RESEARCHREPORT

ENVIRONMENT

Title: Developing a Decision Support Tool to Optimize Swine Production Facility Layout to Minimize Downwind Air Quality Impacts **- NPB #05-118**

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Abstract

One of the most significant and persistent environmental concerns regarding swine production is the transport of odor constituents (e.g. ammonia and hydrogen sulfide), trace gases (e.g. greenhouse gases like methane and nitrous oxide), and particulates from animal production and manure storage facilities. This project involved a series of wind tunnel tests to determine how swine production building orientation and distance between buildings and above-ground slurry tanks or lagoons affect transport of odor constituents (measured as evaporated water). Scale models of swine finisher units, above-ground slurry tanks, and lagoons were constructed and deployed in a series of orientations and spacings. Air flow characteristics (velocity and turbulence intensity) near the models were measured with a hot film anemometer system and evaporation from the slurry tanks and lagoons was monitored with a position transducer.

Although building models perpendicular to air flow reduced air velocity downstream much more than parallel models, evaporation from the model slurry tanks with parallel or perpendicular models were with ~10%. The strong reduction in evaporation at the 2h separation distance (2 x's building height) with 4 building models suggests that velocity reduction by the buildings has a potential "odor trapping" effect over a short distance. Conversely, a strong increase in evaporation at 5h suggests that reattachment of flow may be occurring at that distance that may enhance odor transport. These results indicate relatively strong differences in air flow and evaporation over short distances. As these results were obtained under carefully controlled laboratory conditions, it is uncertain how likely these patterns would be reproduced under field conditions with variable wind speed and direction. Results for the lagoon models offer a strong contrast to the slurry tank results. In this case, evaporation is increased in the majority of runs (all runs with 1 model) regardless of building orientation. A likely explanation is that, even though the building models reduced air velocity, turbulence near the surface in their wake significantly enhanced air mixing and evaporation from the water surface. Over all the runs, evaporation from the lagoon models was, on average, 73% greater than from the slurry tank models. A limited number of runs with model trees and a model hill indicated increased evaporation for most building/manure storage model combinations. This result was unexpected and, as hot film anemometer measurements were not made for these runs, it is difficult to interpret these results. The most likely explanation is that the tree models, even though they reduced the mean velocity, may have increased turbulent mixing near the surface. The hill model upstream did not create a protective "odor trapping" wake zone over the manure storage models but instead enhanced transport.

Introduction

One of the most significant and persistent environmental concerns regarding swine production is the transport of odor constituents (e.g. ammonia and hydrogen sulfide), trace gases (e.g. greenhouse gases like methane and nitrous oxide), and particulates from animal production and manure storage facilities. Building type, facility management, animal diet, and climate determine the amount of potential air quality constituents generated at a production facility. Local environmental conditions, especially wind speed and direction, vegetative cover, and topography determine the amount of odor and trace gas compounds transported from production facilities.

When new swine production facilities are designed, many factors are considered including vehicle access, utility location, land area available, slope, obstructions, and soil properties. Most of the design criteria are concerned with economic issues, that is, minimizing the cost of site development and building construction. However, where a production facility is located and how the animal housing units and manure storage facilities are arranged are key factors in determining the amount and distance that potential air quality constituents are transported.

Due to the large number of potential building arrangements and varying land cover and topography, studies on the transport of air quality constituents from and near buildings of various types (i.e. urban, suburban, and industrial) have often been conducted in wind tunnels (e.g. Huber and Snyder, 1982; Huber, 1989). Wind tunnels offer the advantage of being able to make detailed measurements with scale models of actual buildings under controlled environmental conditions. Some studies combine wind tunnel and field measurements (Mavroidis et al., 2003; Aubrun and Leitl, 2004b) and have generally shown that careful wind tunnel experiments provide an accurate and reproducible assessment of field conditions. Even wind tunnel studies however, are often completed with single or simplified models due to the complexity of air flow disturbance by the models. For the same reason, comprehensive measurement of air flow and air quality constituent transport at full scale swine production facilities requires a very large investment in sophisticated sensing equipment, well beyond the resources of most research teams. Even when such resources are available, the data collected are only relevant as a case study, i.e. for one location under the conditions occurring during the measurement period.

As wind approaches a solid object like a swine-housing unit, the air accelerates around the sides and over the top of the building diverting air and disturbing the airflow downwind. If an aboveground manure storage tank or earthen storage facility (lagoon) is located downwind from a building complex, the orientation of the buildings and the distance between the buildings and manure storage facility will affect transport of air quality constituents from the storage facility. It is, therefore, important to know whether the storage facility is exposed to increased wind speed and turbulence or if it is protected by the upwind structures. If modifying the layout of a production facility reduces the downwind air quality impacts and can be accomplished with no or a small increase in construction costs, then the producer will derive direct air quality benefits for the lifetime of the facility for a minimal one-time cost.

Objectives

The objective of this study is to create a user-friendly decision support tool (software) that incorporates the results of a series of wind tunnel experiments into a practical framework for optimizing swine production facility layout to minimize downwind air quality impacts. This research will determine how swine housing unit orientation and distance from manure storage facilities affect potential air quality constituent (odor and trace gas) transport. *Note: Per correspondence from NPB on 8-16-05 the software component was eliminated and additional wind tunnel experiments with topography and land cover changes were added.*

Materials and Methods

The low-speed wind tunnel of the Air Quality of Agricultural Systems (AQAS) Research Unit at the National Soil Tilth Laboratory (NSTL) is designed for environmental research applications. The AQAS wind tunnel has a centrifugal blower capable of producing a range of air velocities from 0.5 to 12 m s^{-1} (1-27 mph) in a control section 0.46 m tall, 1.22 m wide, and 5.49 m long (18" tall, 48" wide, and 18' long). The control section's roof is adjustable to a 0.76 m (30") height to accommodate experiments with larger scale models. This wind tunnel was designed to enable accurate simulation of atmospheric boundary layer conditions (wind speed, turbulence, and temperature profile) appropriate for environmental applications (Wooding, 1968; Barlow et al., 1999). The AQAS facility includes advanced instrumentation for pinpoint measurement of air velocity and turbulence (1-, 2-, and 3-D hot film anemometers). Supporting instrumentation includes various dataloggers and sensors for monitoring air and surface temperatures, static and dynamic air pressure, and relative humidity. A computer-controlled traversing mechanism enables the precise (sub-mm) movement of these sensors within the wind tunnel control section in x, y, and z coordinates.

Standard wind tunnel tests

Models of swine housing units and manure storage facilities (approximately 1/300th scale) were placed in the control section of the wind tunnel to simulate an array of possible arrangements. Scaling criteria followed standard wind tunnel guidelines described by Snyder (1981) and VDI-guideline (2000). A trip fence and array of triangular spires were used to create a surface boundary layer within the control section with properties similar in scale to the earth's atmospheric boundary layer (Armitt and Counihan, 1968). The floor of the control section was covered with a vinyl mat (Readygrass™) used in model railroad displays that was glued to 1.61 mm-thick (1/8") sheet metal. The vinyl mat provided a uniform surface with a texture similar in scale to mown grass. Evaporation of water from scale models of aboveground (slurry tank) and earthen manure storage (rectangular lagoon) facilities were used to evaluate relative odor/trace gas transport under different building orientations, separation distances, and air velocities. Evaporation of water is used as a surrogate for odor constituents and trace gases as the same transport mechanisms apply to water vapor as for those gaseous compounds. The baseline condition will be the model manure storage facility without any housing unit arrays upwind. Evaporation measurements were made at reference air velocities at the top of the model buildings of 0.5, 2, and 5 m s^{-1} (1, 5, and 11 mph) with data collected on 1-min intervals for a length of time long enough to establish equilibrium conditions at that velocity (~2 hrs).

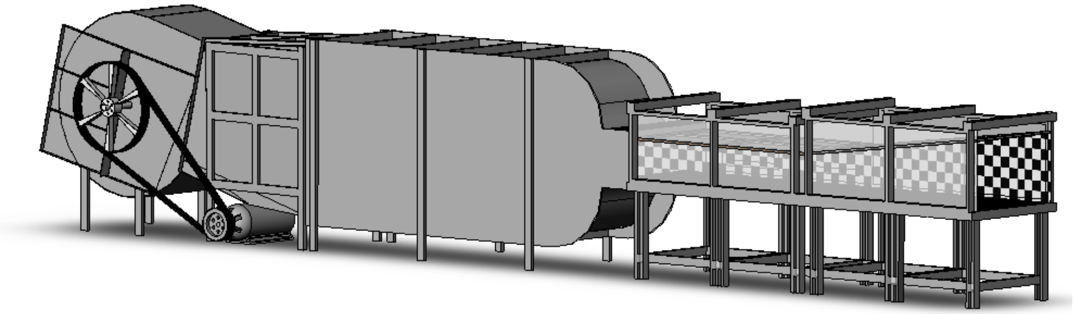


Fig. 1 Schematic diagram of AQAS low-speed wind tunnel showing blower on left and control section on right where models were placed and measurements were made. The control section (with black and white checkerboard pattern) is 1.22 m wide, 0.76 m high, and 5.49 m long (28" wide, 18" high, and 18' long).

Design factors evaluated were: 1) number of housing units, 2) orientation of the housing units with regard to wind direction, 3) distance between the housing units and the manure storage structure, and 4) local surface roughness and topography. Scale models of housing units were constructed following typical dimensions and roof pitches of commercial production facilities. Measurements were made with 1 or 4 housing units of the same dimensions. These models were oriented parallel to airflow, at a 30° angle to airflow, and perpendicular to airflow. All measurements were made with the housing unit arrays upwind from the manure storage models. Separation distance between the housing unit arrays and manure storage models varied by multiples of building height (h). Separation distances evaluated were 2h, 5h, and 10h. The manure storage models were also scaled following standard industry dimensions. Evaporation from the manure storage models was measured using a linear variable digital transformer (LX-PA, Unimeasure, Inc., Corvallis, OR), which can measure water level to 0.01 mm accuracy.

Scale models of 1000-head swine finisher units were made from balsa wood (Fig 2). The models are 40 mm-wide (1.6”) and 200 mm-long (7.9”) with 10.2 mm-tall side walls (0.4”), 2 mm-overhang (0.08”), roof slope of 4/12, and peak height of 17.5 mm (0.7”). Magnets attached to the bottom allowed positioning of the models on the floor of the control section. These models are ~1:300 scale versions of swine finisher buildings approximately 40 ft-wide (12 m) and 200 ft-long (60 m) with 8 ft side walls (2.4 m), 17 ft peak height (5.25 m) and foundation 2 ft above-grade (0.6 m).

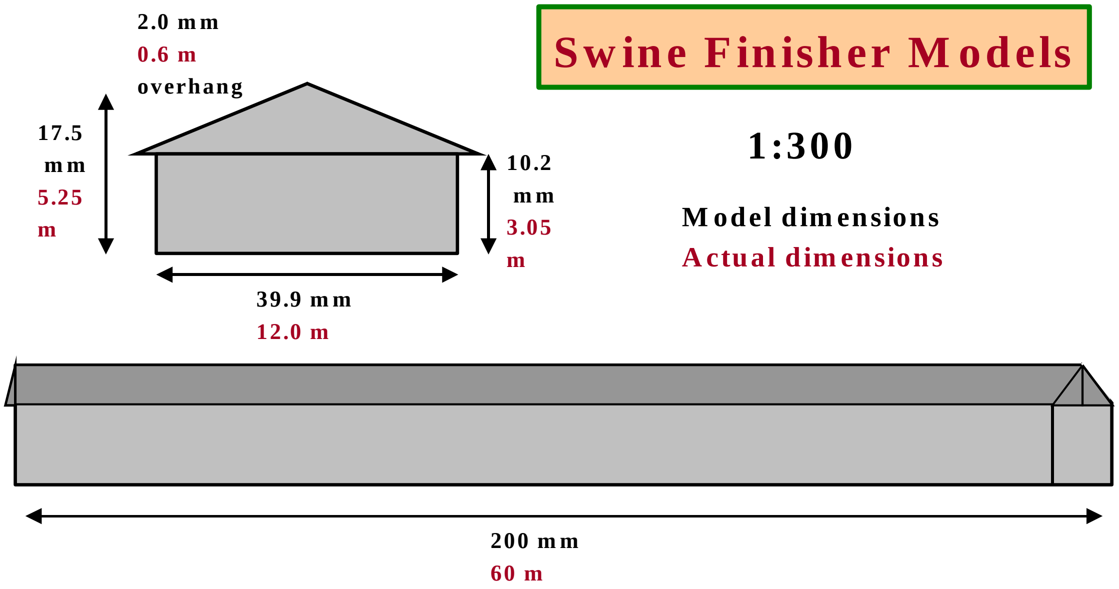


Fig. 2 End and side views of a model hog finisher building.

Models of above-ground liquid manure (slurry) storage tanks were constructed from aluminum tubing and protruded 25 mm (1”) through the floor of the control section. Two sizes were made based on design guidelines for animal numbers in 1 and 4 of the model finisher buildings. The storage tanks models were filled with water and the rate of evaporation was measured using a float system connected to the LVDT position transducer. A wire mesh screen was placed on the water surface to reduce wave action. Water temperature in the slurry tank models was measured with thermocouples and an infrared thermometer (OS137, Omega Engineering, Inc., Stamford, CT) and controlled by a thermoelectric heat exchanger (MTTC-1410, Melcor Corp., Trenton, NJ). This

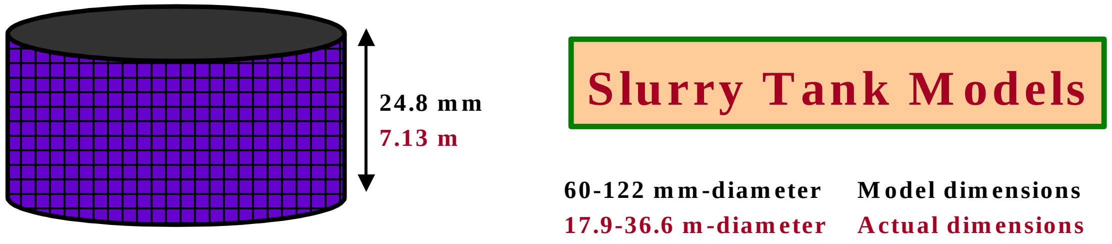
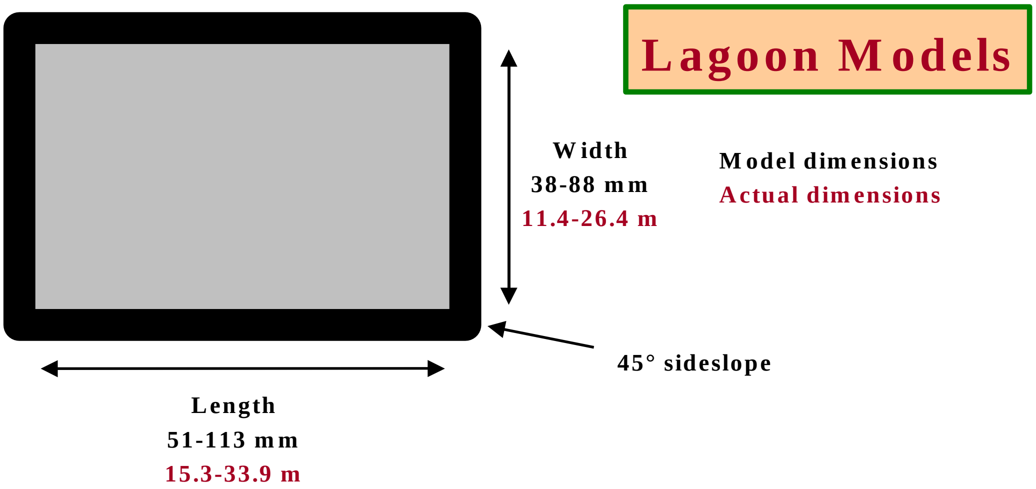


Fig. 3 Side view of model above-ground manure storage tank, tank height, and range of inside dimensions.

allowed for consistency of temperature gradients between water in the models and air in the control section.

Lagoon models were constructed from rectangular steel pipe with 6.35 mm-thick sidewalls (0.25”). The top of the sidewalls sloped inward at a 45° angle to simulate 1:1 sideslopes. The lagoon models had surface areas similar to the aboveground slurry tank models and were built to scale following American Society of Agricultural and Biological Engineers (ASABE) design standards (ASAE 2004a & b). Temperature and evaporation measurements with the lagoon models were made using all the same sensors and techniques as for the aboveground slurry tank models.

Fig. 4 Overhead view of model lagoon and inside dimensions.



The standard measurement program was to measure evaporation from the manure storage model (slurry tank or lagoon) with each of the housing unit model arrays (number, orientation, and separation distance) at the 3 air velocities. These results were then compared to the evaporation from the same manure storage facility model at each velocity with no housing unit models upstream. These results were summarized to develop relationships between number and orientation of housing units and separation distance on air quality constituent transport from the manure storage models. A relative “source strength” factor for air quality constituent transport was calculated for each physical setting using the data from the respective wind tunnel runs without any animal housing unit models as the standard.

Air flow and turbulence measurements and flow visualization

Air flow and turbulence measurements downstream from building model arrays were completed using a constant temperature anemometer system (IFA 300, TSI Inc., Shoreview, MN) equipped with a 3-D hot film probe (Model 1299). Measurements were made at distances of 2h, 5h, and 10h downstream from the building models for 4 building arrays parallel, transverse, and at 30° to air flow (Fig. 5). Measurements were also completed with no models and with 1 building model parallel or transverse to air flow. The 3-D probe was mounted on a traverse mechanism that allowed automated measurement sequences. The air flow measurements were made at each of 83 points in a 215 x 400 mm area (8.5 x 15.7”) centered behind the building models (Fig. 6). Velocity measurements and turbulence statistics were calculated from 26 s of data collected at a

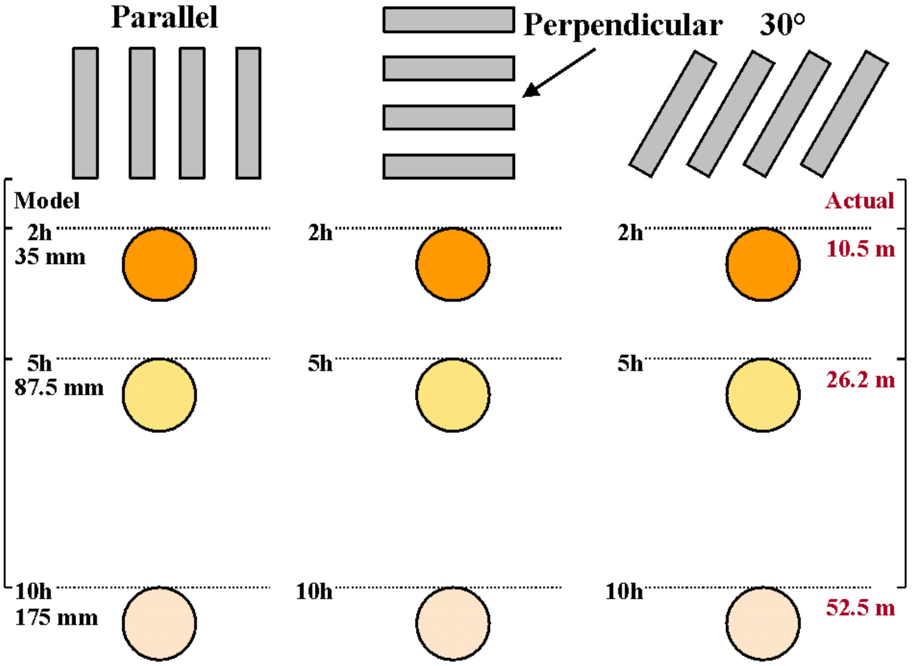


Fig. 5 Example of model layouts for all 4 building arrays with slurry tanks showing both model and actual (full scale) dimensions.

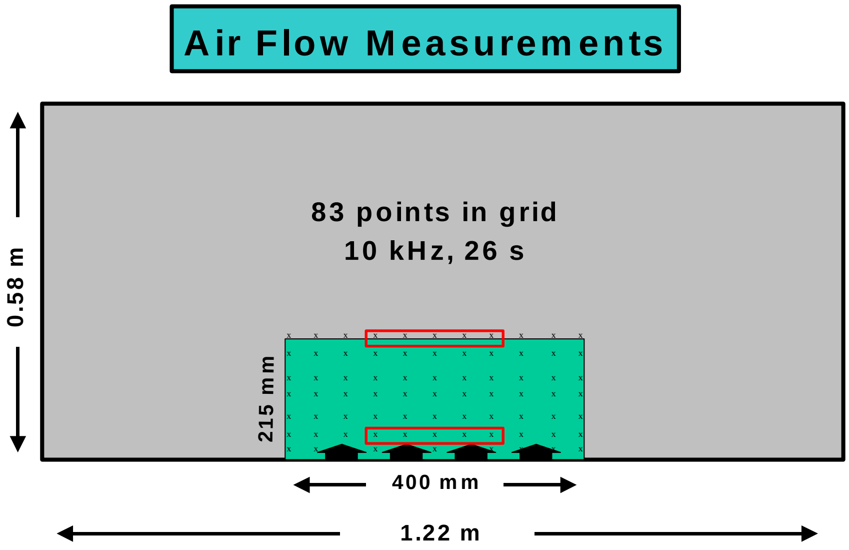


Fig. 6 Measurement zone within control section for hot film anemometer data collection. Four building models oriented parallel to the air flow are shown at the bottom. The red rectangles indicate grid points used to calculate free stream velocities (upper) and velocity at 35 mm (lower) that is affected by the building models.

rate of 10 kHz at each measurement point. Visualization of flow around the building models and slurry tank was accomplished using dry ice to generate a smoke effect. Digital photographs were taken from various points of observation to visually illustrate air flow patterns around these structures.

Wind tunnel tests of roughness and topography effects

A separate series of wind tunnel runs addressed surface roughness and topography influences on air quality constituent transport. These experiments were completed with 4 housing unit models and both slurry tank and lagoon models with a separation distance of 2h at the 0.5 and 2 m s^{-1} air velocities and parallel and transverse building orientations. Runs were completed with 5.25 mm-tall (2“) tree models constructed from 8 x 8 wire mesh following Aubrun and Leitl (2004a) to simulate forested terrain. A model forest consisting of 8 rows of trees perpendicular to air flow was positioned upstream of the building models and downstream of the manure storage models. These runs were repeated with the housing unit and manure storage models upstream and downstream from a model hill 3.75 cm (1.5”) high and 37.5 cm (15”). The model forest and hill were placed in the same locations so a direct comparison of forest and topography could be made.

Fig. 7 Photo of 3D hot film anemometer behind four model swine finisher buildings mounted on vinyl mat. Spires are visible in background. Sensor to left of models is hot needle anemometer used to adjust air velocity at the height of the top of the building models.

Results

Air flow patterns

The effect of the swine finisher models on air flow downwind was a major focus of this project. Figs. 8-10 show several examples of building effects on air flow. Fig. 8 shows graphs of contour lines of air velocity and turbulence intensity (standard deviation of the air velocity divided by the average velocity then multiplied by 100) at the different distances downwind from 4 models (see Fig. 5) oriented parallel to airflow. For actual finisher buildings, Figs. 8 A-C correspond to separation distances of 35, 87.5, and 175 ft downwind from a finisher building with a peak height of 17 ft. The parallel models accelerate airflow between the models and have an effect on overall air velocity up to a height of about 3h (45 mm) from the floor of the control section at a distance of 2h (35 mm) downwind from the models. There is still some effect on air velocity at 5h downwind but the air flow appears to be little-effected by the buildings at a distance 10h downwind. Mean air velocity 35 mm above the floor of the control section was 60-64%

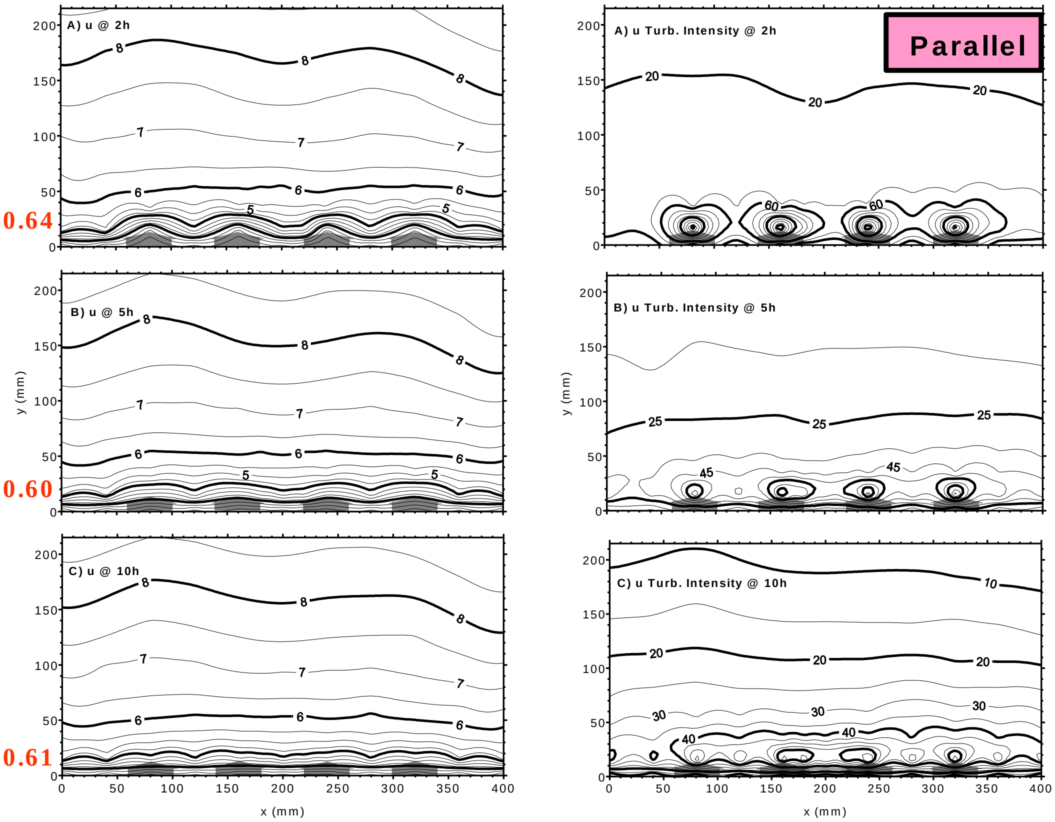


Fig. 8 Contour plots of air velocity (left) and turbulence intensity (right) for 4 finisher models oriented parallel to air flow at distances of 2h (top), 5h (middle), and 10h (bottom) downstream. The mean velocity at the building model height was 5 m s^{-1} (11 mph). Large numbers on left are the ratio of the average velocity at 35 mm to the free air velocity at 215 mm.

of the free stream velocity. This is only slightly lower that when no building models were present when the velocity at 35 mm averaged 67% of the free stream velocity.

These graphs also show that the variation of air flow with time is very high near the building models. In the atmosphere, turbulence intensity is often 20-30%, which is similar to the values 150-200 mm above the models in Fig. 8. High turbulence intensity indicates very “gusty” conditions due to airflow around the solid models that may increase the likelihood of enhanced transport of gases and particles away from the buildings. These results indicate that building models oriented parallel to air flow reduce the mean velocity ~5% and create some localized zones of high turbulence intensity.

Fig. 9 is of the same format as Fig. 8 except for 4 building models oriented perpendicular to air flow. In this instance, there are more dramatic effects on air flow patterns. Mean velocity at 35 mm was now only 48-51% of the free stream velocity and was consistent at all separation distances. A large wake region of reduced velocity was observed behind the center 1/3 of the models that extended to a height of ~5h (95 mm). Over all

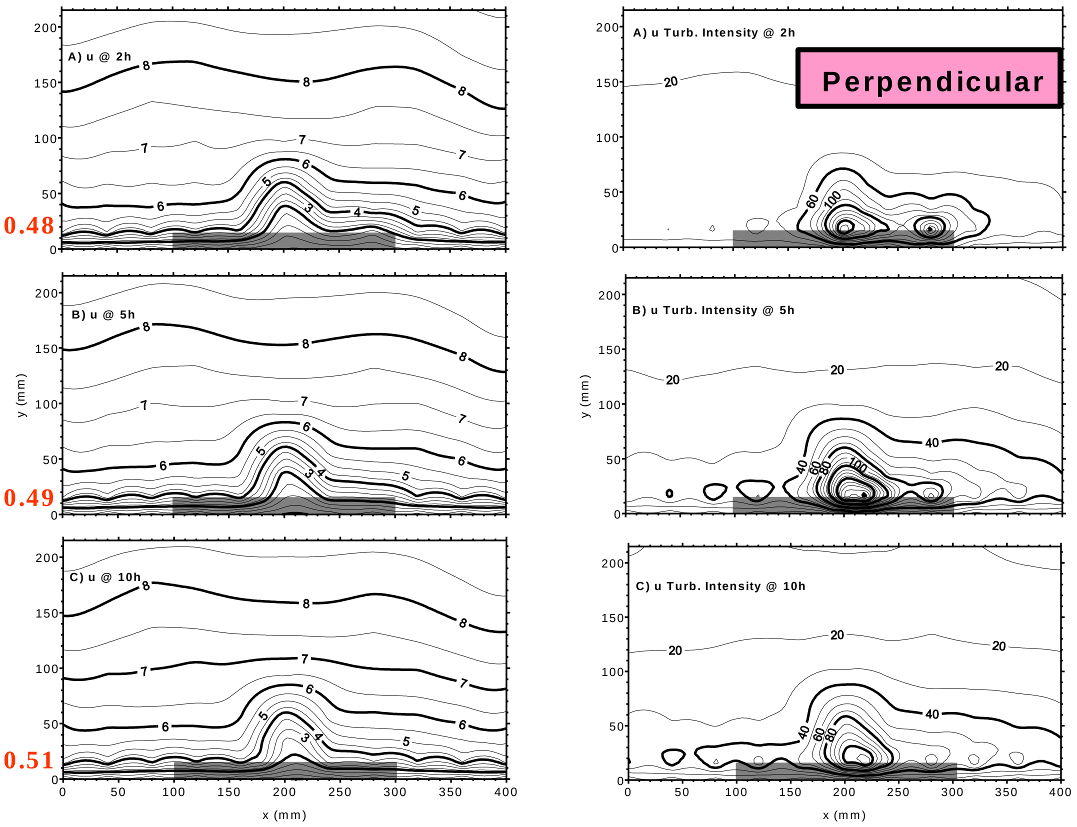


Fig. 9 Contour plots of air velocity (left) and turbulence intensity (right) for 4 finisher models oriented perpendicular to air flow at distances of 2h (top), 5h (middle), and 10h (bottom) downstream. The mean velocity at the building model height was 5 m s^{-1} (11 mph). Large numbers on left are the ratio of the average velocity at 35 mm to the free air velocity at 215 mm.

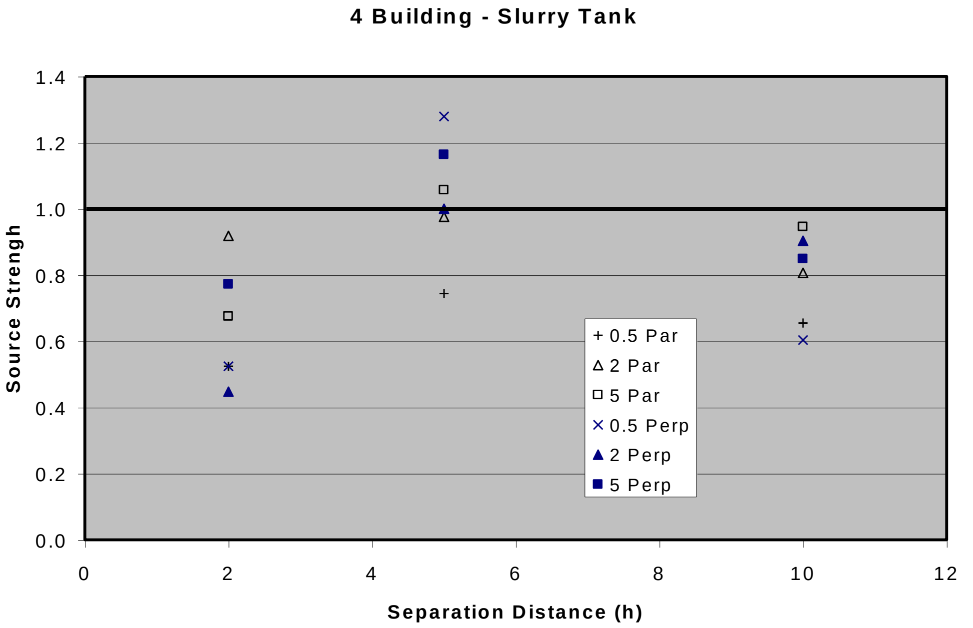
velocities, the parallel and perpendicular models had mean air velocities at 35 mm of 61% and 38% of the free stream velocity, which compares with 67% when no models were present. Values ranged from a low of 13% for perpendicular models at 0.5 m s^{-1} and 2h separation distance to 64% for parallel models at 5 m s^{-1} and 2h separation distance.

Air flow patterns were also measured behind 4 models oriented at a 30° angle to air flow (data not shown). This model orientation showed intermediate effects on velocity reduction (average 54% of free stream) and a non-distinct turbulent wake zone similar to the parallel model tests. For these reasons, further experiments with this orientation were not completed. Tests with single building models produced results that were not always comparable to the tests with 4 models (data not shown). Over all tests, a single building parallel or perpendicular to air flow produced mean velocities at 35 mm of 57% and 55% of the free stream velocity, respectively. Unlike the 4 building tests, in this case greater mean velocity reduction was observed at the lowest velocity of 0.5 m s^{-1} (44.3% and 37.5% of the free stream velocity for a parallel and perpendicular model with values >60% at the other velocities).

Evaporation/source strength

Results of the evaporation tests showed clear differences in relative source strength between the slurry tank and lagoon models with less distinct differences for building model orientation and separation distance (Figs. 10-13). For all of these figures, source strength was calculated by taking 60 data points (minutes) of evaporation data for each combination of building model (number and orientation) with manure storage model (slurry tank or lagoon at 3 separation distances) after equilibrium conditions had been reached to determine a mean evaporation rate for that physical setup. This value was then divided by the mean evaporation rate for the respective manure storage model and position without any buildings present. Thus, a source strength = 1 indicated that the presence of the building models had no significant effect on evaporation. A value < 1 indicated the buildings reduced evaporation from the manure storage model and a value > 1 indicated that the buildings increased evaporation from the manure storage model.

Fig. 10 Source strength vs. separation distance for 0.5, 2, and 5 m s^{-1} air velocities and 4 building models either parallel (Par) or perpendicular (Perp) to air flow upstream of a slurry tank model.



Source strength for slurry tank experiments produced more consistent results between runs than for lagoon experiments. For the 4 building runs (Fig. 10), the parallel and perpendicular building models reduced evaporation an average of 19% and 16%, respectively. All building arrays reduced evaporation at the 2h and 10h separation distances (average of 36% and 21%, respectively) but had little effect at 5h (average 4% increase). For the 1 building runs (Fig. 11), the building models, on average, produced only a 4% decrease (parallel models) or a 5% increase (perpendicular models) in source strength. However, there was a consistent decrease in evaporation with separation distance from an average increase of 21% at 2h to an average 17% decrease at 10h.

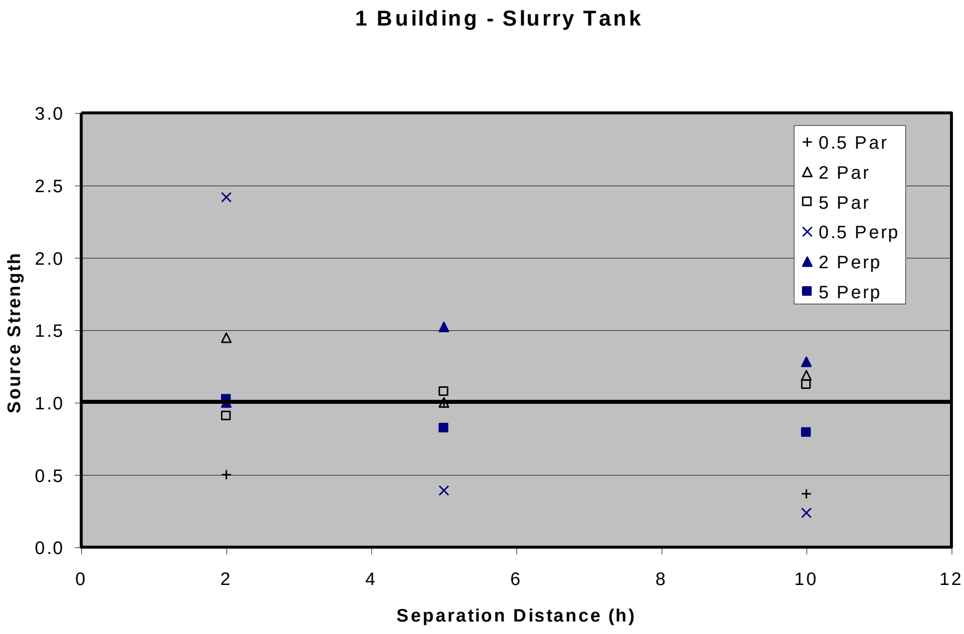


Fig. 11 Source strength vs. separation distance for 0.5, 2, and 5 m s^{-1} air velocities and 1 building model either parallel (Par) or perpendicular (Perp) to air flow upstream of a slurry tank model.

Results for the lagoon test runs contrast sharply with the results for the slurry tank models (Figs. 11-12). For the 4 model runs (Fig. 11), both parallel and perpendicular model arrays increased evaporation (average of 79% and 40%, respectively). Also, average evaporation was greater at all separation distances (47%, 113%, and 19% at 2h, 5h, and 10h, respectively). Compared to the slurry tank runs, there was more variation among runs and some outlying values were observed at 2h and 5h. However, the degree of variation was even greater for the 1 model runs (Fig. 12), especially for the 5h separation distance. In addition, source strength values were much greater for the 1 building lagoon runs than for any other series of experiments. On average, parallel and perpendicular models increased evaporation by factors of 6.2 and 8.7, respectively. Evaporation at each separation distance was also increased dramatically, by average factors of 4.3, 10.6, and 7.4 at 2h, 5h, and 10h, respectively.

Results with the model trees and model hill upstream or downstream from the building and slurry tank or lagoon models gave unexpected results (data not shown). Even though

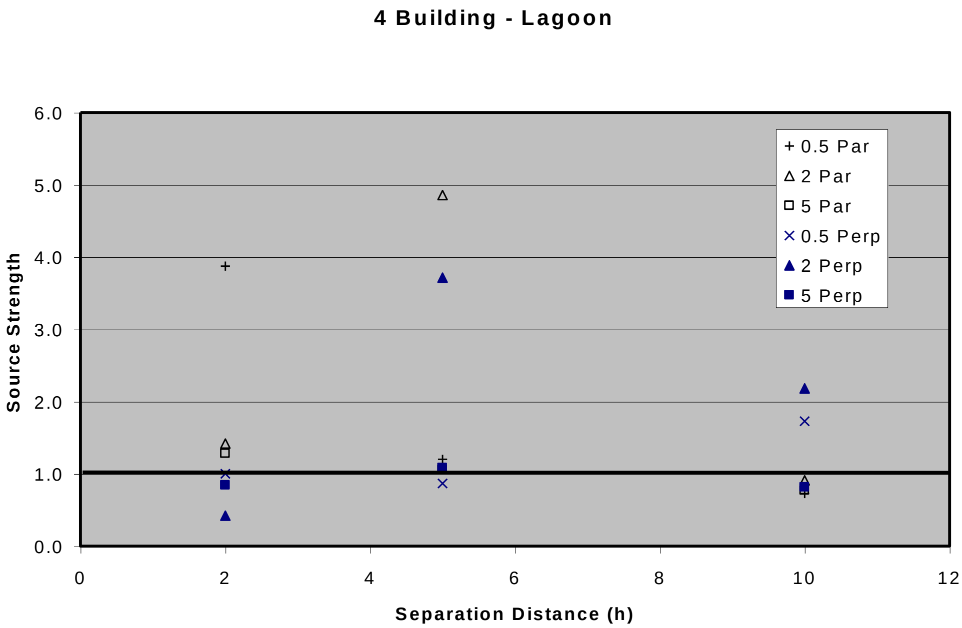


Fig. 12 Source strength vs. separation distance for 0.5, 2, and 5 m s^{-1} air velocities and 4 building models either parallel (Par) or perpendicular (Perp) to air flow upstream from a lagoon model.

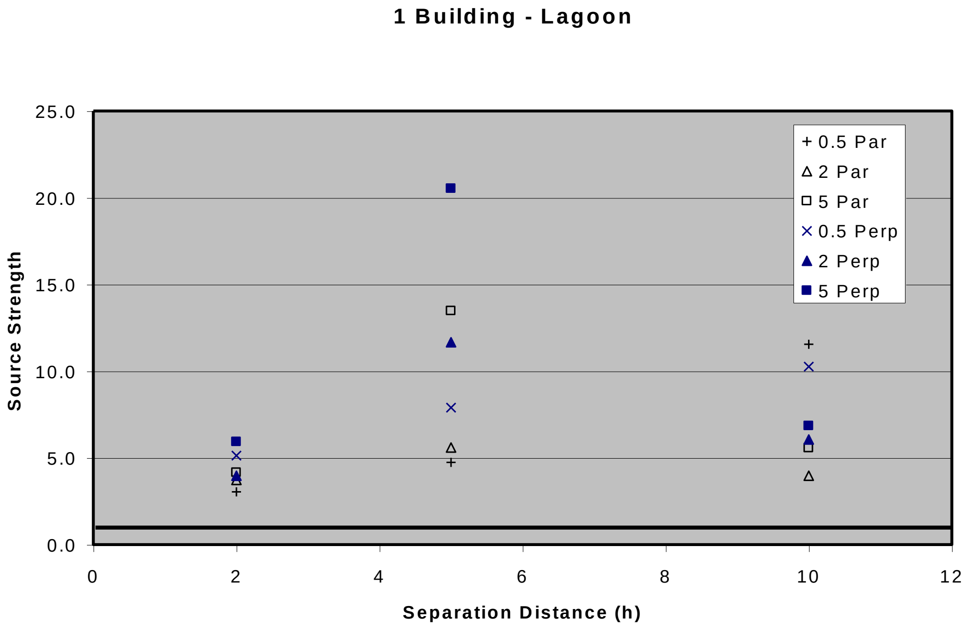


Fig. 13 Source strength vs. separation distance for 0.5, 2, and 5 m s^{-1} air velocities and 1 building model either parallel (Par) or perpendicular (Perp) to air flow upstream from a lagoon model.

tree models upstream reduced air velocity at the building models, this did not always translate to a reduction in evaporation. For all test runs, tree models upstream increased evaporation an average of 47% compared to the same building/manure storage model with no trees. The combination of upstream forest with perpendicular building models effectively doubled the evaporation rate. These results are difficult to explain and further study will be necessary to fully understand why the reduction in mean air velocity did not reduce evaporation. There were no hot film anemometer measurements made with the tree or hill models. Future air flow characterization measurements would likely help explain these results.

Results of runs with the model hill showed some similarities with the forest model results although the hill had limited effect on mean air velocity near the model buildings and slurry tank or lagoon. For all measurements made with the model hill upstream, evaporation was nearly doubled (92% increase) compared to the no-hill runs. As for the tree models, the combination of hill upstream and perpendicular building models resulted in the highest average evaporation rates (2.4 x's). While the tree models likely increased turbulence near the surface, it is unclear how the model hill would have enhanced evaporation downstream.

Discussion

The challenge of data interpretation for this study in linking the observed air flow characteristics with the evaporation measurements. Building effects on turbulence intensity were more distinct when the models were perpendicular to air flow as a zone of high turbulence intensity was observed in conjunction with the zone of velocity reduction. This strong wake region of low mean velocities and high turbulence intensities is typical of near-wake behavior behind solid obstacles. However, wakes behind 3-D obstacles are particularly complex since flow separation and reattachment can occur in many different forms and at different locations. For instance, it is likely that there was flow reversal behind the building models and a recirculating frontal vortex beneath the eave of the leading model. The sloping roof of the first model likely encouraged an upward jet of air that encouraged skimming flow over the downstream models. Flow visualization (smoke) experiments were helpful in observing some of these effects (Fig. 14), especially effects on the leading edges of models. However, diffusion of the smoke with distance makes it very difficult to visually observe air flow patterns downstream from the models, which are critical to interpretation of the evaporation data. Edge effects on the lateral ends of the perpendicular models also likely produced the characteristic shape of the turbulent wake over the middle 1/3 of the perpendicular models. These effects and flow reattachment downstream are also likely to be influenced by air velocity.

As the slurry tank models themselves disturb the local air flow, it is to be expected that evaporation from the slurry tank models would not be as strongly affected by the upstream building models. Thus, although the perpendicular building models reduced air velocity downstream much more than the parallel models, evaporation from the model slurry tanks with parallel or perpendicular models were with ~10%. The strong reduction in evaporation at the 2h separation distance with 4 building models does suggest that velocity reduction by the buildings has an "odor trapping" effect over a short distance.

Fig. 14 Flow visualization showing smoke flow skimming across 4 swine finisher models perpendicular to air flow with a lagoon model 2h downstream. Air flow was 2 m s^{-1} (5 mph).

Wire mesh tree models are visible on the right.

Conversely, the strong increase in evaporation at 5h suggests that reattachment of flow may be occurring at that distance. These results suggest relatively strong differences in air flow and evaporation over short distances. As these results were obtained under carefully controlled laboratory conditions, it is uncertain how likely these patterns would be reproduced under field conditions with variable wind speed and direction.

Results for the lagoon models offer a strong contrast to the slurry tank results. In this case, evaporation is increased in the majority of runs (all runs with 1 model) regardless of building orientation. A likely explanation is that, even though the building models reduced air velocity, turbulence near the surface in their wake significantly enhanced air mixing and evaporation from the water surface. Over all the runs, evaporation from the lagoon models was, on average, 73% greater than from the slurry tank models. This includes the reference runs when no building models were present.

A limited number of runs with model trees and a model hill indicated increased evaporation for most building/manure storage model combinations. This result was unexpected and, as hot film anemometer measurements were not made for these runs, it is difficult to interpret these results. The most likely explanation is that the tree models, even though they reduced the mean velocity, may have increased turbulent mixing near the surface. Clearly, the hill model upstream did not create a protective “odor trapping” wake zone over the manure storage models but instead enhanced transport.

Lay Interpretation

These model experiments of air flow characteristics suggest that when swine confinement buildings are oriented so that the approaching wind is parallel to the buildings the wind is reduced less than when the buildings are oriented across the wind direction. This can be attributed to the smaller frontal area of the buildings blocking the wind (ends of buildings vs. sides of buildings facing the wind) and differences in air flow patterns. It is likely that the parallel buildings cause acceleration of the wind between them and toward the downwind slurry tank or lagoon. By comparison, the sloping roof of buildings perpendicular to the wind direction forces the air up and around the ends of the buildings and away from the slurry tank or lagoon. These changes in wind speed, wind direction and mixing may all have potential impact on odor constituent transport from manure storage structures.

Results of these experiments suggest that orienting swine production buildings so that they are perpendicular to prevailing wind direction may reduce odor transport from a downwind slurry tank or lagoon, especially if the manure storage unit is close to multiple buildings. However, these studies were completed with steady wind and unchanging wind direction so results under field conditions may be somewhat different than these wind tunnel results and should be verified by field measurements. The wind tunnel experiments also indicate that upwind building effects on odor constituent transport from slurry tanks is not affected as much as that from lagoons and that buildings upwind will tend to increase transport from a lagoon. Experiments simulating the effects of trees or a hill up or downwind from the production facility gave unexpected results. Even though trees upwind will slow down the wind, this did not always result in a reduction in evaporation from downwind slurry tanks or lagoons. This study demonstrated that the complicated effects of buildings on air flow make generalizations about their effects on downwind processes difficult.

Acknowledgements

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