse anywhere in the area surrounding the poultry building, making it very difficult to predict optimal sampling locations.

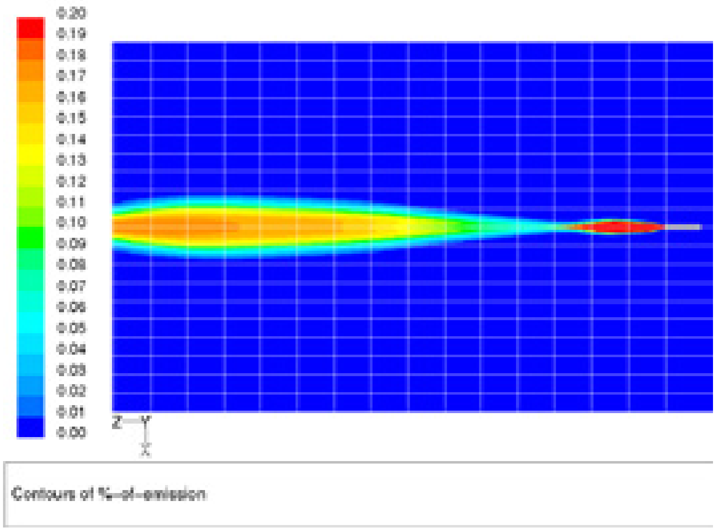


Figure 101. Example of a complex GLC contour plot from CFD modelling the emission of a tunnel ventilated poultry building (from Appendix 2)

A further issue with the sparse positioning of the samplers was that there was no way to know what happened between the sampling points. By positioning a very limited number of sampling points over an extensive area, the opportunity existed for a very narrow plume (often experienced under stable conditions) to pass between two sampling points and completely miss the sampling equipment.

The sampling frequency and duration of the tracer gas plume required special consideration to produce meaningful results. The sampling period used in *Trial A* was four hours and the sampling period for *Trial B* was one hour. Due to the use of sorbent tubes, the mass of tracer gas collected in the tube was an average over the sampling period. Due to variations in wind conditions and atmospheric stability over the tracer sampling period, the concentration of tracer gas would naturally fluctuate over the sampling period. There was no way to tell whether the mass of tracer gas trapped in the sampling tube was representative of a short period of high concentration, or a long period of low concentration.

In order to overcome many of the identified issues, a dense array of high resolution, high frequency sampling instruments would be required. Given budget and practical limitations, this approach was not appropriate for this project.

Considering the problems experienced during the tracer gas trials in this study and the issues associated with accurately measuring tracer gas plumes with discrete sorbent tube samplers, it is recommended that tracer gases should not be used to measure or compare the dispersion of plumes from tunnel ventilated poultry unless more sophisticated sampling techniques can be adopted.

Smoke observations

Following unsuccessful attempts to use tracer gas methods to quantify the dispersion from the control and windbreak wall situations, smoke observation methods were adopted. A full size windbreak wall was constructed at a meat chicken farm along with a smoke release system. Smoke was released sequentially from the windbreak wall and a control shed, photographed and analysed for visual differences in dispersion and movement.

A major advantage of using smoke releases was the short duration of each smoke release and the frequency at which sequential smoke releases could be repeated. This enabled the project team to sequentially and very rapidly compare the control and windbreak situations under a wide range of weather, atmospheric stability and shed ventilation conditions. Also, because of the ability to rapidly repeat smoke releases, smoke observations could be made for the windbreak wall and control situation under nearly identical conditions.

Releasing smoke across such a wide range of conditions provided the research team with a well-rounded understanding of how plumes dispersed from a conventional tunnel ventilated poultry building, as well as the conditions under which dispersion was enhanced or impaired by the installation of the windbreak wall.

The visual nature of smoke releases enabled positive identification of smoke plume movement and dispersion after being exhausted from the shed. Visibility of the smoke plume also enabled the research team to identify objects and geographical landforms across the landscape that influenced the movement, turbulent mixing and dispersion of the exhaust plumes.

One drawback of using smoke to visualise the movement of exhaust plumes was the decrease in visibility as the plume dispersed. Under stable conditions (low dispersion), the plume occasionally remained visible for kilometres whereas under unstable conditions (high dispersion), the smoke plume was invisible after 100–200 m. A further issue with visibility was that the smoke plume was virtually invisible at night in the dark. Powerful lighting was required to observe smoke plumes as they travelled away from the poultry sheds. As the smoke moved further downwind away from the lit area, the plume became invisible and it was impossible to know where the exhaust air moved to or how much it had dispersed.

Analysis of the smoke releases indicated that under stable atmospheric conditions, the windbreak wall was unlikely to significantly enhance dispersion of the air exhausted from a tunnel ventilated poultry building. Under neutral atmospheric conditions, it appeared that the windbreak wall may slightly enhance dispersion of exhausted air. Under unstable conditions, it appeared that dispersion from the control situation was so great that the windbreak wall would be unlikely to provide additional benefit. Enhancement of dispersion due to the windbreak wall appeared to decrease as horizontal wind speed increased because the vertical motion imparted on the plume by the windbreak wall was quickly overpowered by the horizontal wind movement.

A further observation made while using smoke was the ability of thermal buoyancy to create vertical rise and mixing of the air exhausted from the control shed. Vertical rise of thermally buoyant plumes was particularly noticeable during still wind conditions. Thermal buoyancy was more obvious on cooler mornings when there was a greater temperature difference between the exhausted air (15–22 °C) and the cooler ambient air (0–18 °C).

CFD modelling

CFD modelling proved to be a very useful tool to assess the performance of a windbreak wall and short stacks to improve dispersion of tunnel ventilated poultry shed exhaust. Results from the CFD modelling were very similar to those observed during the smoke releases for the windbreak wall and control situations, which demonstrated the suitability of CFD for modelling emissions from these sources. Additional smoke releases from short stacks may increase the confidence placed on the results predicted using CFD modelling.

One of the major advantages of using CFD modelling for comparing dispersion from the three shed configurations (control, windbreak wall and short stacks) was the ability to replicate conditions such as wind speed, ambient temperature, exhaust temperature, number of active fans and stability class. This provided an accurate comparison between the three configurations. Another benefit of CFD modelling was the numerical output of GLCs, which enabled quantitative comparison between the different shed configurations.

There are several potential shortcomings of CFD modelling. Firstly, CFD modelling will only be as accurate as the way that the modelling scenarios, domain and assumptions are defined. The modeller needs to clearly understand what is required from the modelling and the factors that may interfere with the outcomes. It is therefore crucial to employ experienced modellers to undertake CFD modelling. CFD modelling can be a costly activity, especially for accurate modelling of complex situations. However, as the outputs from the CFD modelling in this study have demonstrated, CFD generates outputs that can add significant value to the understanding of complex situations.

The CFD modelling for this study clearly showed that short stacks provided the greatest reduction in GLCs for most of the modelled scenarios. Windbreak walls improved dispersion for some of the modelled scenarios, but overall, reduction in GLC was marginal beyond a very short distance (150 m). Windbreak walls performed very poorly under stable conditions, often increasing the downwind GLC when compared to the control.

Observations other than assessment of dispersion

Several potential benefits of installing windbreak walls on tunnel ventilated poultry sheds were observed while undertaking the smoke release fieldwork. These benefits included:

- shielding the ventilation fans from strong opposing winds which helped maintain fan performance and efficiency;
- casting a shadow on the ventilation fans which helped to prevent solar heating within the shed and improved control of lighting; and
- intercepting dust particles which helped to reduce dustiness on the ground immediately downwind of the tunnel fans and might trap larger dust particles within the windbreak wall.

These potential benefits were not specifically addressed or quantified in this study, but may be of value or interest to poultry growers looking to improve lighting control, improve the efficiency of their fans (during unfavourable wind conditions) or reduce dustiness immediately outside the shed.

The value of windbreak walls for improving dispersion

The principle objective of this study was to identify the value of windbreak walls for improving dispersion of exhaust from tunnel ventilated poultry sheds. There is no definitive answer to this question because the efficacy of the windbreak wall to improve dispersion was almost completely dependent on the conditions under which it was being used. Variations in atmospheric stability, weather conditions and shed operating parameters affected the ability of the windbreak wall to enhance dispersion. However, overall conclusions drawn from the smoke observations and the CFD modelling indicated that the windbreak wall *did not* dramatically improve dispersion or reduce ground level concentrations (of odour) beyond a reasonably short distance from the shed (150–500 m downwind) under the experienced or modelled conditions. Performance of the windbreak walls to improve dispersion seemed particularly poor under stable conditions.

Consequently, windbreak walls did not appear to provide much value for improving dispersion when compared to the control.

The performance of the short stacks (assessed using CFD modelling only) was more promising relative to the windbreak wall. Short stacks reduced the downwind GLC for most of the scenarios that were modelled. Based on CFD modelling alone, it appeared that short stacks provided greater value for improving dispersion compared to the windbreak wall and the control.

The use of smoke observations and CFD modelling enabled windbreak walls and short stacks to be evaluated under a wider range of conditions than has been reported previously, or would be possible to assess using tracer gas techniques.

Windbreak walls as an odour reduction strategy

A further objective of this study was an evaluation of windbreak walls as an odour reduction strategy for meat chicken sheds. The smoke observations and CFD modelling indicated that the windbreak wall did not significantly improve dispersion or reduce downwind ground level concentrations. Therefore, windbreak walls would not be suitable as a basis for an odour reduction strategy. Improvements in dispersion offered by the windbreak wall were marginal, and were highly influenced by factors such as atmospheric stability, ambient temperature, wind speed and number of active fans. Windbreak walls *should not* be seen as a reliable technology for reducing odour impacts.

In the context of tunnel ventilated poultry production, if a nearby receptor (further than several hundred meters from the exhaust fans of a tunnel ventilated poultry shed) was experiencing significant odour impacts, simply installing a windbreak wall would be unlikely to reduce these impacts under most conditions.

Although windbreak walls would be unlikely to significantly reduce odour impacts, installation of windbreak walls may reduce the impacts of dust and noise emissions on nearby receptors. The windbreak wall also shields the fans from view.

From the poultry farmer's point of view, installation of the windbreak wall would help to maintain fan performance during periods of strong opposing winds and may reduce the amount of sunlight entering the shed through open fan shutters in the late afternoon (or morning depending on the orientation of the shed). Additionally, installation of windbreak walls can reduce dustiness in the area downwind of the ventilation fans.

Windbreak walls are relatively cheap to build (up to approximately $5000 each) and could be constructed by most practical farm workers from readily available materials. They offer some benefits which may be seen as valuable by some farm managers. Therefore, whilst windbreak walls may not offer much value for improving odour dispersion, the combined benefits (some dust control, light interception and sound containment) may still make them worthwhile for the moderate outlay in costs.

Short stacks may improve dispersion, and like windbreak walls, would most likely block sunlight from entering through the fans and may reduce stray fan noises. The influence of short stacks on dust deposition is unknown at this stage. Whilst short stacks appear to offer more value for improving dispersion than windbreak walls, they would be more expensive to install and would reduce fan efficiency, increasing fan running costs. This would need to be taken into account before deciding whether to install short stacks.

It must be remembered that neither windbreak walls nor short stacks are capable of reducing odour emissions from tunnel ventilated poultry sheds. They only deflect the emissions upward, hopefully improving mixing and enhancing dispersion. If this increase in mixing and dispersion is negligible, neither device will reduce odour impacts downwind from poultry sheds. The amount of mixing will depend on factors such as atmospheric stability, wind speed and direction, temperature differences between the exhausted and ambient air and the momentum of the air as it exits the shed. Constantly varying combinations of these factors will tend to enhance or retard mixing and dispersion of the exhausted plume. For these reasons, neither the windbreak walls nor short stacks should be viewed as technology that can provide reliable odour control. For reliable control, odour emissions need to be reduced at the source, i.e. within the poultry shed.

Potential users of windbreak walls or short stacks, for the purpose of reducing odour impacts, must thoroughly understand the conditions under which impacts are occurring in their specific situation before considering whether or not the installation of windbreak walls or short stacks will provide any benefit.

Appendices

Appendix 1

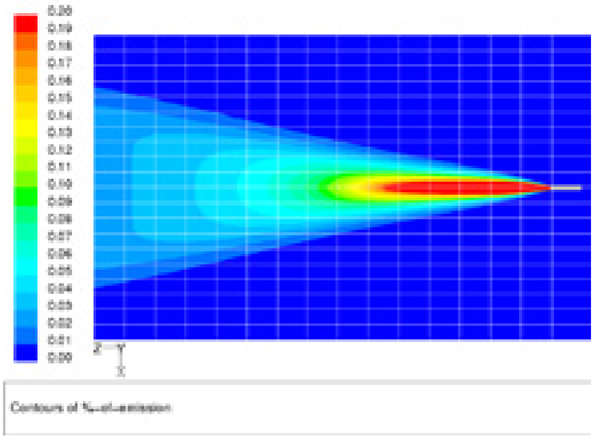
Weather station sensor information

Sensor/Parameter	Brand	Model Number	Sensitivity	Range
Data Collection	DataTaker	DT500 (version7)	0.11% for Voltage 0.21% for Current	0-2500mV 0.25-25 mA
Temperature	Vaisala	50Y Humitter	±0.6°C at 20°C	-10 to +60°C
Temperature (2)		PT100		
Humidity	Vaisala	50Y Humitter	±3% at 90% RH	10 to 90%
Temperature	RS	PT100		-50 to + 250°
Wind Speed	Gill Windsonic	1405-PK-040 Option 3	±4% at 20 m/s	0 to 60 m/s
Wind Direction	Gill Windsonic	1405-PK-040 Option 3	+- 3° at 20m/s	0 to 359°
Total Radiation	Li-Cor	LI200SZ	0.2 kW/m²/mV	
Barometric Pressure	Vaisala	PTB101B	±0.5 hPa at 20°C	600 to 1060 hPa
			±2 hPa at 0-40°C	
Rainfall	Hydrological Services	TB3	one tip/0.2mm rain	0 to 700mm/hr

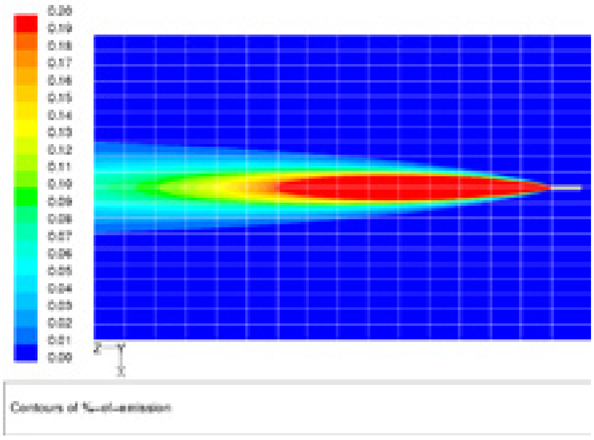
Appendix 2

Ground level concentration (GLC) contour plots (scale 0% to 0.2% of emission)

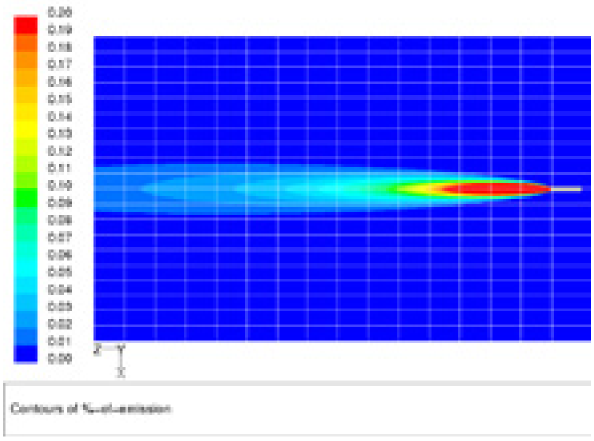
Captions refer to "run number: building configuration, stability class, active fans, wind speed and external ground temperature." Grid lines for the horizontal axis are spaced every 100 m while the gridlines for the vertical axis are spaced every 50 m.



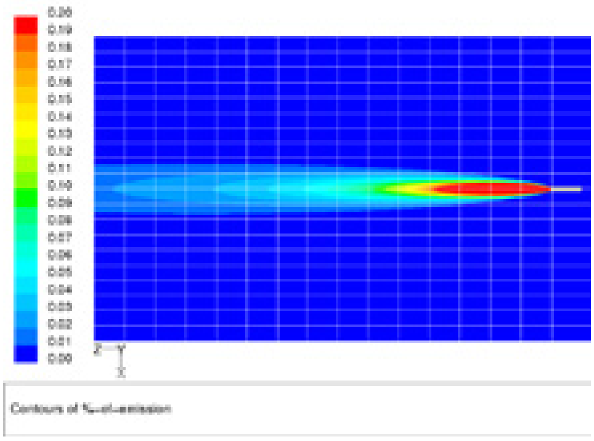
Run 1: Control, neutral, 2 fans, 1 m/s, 5 °C



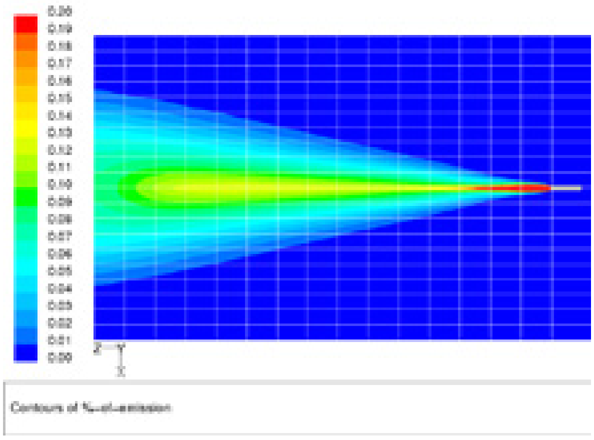
Run 2: Control, neutral, 2 fans, 1 m/s, 20 °C



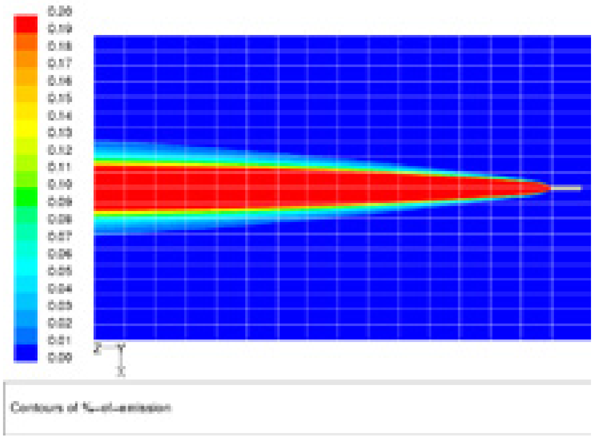
Run 3: Control, neutral, 2 fans, 4.5 m/s, 5 °C



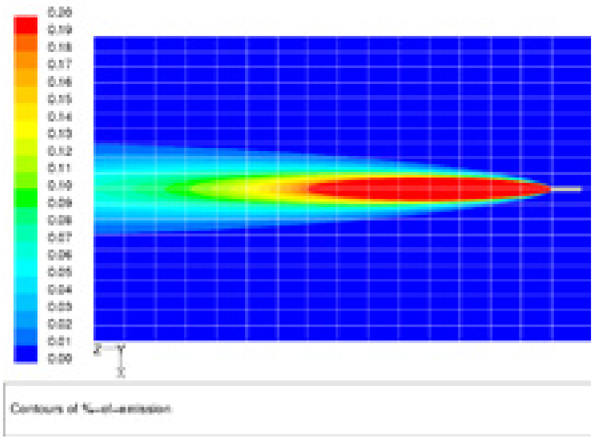
Run 4: Control, neutral, 2 fans, 4.5 m/s, 20 °C



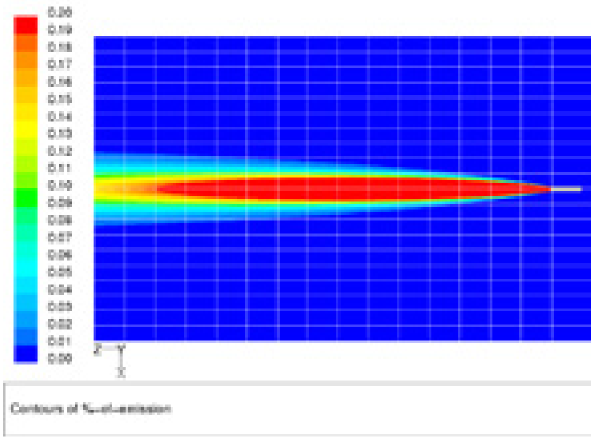
Run 5: Control, neutral, 8 fans, 1 m/s, 5 °C



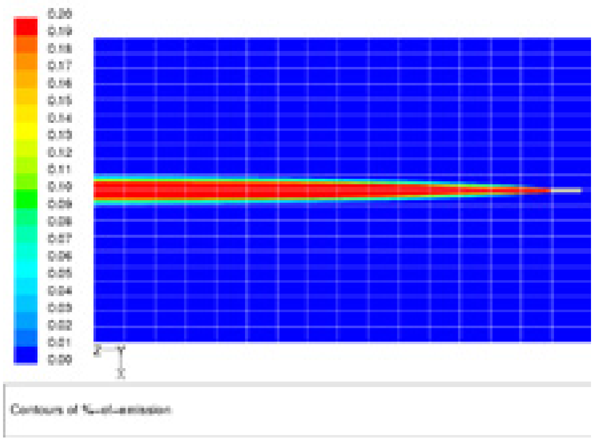
Run 6: Control, neutral, 8 fans, 1 m/s, 20 °C



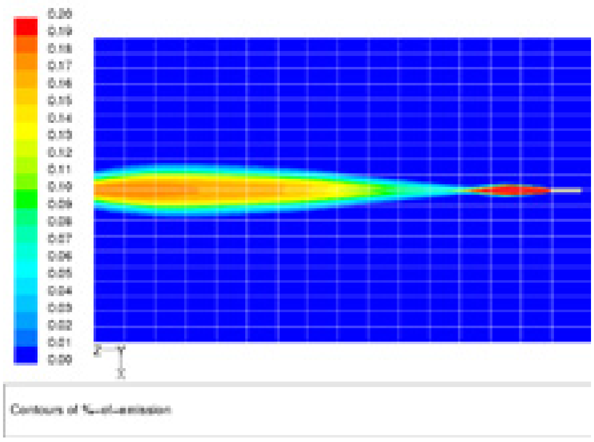
Run 7: Control, neutral, 8 fans, 4.5 m/s, 5 °C



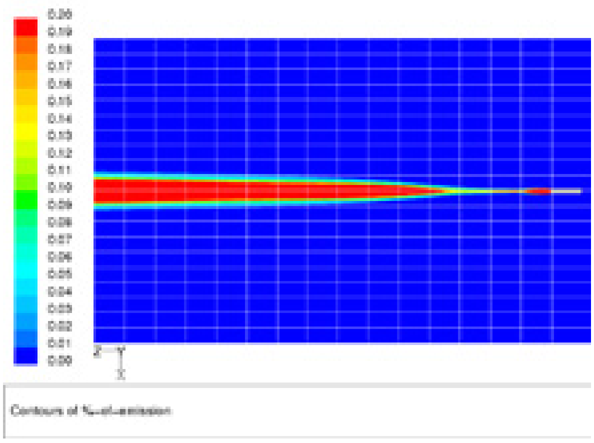
Run 8: Control, neutral, 8 fans, 4.5 m/s, 20 °C



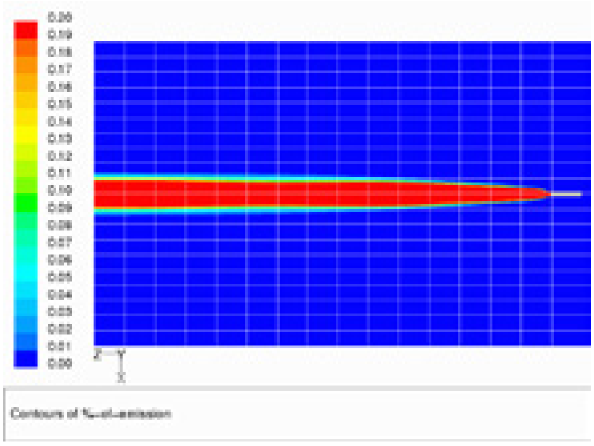
Run 9: Control, stable, 2 fans, 1 m/s, 5 °C



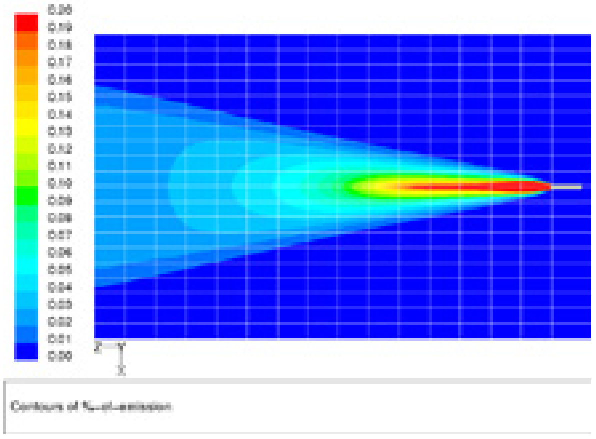
Run 10: Control, stable, 2 fans, 1 m/s, 20 °C



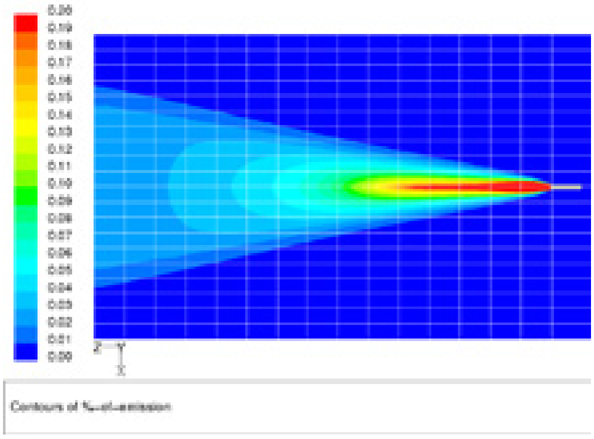
Run 11: Control, stable, 8 fans, 1 m/s, 5 °C



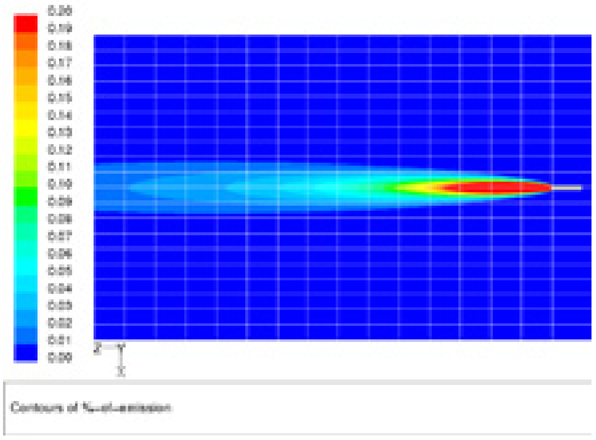
Run 12: Control, stable, 8 fans, 1 m/s, 20 °C



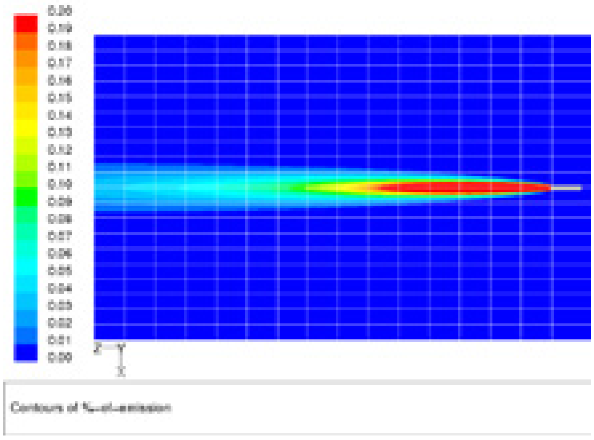
Run 21: Windbreak wall, neutral, 2 fans, 1 m/s, 5 °C



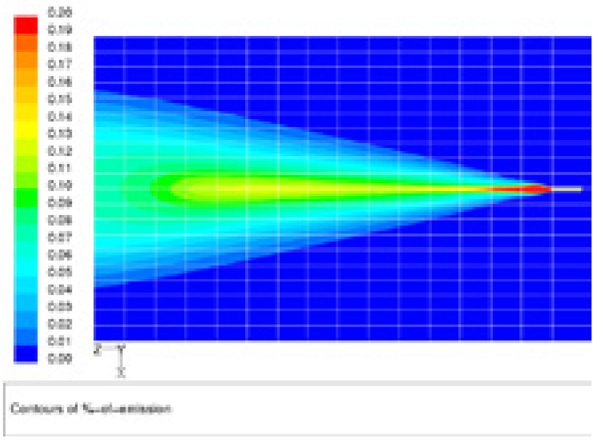
Run 22: Windbreak wall, neutral, 2 fans, 1 m/s, 20 °C



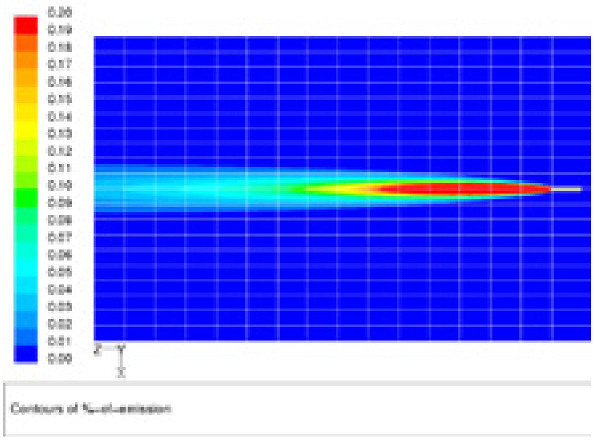
Run 23: Windbreak wall, neutral, 2 fans, 4.5 m/s, 5 °C



Run 24: Windbreak wall, neutral, 2 fans, 4.5 m/s, 20 °C



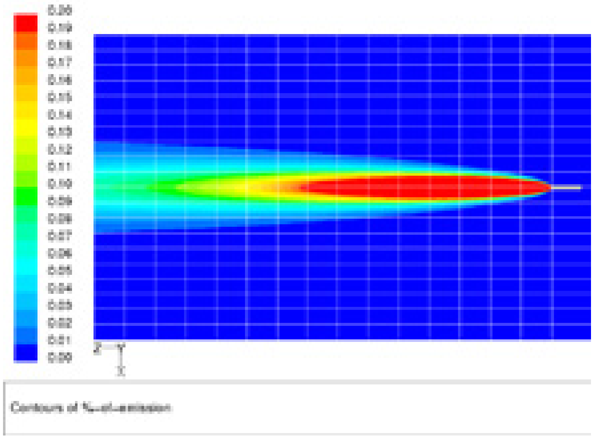
Run 25: Windbreak wall, neutral, 8 fans, 1 m/s,



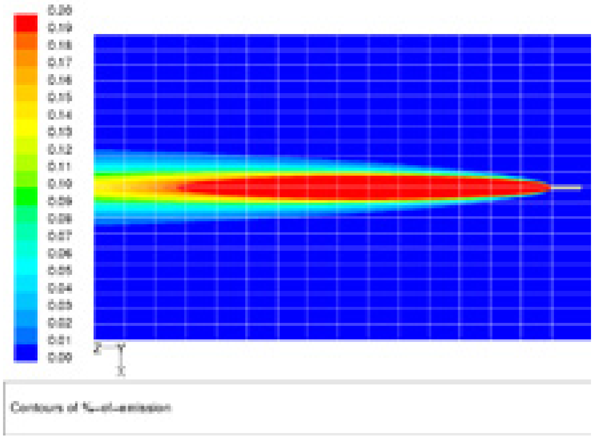
Run 26: Windbreak wall, neutral, 8 fans, 1 m/s,

5 °C

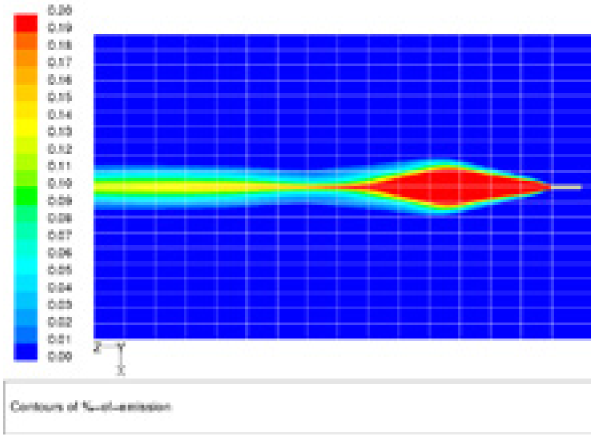
20 °C



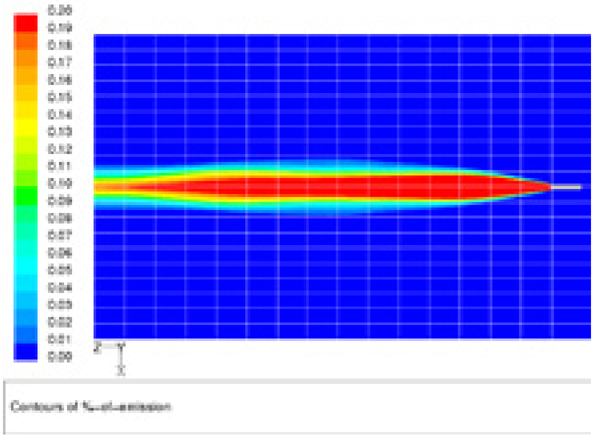
Run 27: Windbreak wall, neutral, 8 fans, 4.5 m/s, 5 °C



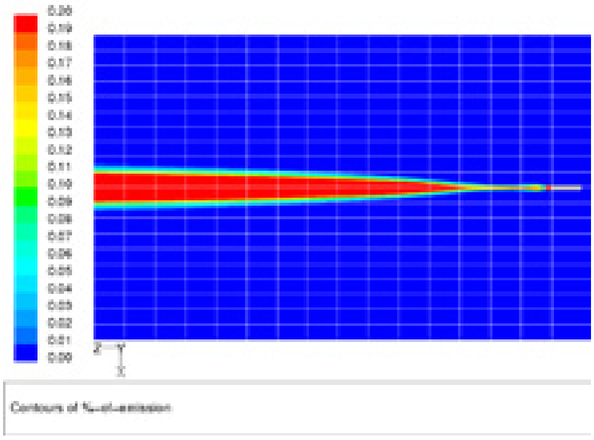
Run 28: Windbreak wall, neutral, 8 fans, 4.5 m/s, 20 °C



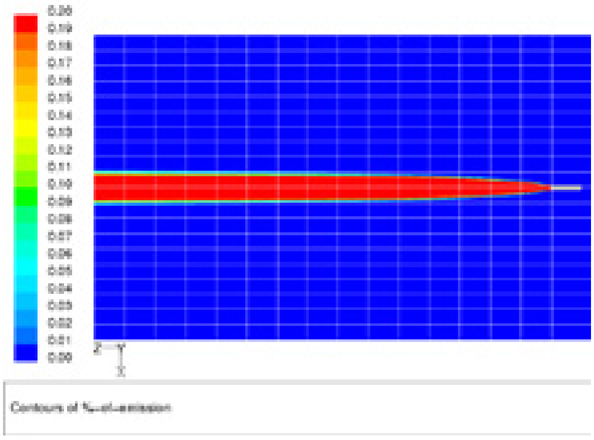
Run29: Windbreak wall, stable, 2 fans, 1 m/s , 5 °C



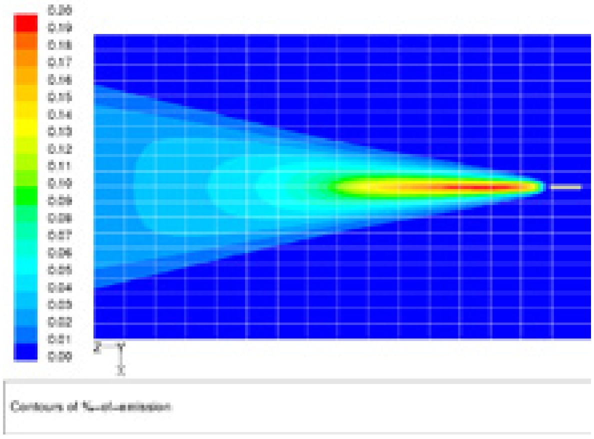
Run 30: Windbreak wall, stable, 2 fans, 1 m/s, 20 °C



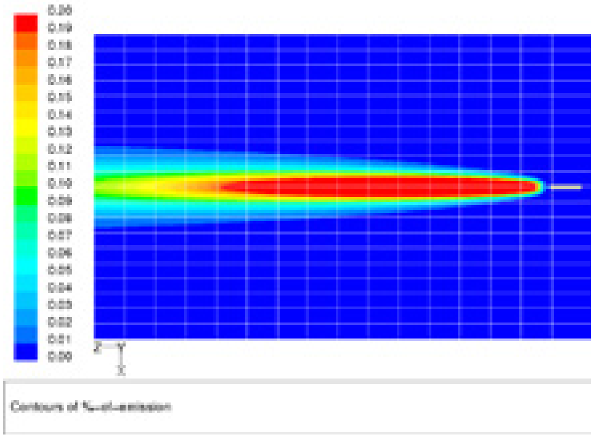
Run 31: Windbreak wall, stable, 8 fans, 1 m/s, 5 °C



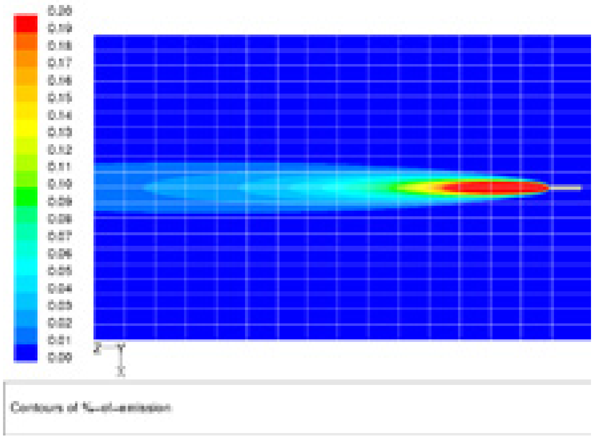
Run 32: Windbreak wall, stable, 8 fans, 1 m/s, 20 °C



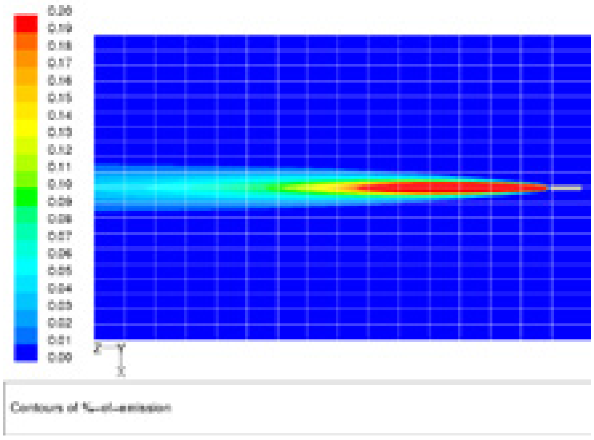
Run 41: Short stacks, neutral, 2 fans, 1 m/s, 5 °C



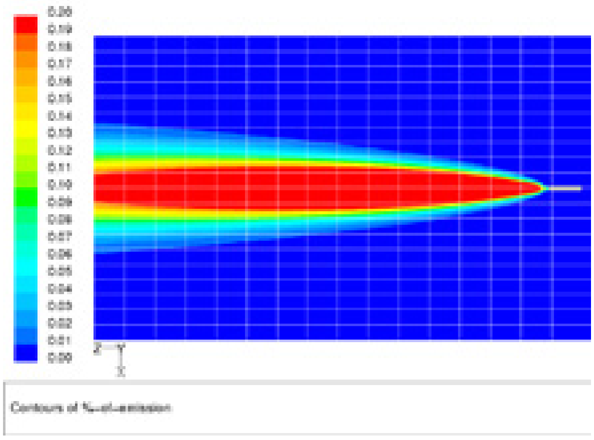
Run 42: Short stacks, neutral, 2 fans, 1 m/s, 20 °C



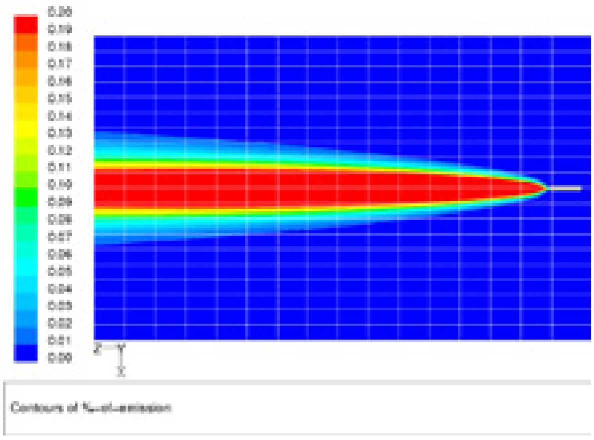
Run 43: Short stacks, neutral, 2 fans, 4.5 m/s, 5 °C



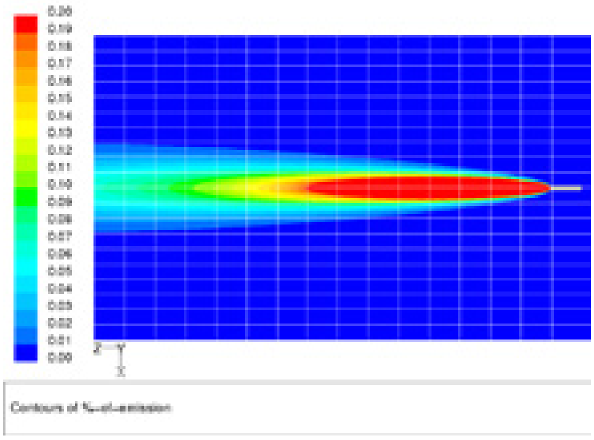
Run 44: Short stacks, neutral, 2 fans, 4.5 m/s, 20 °C



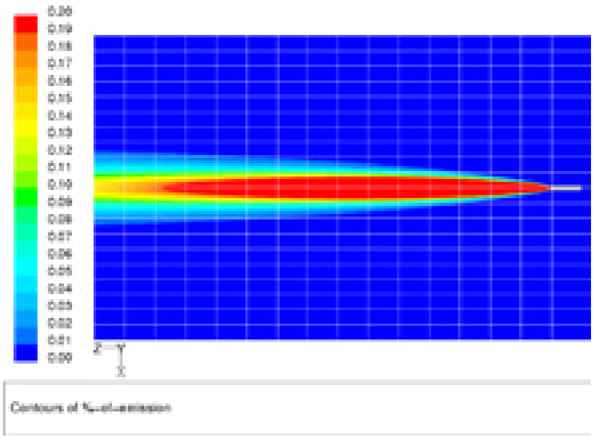
Run 45: Short stacks, neutral, 8 fans, 1 m/s, 5 °C



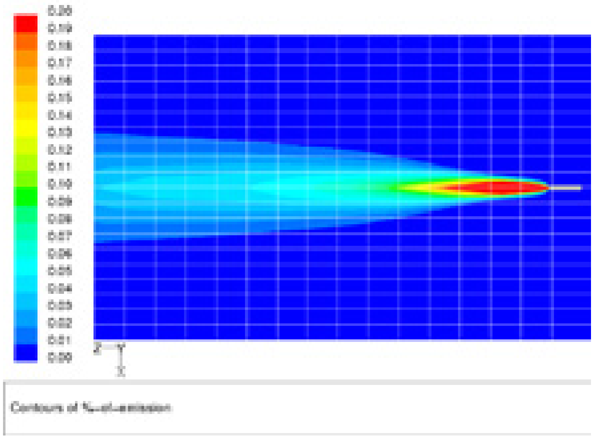
Run 46: Short stacks, neutral, 8 fans, 1 m/s, 20 °C



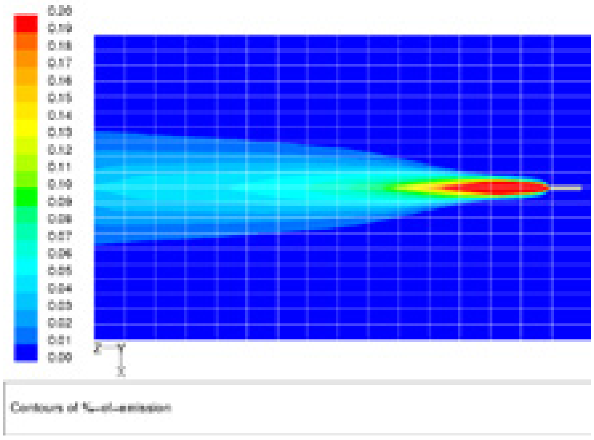
Run 47: Short stacks, neutral, 8 fans, 4.5 m/s, 5 °C



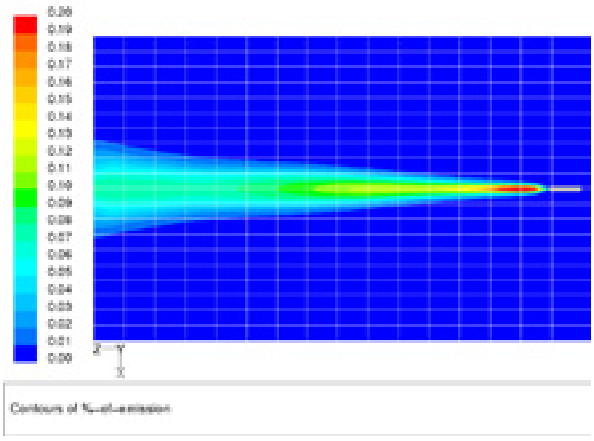
Run 48: Short stacks, neutral, 8 fans, 4.5 m/s, 20 °C



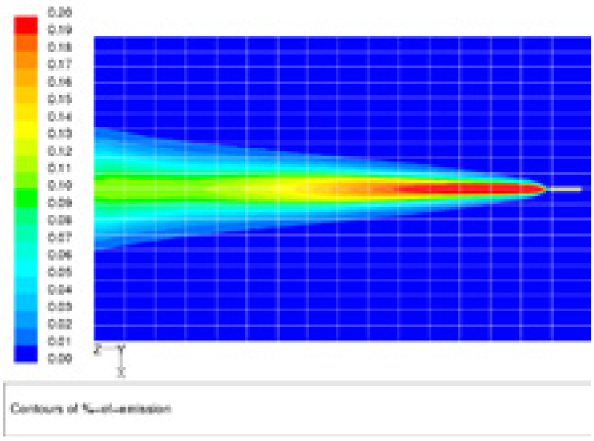
Run 49: Short stacks, stable, 2 fans, 1 m/s , 5 °C



Run 50: Short stacks, stable, 2 fans, 1 m/s, 20 °C



Run 51: Short stacks, stable, 8 fans, 1 m/s, 5 °C

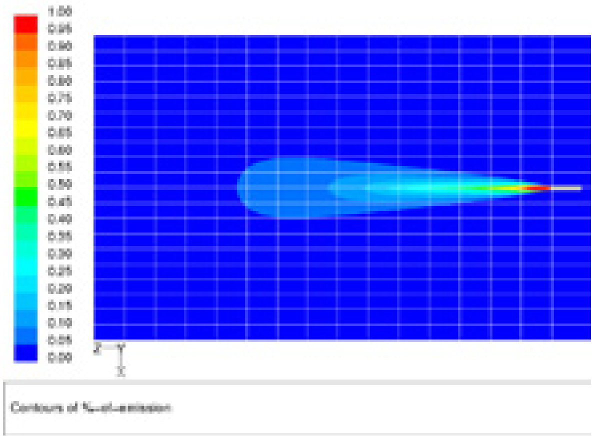


Run 52: Short stacks, stable, 8 fans, 1 m/s, 20 °C

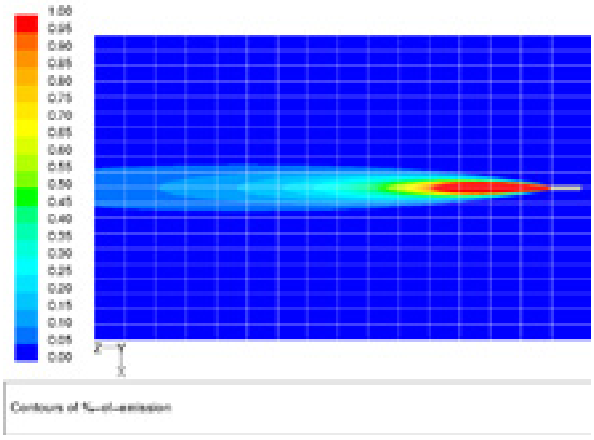
Appendix 3

Ground level concentration (GLC) contour plots (scale 0% to 1.0% of emission)

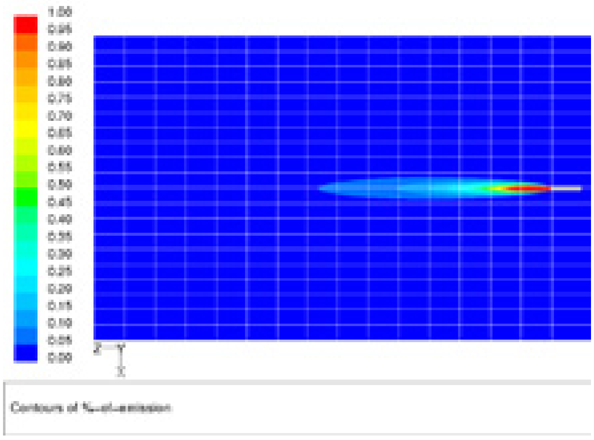
Captions refer to "run number: building configuration, stability class, active fans, wind speed and external ground temperature." Grid lines for the horizontal axis are spaced every 100 m while the gridlines for the vertical axis are spaced every 50 m.



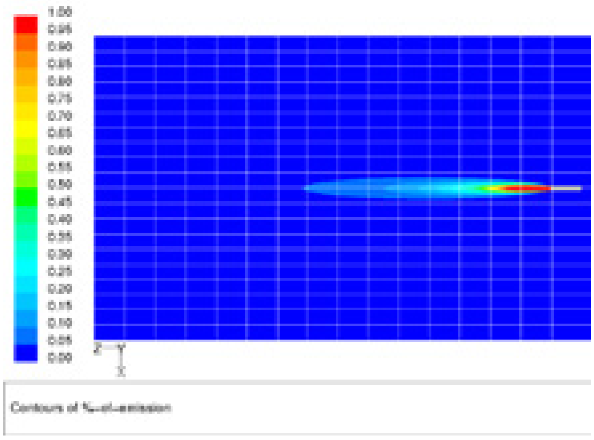
Run 1: Control, neutral, 2 fans, 1 m/s, 5 °C



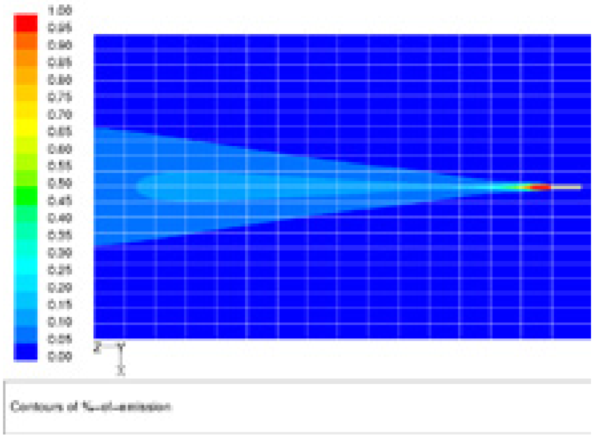
Run 2: Control, neutral, 2 fans, 1 m/s, 20 °C



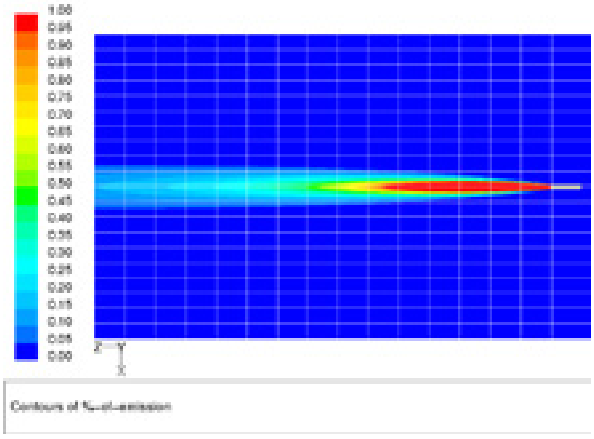
Run 3: Control, neutral, 2 fans, 4.5 m/s, 5 °C



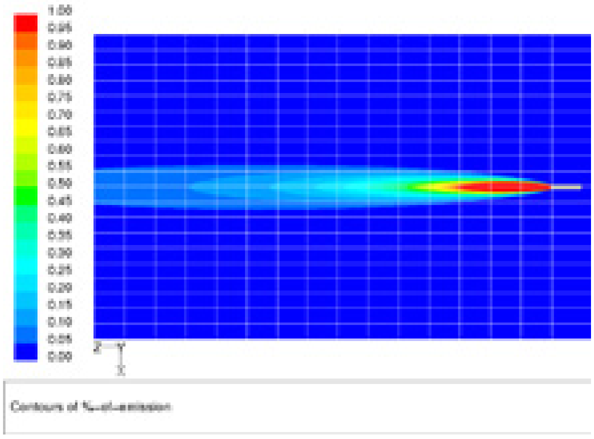
Run 4: Control, neutral, 2 fans, 4.5 m/s, 20 °C



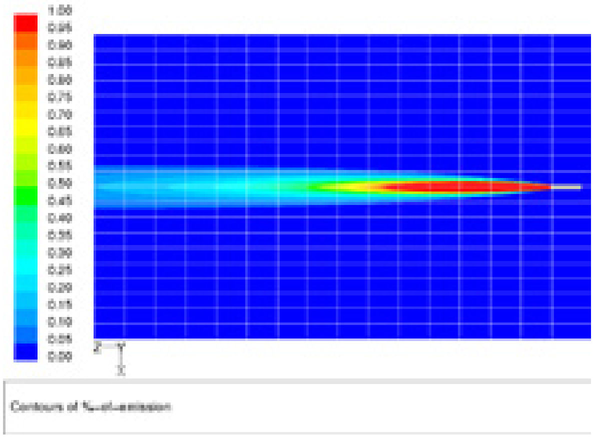
Run 5: Control, neutral, 8 fans, 1 m/s, 5 °C



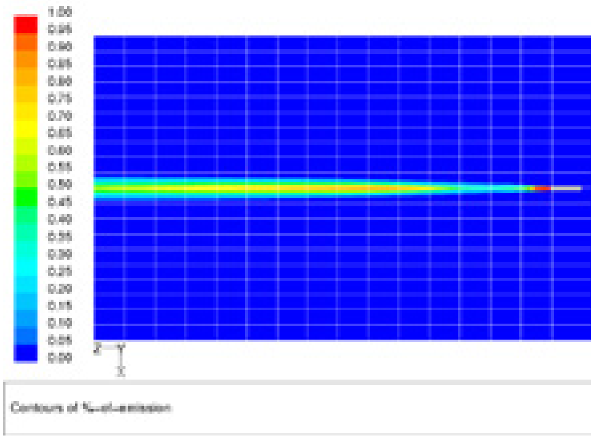
Run 6: Control, neutral, 8 fans, 1 m/s, 20 °C



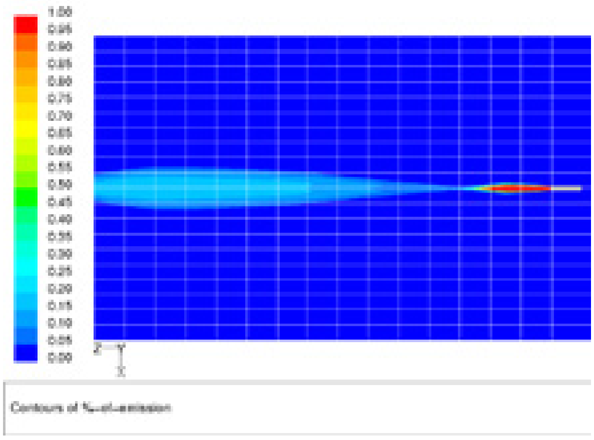
Run 7: Control, neutral, 8 fans, 4.5 m/s, 5 °C



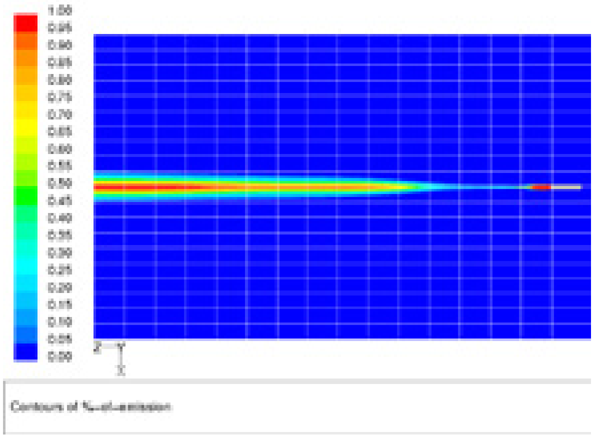
Run 8: Control, neutral, 8 fans, 4.5 m/s, 20 °C



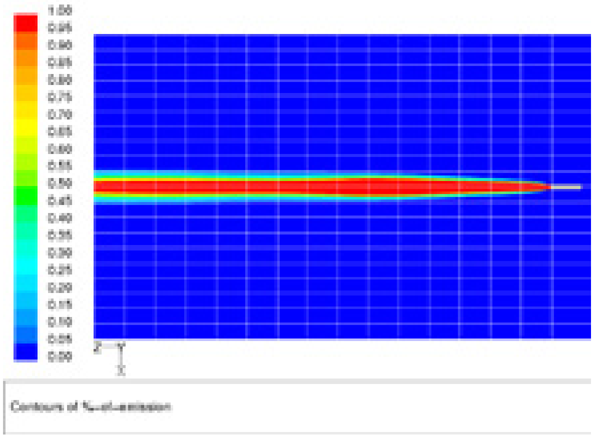
Run 9: Control, stable, 2 fans, 1 m/s, 5 °C



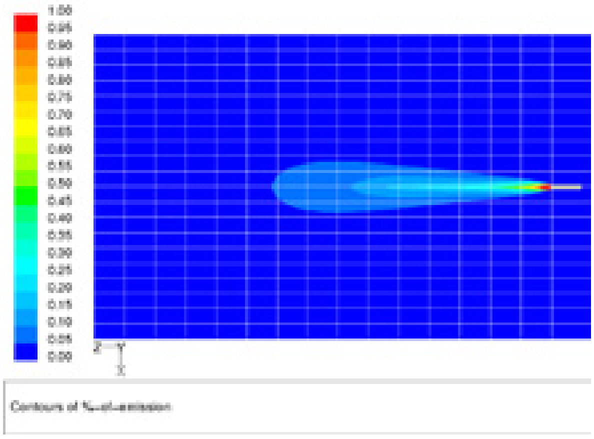
Run 10: Control, stable, 2 fans, 1 m/s, 20 °C

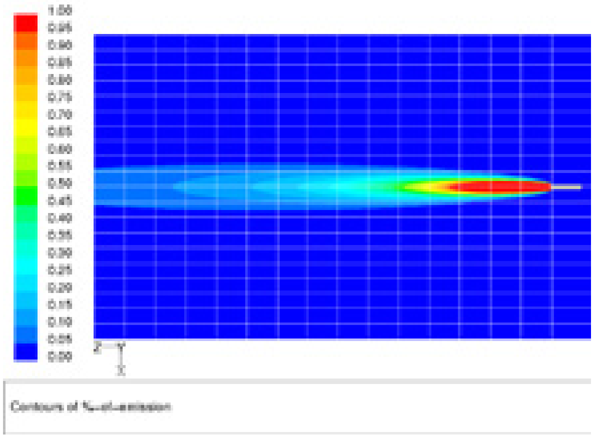


Run 11: Control, stable, 8 fans, 1 m/s, 5 °C



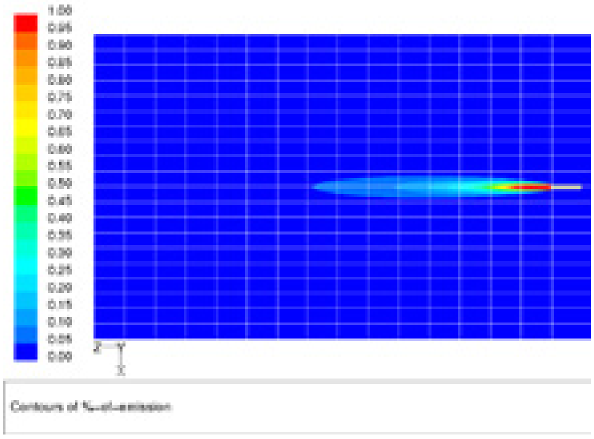
Run 12: Control, stable, 8 fans, 1 m/s, 20 °C

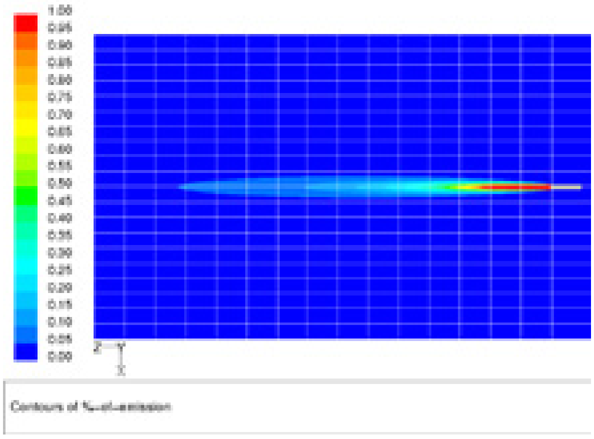




Run 21: Windbreak wall, neutral, 2 fans, 1 m/s, 5 °C

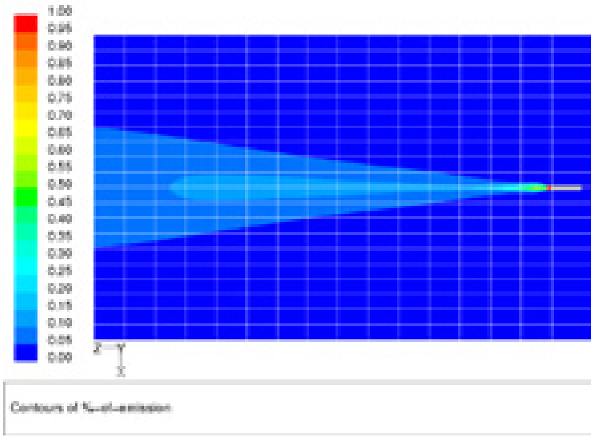
Run 22: Windbreak wall, neutral, 2 fans, 1 m/s, 20 °C

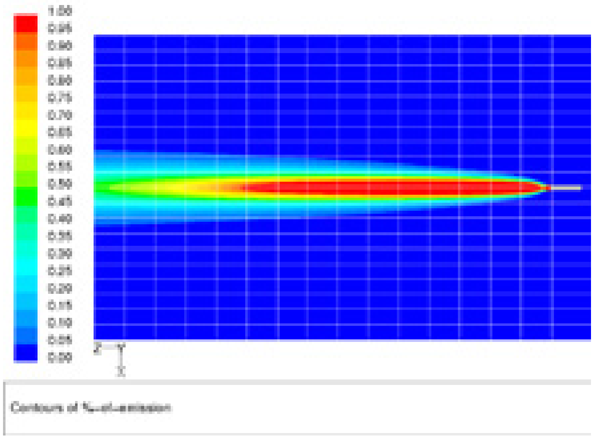




Run 23: Windbreak wall, neutral, 2 fans, 4.5 m/s, 5 °C

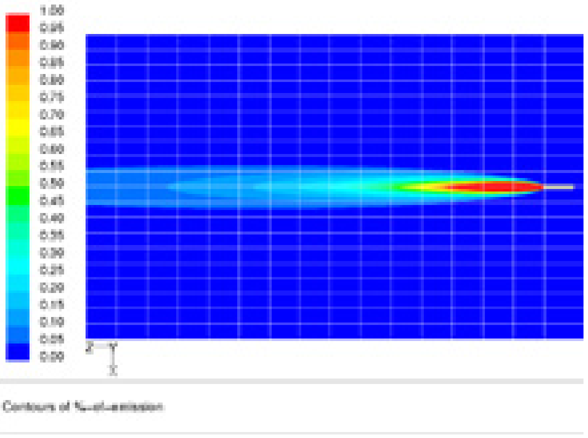
Run 24: Windbreak wall, neutral, 2 fans, 4.5 m/s, 20 °C

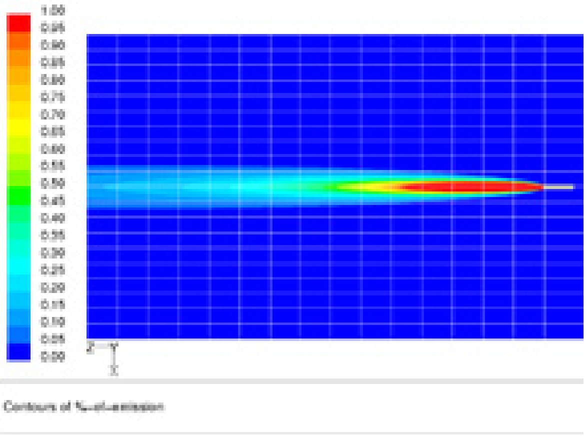




Run 25: Windbreak wall, neutral, 8 fans, 1 m/s, 5 °C

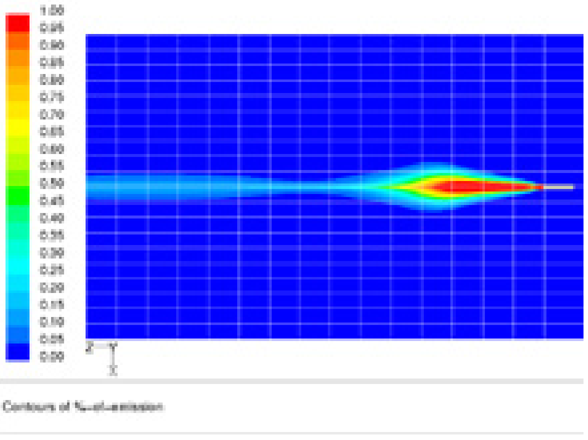
Run 26: Windbreak wall, neutral, 8 fans, 1 m/s, 20 °C

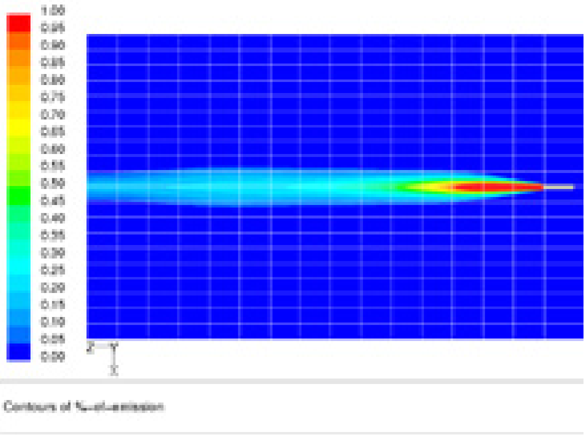




Run 27: Windbreak wall, neutral, 8 fans, 4.5 m/s, 5 °C

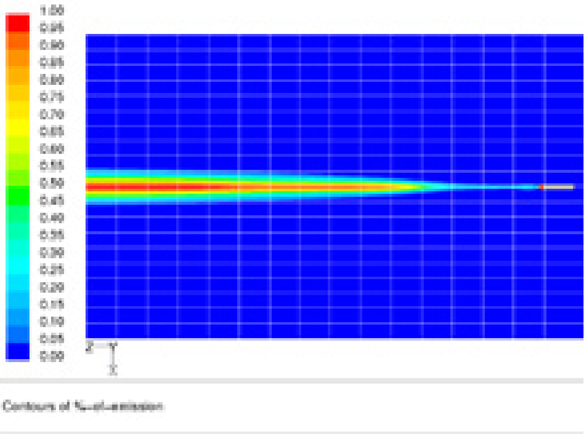
Run 28: Windbreak wall, neutral, 8 fans, 4.5 m/s, 20 °C

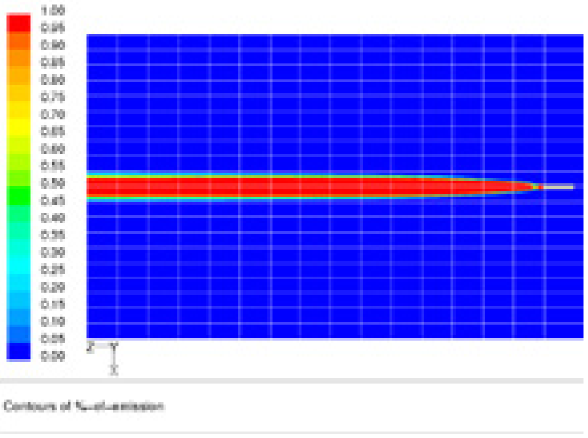




Run29: Windbreak wall, stable, 2 fans, 1 m/s , 5 °C

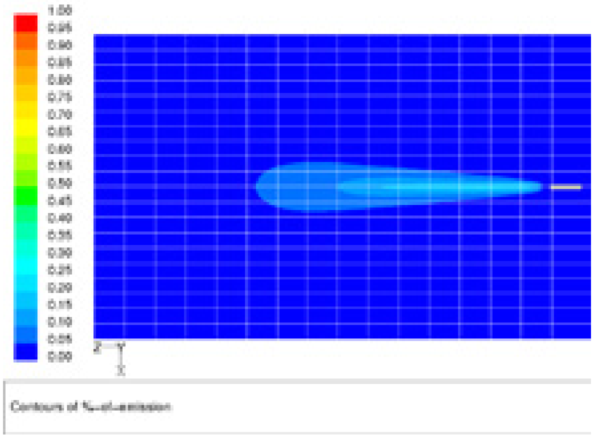
Run 30: Windbreak wall, stable, 2 fans, 1 m/s, 20 °C



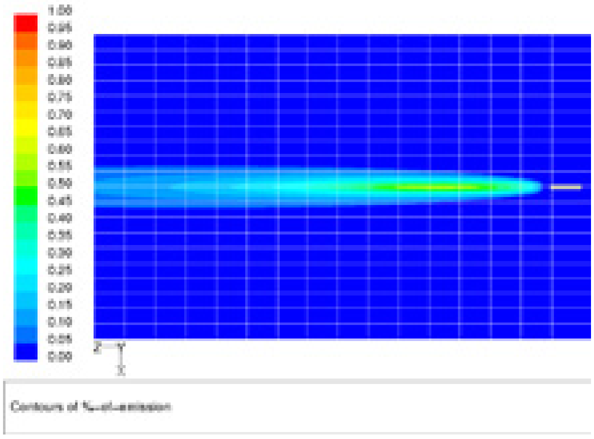


Run 31: Windbreak wall, stable, 8 fans, 1 m/s, 5 °C

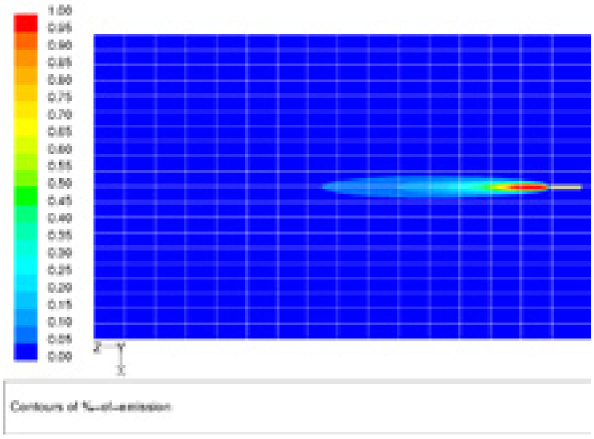
Run 32: Windbreak wall, stable, 8 fans, 1 m/s, 20 °C



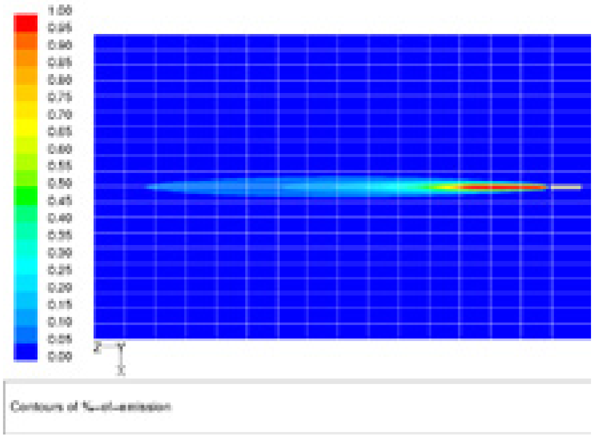
Run 41: Short stacks, neutral, 2 fans, 1 m/s, 5 °C



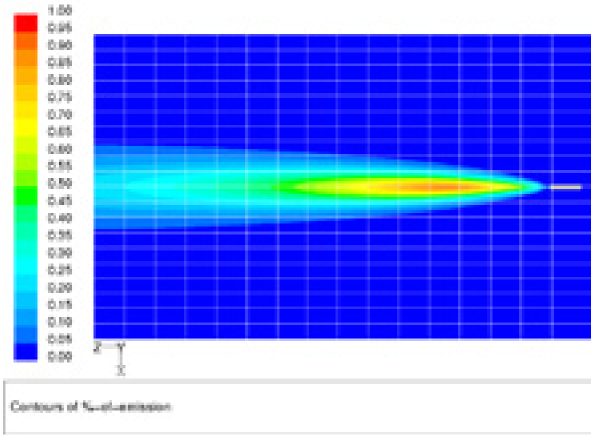
Run 42: Short stacks, neutral, 2 fans, 1 m/s, 20 °C



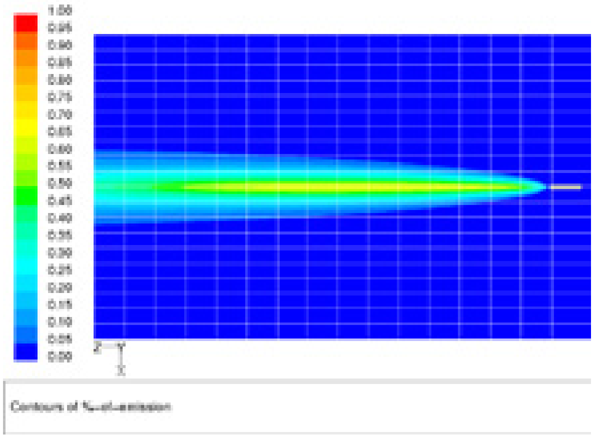
Run 43: Short stacks, neutral, 2 fans, 4.5 m/s, 5 °C



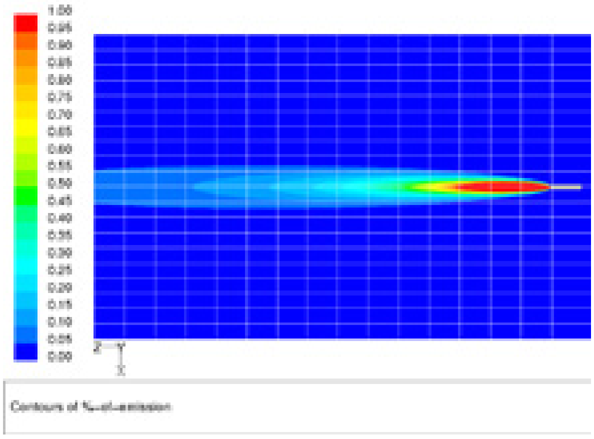
Run 44: Short stacks, neutral, 2 fans, 4.5 m/s, 20 °C



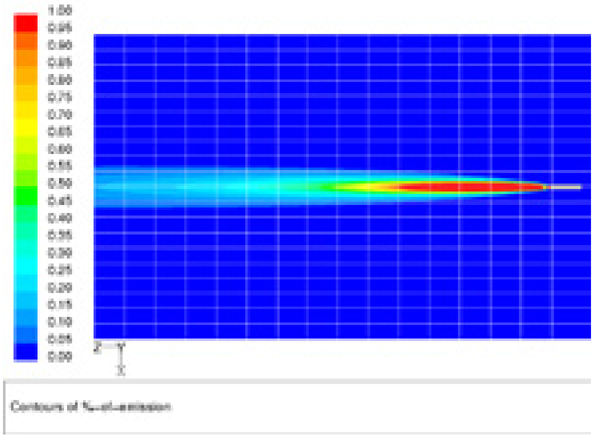
Run 45: Short stacks, neutral, 8 fans, 1 m/s, 5 °C



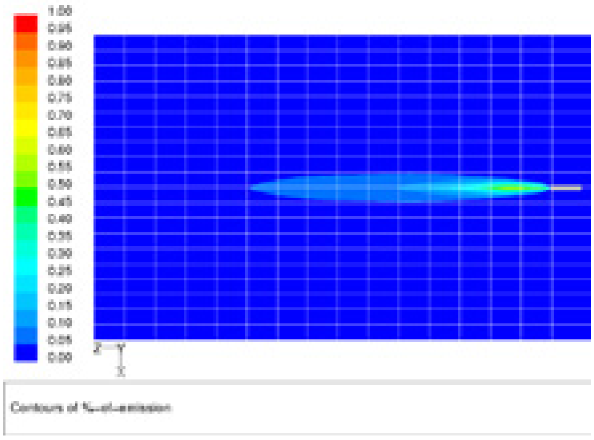
Run 46: Short stacks, neutral, 8 fans, 1 m/s, 20 °C



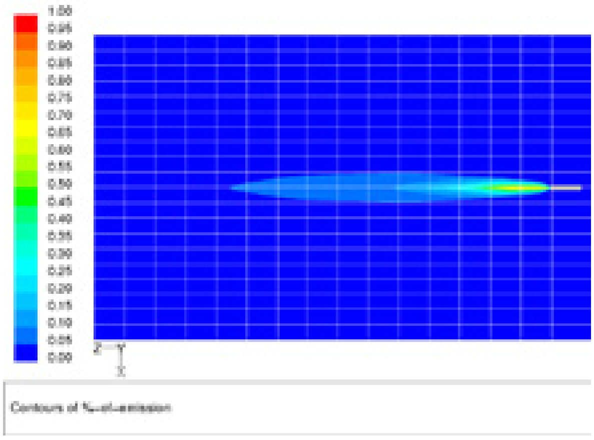
Run 47: Short stacks, neutral, 8 fans, 4.5 m/s, 5 °C



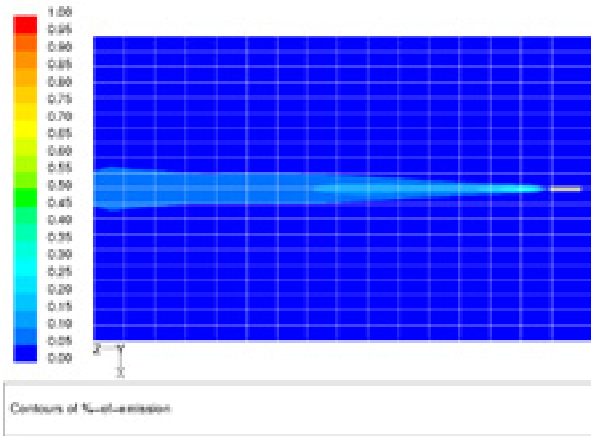
Run 48: Short stacks, neutral, 8 fans, 4.5 m/s, 20 °C



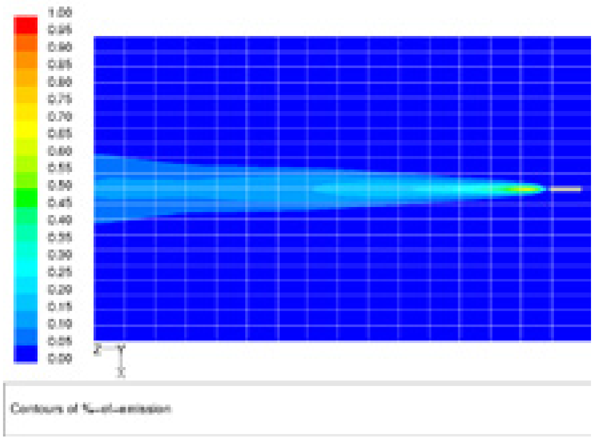
Run 49: Short stacks, stable, 2 fans, 1 m/s, 5 °C



Run 50: Short stacks, stable, 2 fans, 1 m/s, 20 °C



Run 51: Short stacks, stable, 8 fans, 1 m/s, 5 °C



Run 52: Short stacks, stable, 8 fans, 1 m/s, 20 °C

Appendix 4

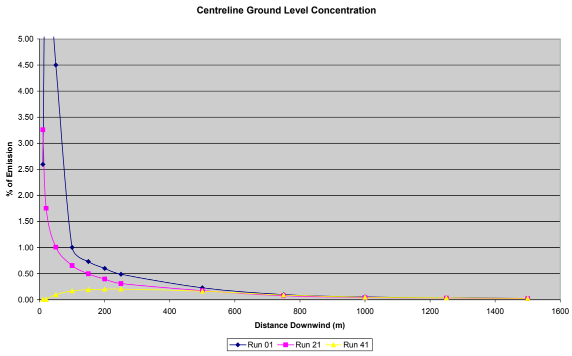
CFD modelling results - centreline ground level concentration data

Building configuration	Stability class	Active fans	Wind speed (m/s)	External ground temperature (^oC)	Run ID number	Distance Downwind											
						10	20	50	100	150	200	250	500	750	1000	1250	1500
Control	Neutral	2	1	5	1	2.60	6.69	4.50	1.00	0.73	0.60	0.49	0.23	0.10	0.05	0.04	0.03
				20	2	2.75	12.45	29.20	21.89	12.34	6.20	2.82	0.58	0.28	0.16	0.11	0.08
			4.5	5	3	24.89	20.22	6.80	2.13	1.07	0.66	0.39	0.10	0.05	0.03	0.02	0.02
				20	4	25.45	21.67	7.24	2.43	1.27	0.77	0.46	0.12	0.06	0.04	0.03	0.02
		8	1	5	5	87.78	82.59	13.41	0.97	0.50	0.33	0.21	0.12	0.12	0.13	0.12	0.08
				20	6	88.73	83.50	63.51	41.16	32.11	26.60	21.44	9.96	4.62	2.38	1.53	1.08
			4.5	5	7	91.88	75.40	25.42	7.87	3.96	2.47	1.50	0.42	0.22	0.13	0.09	0.07
				20	8	93.66	89.86	77.67	35.77	17.43	10.15	5.48	1.15	0.54	0.31	0.21	0.15
	Stable	2	1	5	9	1.79	2.89	7.21	0.83	0.49	0.41	0.40	0.82	0.80	0.72	0.64	0.55
				20	10	4.87	14.11	24.14	19.07	14.86	7.05	0.94	0.08	0.14	0.17	0.17	0.18
		8	1	5	11	86.95	82.10	13.33	0.83	0.37	0.23	0.15	0.71	0.92	0.92	0.99	0.99
				20	12	91.59	87.80	56.87	20.00	11.54	8.77	7.43	3.84	2.40	1.74	1.45	1.24
Windbreak Wall	Neutral	2	1	5	21	3.26	1.76	1.01	0.66	0.50	0.40	0.31	0.17	0.08	0.04	0.03	0.02
				20	22	16.29	13.37	9.17	5.80	3.77	2.61	1.66	0.48	0.25	0.15	0.10	0.07
			4.5	5	23	9.27	6.09	3.02	1.47	0.88	0.59	0.37	0.11	0.06	0.03	0.02	0.02
				20	24	13.29	9.55	4.99	3.19	2.13	1.48	0.93	0.24	0.12	0.07	0.05	0.04
		8	1	5	25	1.41	0.71	0.59	0.44	0.31	0.23	0.17	0.12	0.12	0.13	0.10	0.08
				20	26	6.23	1.76	1.31	1.86	2.09	2.19	2.22	2.00	1.58	0.99	0.68	0.49
			4.5	5	27	14.24	6.15	5.43	4.02	2.82	2.29	1.53	0.45	0.23	0.14	0.10	0.08
				20	28	18.57	9.25	6.01	5.57	4.94	4.19	3.05	0.85	0.44	0.27	0.19	0.15
	Stable	2	1	5	29	7.91	2.77	0.65	1.33	1.58	1.64	1.43	0.59	0.20	0.15	0.14	0.13
				20	30	19.63	14.03	6.72	3.74	2.47	1.84	1.28	0.44	0.28	0.23	0.20	0.18
		8	1	5	31	1.86	0.52	0.28	0.28	0.23	0.20	0.18	0.82	0.93	0.95	0.99	0.98
				20	32	6.80	2.06	1.39	2.91	3.86	4.63	5.66	5.67	5.00	4.22	3.61	3.08
Short Stacks	Neutral	2	1	5	41	0.01	0.01	0.10	0.17	0.19	0.20	0.21	0.16	0.09	0.05	0.04	0.03
				20	42	0.03	0.04	0.16	0.31	0.39	0.45	0.50	0.51	0.34	0.22	0.15	0.11
			4.5	5	43	0.97	2.77	2.56	1.46	0.91	0.61	0.38	0.10	0.05	0.03	0.02	0.02
				20	44	0.04	2.86	4.30	3.24	2.47	2.08	1.52	0.31	0.14	0.08	0.06	0.04
		8	1	5	45	0.06	0.11	0.28	0.49	0.62	0.70	0.82	0.81	0.58	0.41	0.30	0.23
				20	46	0.05	0.18	0.35	0.49	0.55	0.58	0.61	0.65	0.65	0.60	0.49	0.38
			4.5	5	47	3.82	2.20	3.33	3.61	2.80	2.13	1.46	0.44	0.22	0.13	0.09	0.07
				20	48	2.43	0.59	1.64	2.55	2.91	2.98	2.81	0.98	0.48	0.28	0.20	0.15
	Stable	2	1	5	49	0.29	0.46	0.50	0.55	0.57	0.51	0.35	0.10	0.06	0.05	0.05	0.04
				20	50	0.46	0.70	0.73	0.73	0.69	0.60	0.39	0.11	0.06	0.05	0.05	0.04
		8	1	5	51	0.04	0.09	0.21	0.27	0.23	0.19	0.15	0.11	0.10	0.08	0.08	0.08
				20	52	0.08	0.23	0.56	0.64	0.50	0.41	0.32	0.19	0.16	0.12	0.11	0.11

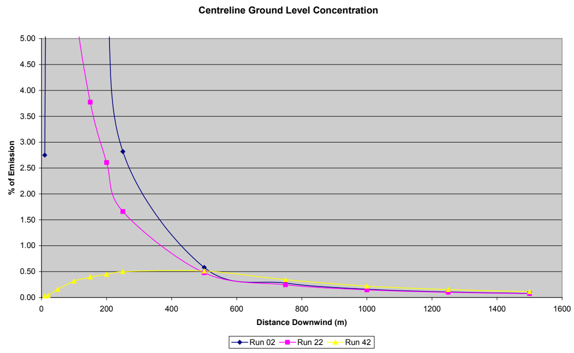
Appendix 5

Centreline GLC charts for all modelling scenarios to compare the performance of the windbreak wall and short stacks against the control

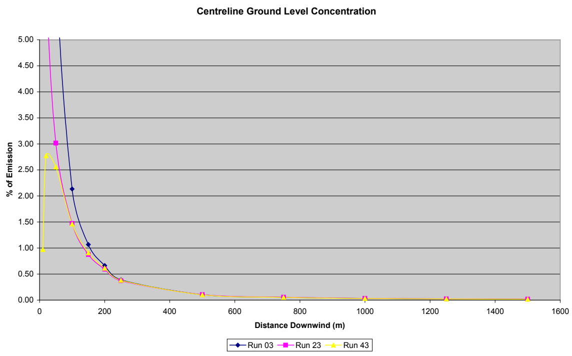
Captions refer to “run number: stability class, active fans, wind speed and external temperature.”



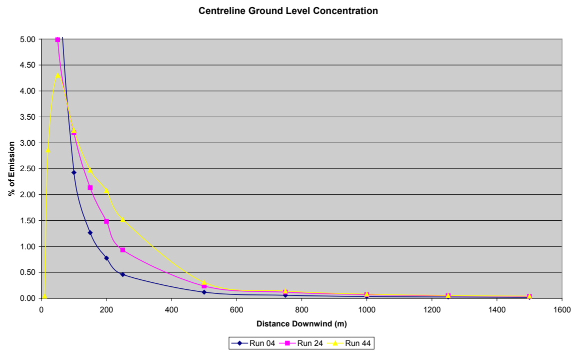
Runs 1, 21 & 41: Neutral, 2 fans, 1 m/s, 5 °C



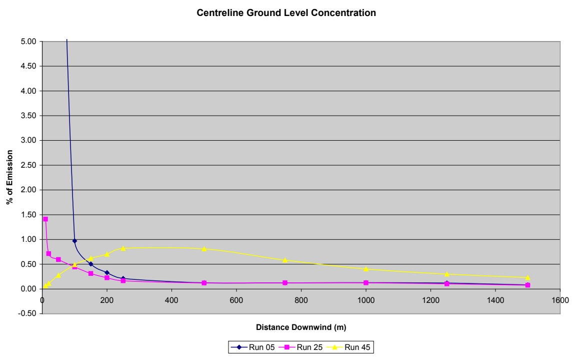
Runs 2, 22 & 42: Neutral, 2 fans, 1 m/s, 20 °C



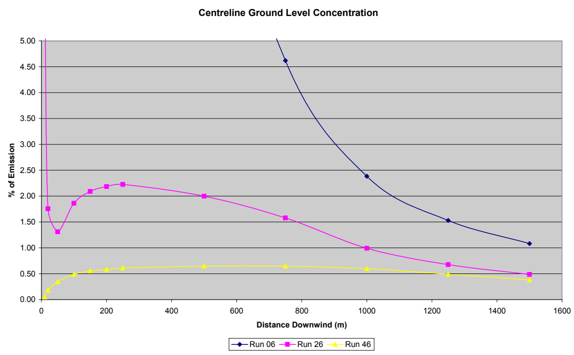
Runs 3, 23 & 43: Neutral, 2 fans, 4.5 m/s, 5 °C



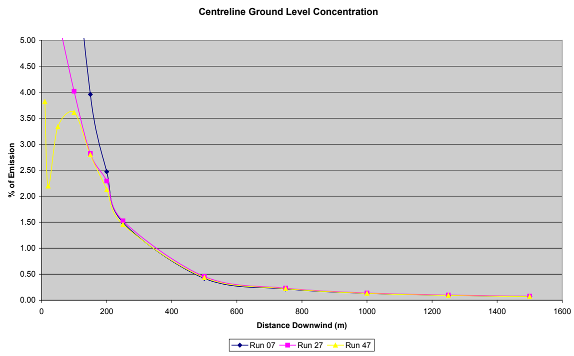
Runs 4, 24 & 44: Neutral, 2 fans, 4.5 m/s, 20 °C



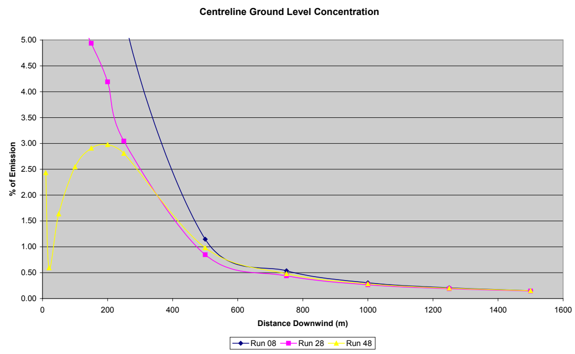
Runs 5, 25 & 45: Neutral, 8 fans, 1 m/s, 5 °C



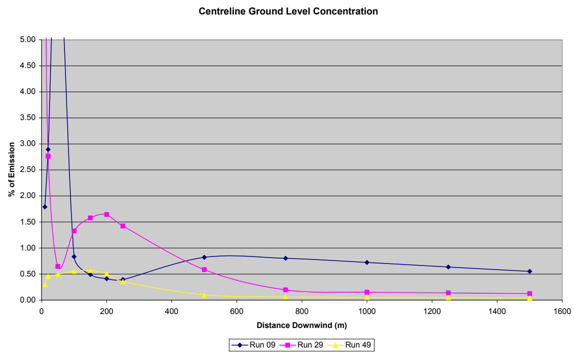
Runs 6, 26 & 46: Neutral, 8 fans, 1 m/s, 20 °C



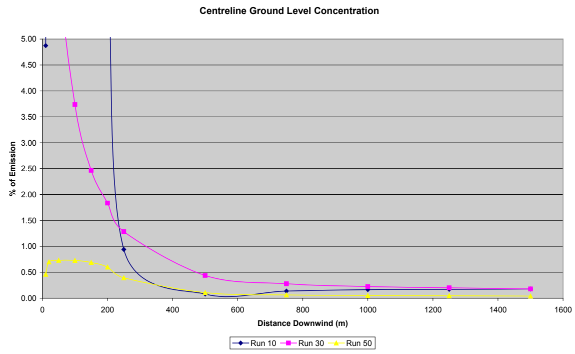
Run 7, 27 & 47: Neutral, 8 fans, 4.5 m/s, 5 °C



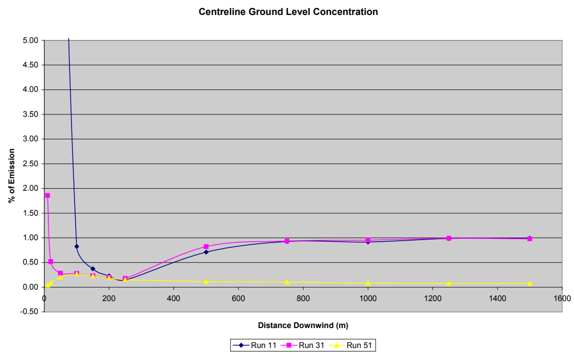
Run 8, 28 & 48: Neutral, 8 fans, 4.5 m/s, 20 °C



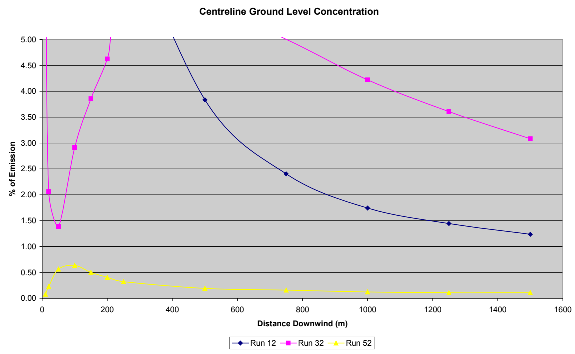
Runs 9, 29 & 49: Stable, 2 fans, 1 m/s, 5 °C



Runs 10, 30 & 50: Stable, 2 fans, 1 m/s, 20 °C



Runs 11, 31 & 51: Stable, 8 fans, 1 m/s, 5 °C



Runs 12, 32 & 52: Stable, 8 fans, 1 m/s, 20 °C

References

Abernathy, R.N., Min, I.A., Lundblad, B.L. and Kempf, W.S. 1999. *Tracer Puff Dispersion at Launch Sites.* TR-99(1413)-4, California: The Aeropace Corporation.

Wind Rose. Advanced Technology Systems, I. 1999, 5.1.2600.1106. Tennessee: ATS.

Bottcher, R.W., Munilla, R.D., Baughman, G.R., and Keener, K.M. 2000. Designs for Windbreak Walls for Mitigating Dust and Odor Emissions from Tunnel Ventilated Swine Buildings. *In Swine Housing, Proceedings of the First International Conference,* St Joseph, Michigan: ASAE.

Bottcher, R.W., Munilla, R.D., Keener, K.M., and Gates, R.S. 2001. Dispersion of Livestock Building Ventilation Using Windbreaks and Ducts. *2001 ASAE Annual International Meeting,* no. 01-4071. St Joseph, Michigan: ASAE.

Bottcher, R.W., Keener, K.M., and Munilla, R.D. 2000. Comparison of odor control mechanisms for wet pad scrubbing, indoor ozonation, windbreak walls and biofilters. *2000 ASAE Annual International Meeting,* Michigan: ASAE.

Briggs, G. 2004. *Agnote: Odour management options for meat chicken farms.* Agnote DAI-325, Tocal: NSW Agriculture.

Calpuff. Earth Tech, I. version 5.7. Concorde, MA: Avalable from http://www.src.com.

Ausplume. EPA Victoria and CAMM , version 5.4. Victoria, Australia: EPA Victoria.

Featherstone, D. 2006. *CFD modelling of windbreak wall for shed emission dispersion.* 6047, Melbourne: Synergetics Environmental Engineering.

Ford, S.E. and Riskowski, G.L. 2003 . Effect of Windbreak Wall Location on Ventilation Fan Performance. *Applied Engineering in Agriculture* 19, 343-346.

Kai, P., Ellermann, T., Mikkelsen, T., Lofstrom, P., and Jorgensen, H. 2003. Effect of Stack Height on Close Range Dispersion of Exhaust Air from Pig Houses. *Proceedings of CIGR International Symposium on "Gaseous and Odour Emissions from Animal Production Facilities".*

McGahan, E., Kolominskas, C., Bawden, K., and Ormerod, R. 2002. Strategies to reduce odour emissions from meat chicken farms. *Poultry Information Exchange*.

Pollock, T. and Anderson, S. 2004. *Review of Modelling, Emission Measurement and Treatment of Odour and Dust Emissions from Broiler Farms.* 03-29, Armidale: Australian Poultry Cooperative Research Centre.

Robinson, S. and Hulme, T. 2004. *NSW Meat Chicken Farming Guidelines: Managing Planning, Development and Environmental Issues*, New South Wales: NSW Agriculture.

Santos, J.M., Griffiths, R.F., Roberts, I.D. and Reis Jr., N.C. 2005 . A field experiment on turbulent concentration fluctuations of an atmospheric tracer gras in the vicinity of a complex shaped building. *Atmospheric Environment* 39, 4999-5012.

Standards Australia 1987. Australian Standard: Ambient Air - Guide for measurement of horizontal wind for air quality applications (AS 2923-1987). Sydney: Standards Australia International Ltd.

US Environmental Protection Agency: Centre for Environmental Research Information 1999. *Compendium Method TO-17: Determination of Volatile Organic Compounds in Ambient Air Using*

*Active Sampling onto Sorbent Tubes.*Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air. EPA/625/R-96/010b, Cincinnati, OH: USEPA.

USEPA 2000. *Meteorological Monitoring Guidance for Regulatory Modelling Applications.* Meteorological Monitoring Guidance for Regulatory Modelling Applications (EPA-454/R-99-005), USA: USEPA, Office of Air Quality Planning and Standards.

Venkatram, A., Isakov, V., Pankratz, D., Heumann, J. and Yuan, J. 2004a . The analysis of data from an urban dispersion experiment. *Atmospheric Environment* 38, 3647-3659.

Venkatram, A., Isakov, V., Pankratz, D. and Yuan, J. 2004b . Modelling dispersion at distances of meters from urban sources. *Atmospheric Environment* 38, 4633-4641.

Control of Odour and Dust from Chicken Sheds

Evaluation of windbreak walls

By Mark Dunlop and Geordie Galvin

Pub. No. 13/001

Odour from tunnel ventilated broiler sheds has the potential to cause odour impacts. Meat chicken producers are under pressure to reduce odour impacts and need cost-effective solutions. Windbreak walls have been proposed as an affordable technology that may improve the dispersion of odours from tunnel ventilated broiler sheds, in turn reducing odour impacts.

Information presented in this report will enable better decision making for those considering or recommending windbreak walls to reduce odour impacts.

RIRDC is a partnership between government and industry to invest in R&D for more productive and sustainable rural industries. We invest in new and emerging rural industries, a suite of established rural industries and national rural issues.

Most of the information we produce can be downloaded for free or purchased from our website <www.rirdc.gov.au>.

RIRDC books can also be purchased by phoning 1300 634 313 for a local call fee.

RURAL INDUSTRIES
Research & Development Corporation

Phone:	02 6271 4100
Fax:	02 6271 4199
Bookshop:	1300 634 313
Email:	rirdc@rirdc.gov.au
Postal Address:	PO Box 4776, Kingston ACT 2604
Street Address:	Level 2, 15 National Circuit, Barton ACT 2600

www.rirdc.gov.au