Title: Development of a Site-Specific Odor Impact Distance Guideline for Swine Production Systems – **NPB#98-131**

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Abstract

The determination of odor-based setbacks for swine facilities is an important issue for producers today. Sufficient setbacks prevent costly nuisance complaints and lawsuits, and excessive setbacks stifle expansion, but until now, a science-based setback estimation tool to guide and educate livestock producers and regulators did not exist. A simple-to-use, site-specific setback guideline was developed for U.S. swine production systems in this project. The guideline considers facility size, orientation and shape, wind frequency, land use, topography, building design and management, manure handling characteristics, and odor abatement effectiveness. Odor emission factors were based in part on actual odor emission measurements in commercial nursery and finishing buildings. Atmospheric dispersion models were used to enhance and validate the setback guideline. The guideline is interactive and has been published on the World Wide Web at http://danpatch.ecn.purdue.edu/~odor/. Producers, neighbors and other interested parties can access the interactive guideline on the web. The guideline is both a planning and educational tool for determining odor impact distance from swine facilities.

Introduction

The United States pork industry is currently investing significant resources towards reducing or eliminating nuisance odor created by pork production facilities. The issue of separation distance between facilities and neighbors is important for swine producers because excessively high setbacks may hinder expansion opportunities and insufficient separation distances can be costly in terms of nuisance complaints and lawsuits. However, determining proper odor-based setbacks for swine facilities is a very difficult and complex issue with few research-based tools to guide the process. Nuisance odor complaints depend on odor production at the facility, odor transport between the facility and neighbors, and odor tolerance by the neighbors. Since each of these factors is highly variable, the odor impact distance is a judgement based on statistical probabilities, resulting in widely varying state and county setbacks across the United States. A science-based setback guideline is therefore needed to guide and educate livestock producers and policy makers.

Pig numbers and weight, building design and management, weather, manure management methods, and odor control technologies influence the quantity and nature of odors emitted from a swine facility. Odor dispersion from a facility at a given emission rate depends on wind, weather, and local topography. No setback guidelines in the U.S. consider site-specific topography or prevailing winds, yet such information is readily available.

Some fixed setback distances based only on land use have been recommended. However, a “one-size fits all” setback tends to meet the needs of the worst odor emission problem, the worst dispersion characteristics, and the most sensitive neighborhoods. Lost with fixed setbacks is the ability of individual farms to achieve sufficient odor dilution, or of communities to accept detectable odors periodically and thereby reduce setbacks. Given the extremely complex nature of agricultural odor impact on surrounding communities, “formalized judgement” is needed to estimate setback distances.

A setback guideline (Schauberger and Piringer, 1997) has been utilized for swine facilities by Heber (1997). The parameter values and scoring methods for this guideline needed to be modified to more accurately represent the influence of design, management and odor control technologies used in the United States.

The measurement of baseline odor emissions from typical commercial facilities is important for modelers, engineers, regulators, producers and manufacturers of odor control products and equipment, yet the available information is limited. Baseline odor emissions are needed to: 1) assess nuisance potential, 2) provide inputs to odor dispersion models, 3) compare research results, 4) gain understanding of emission characteristics, and 5) build a data base that reveals trends between building types, design and management. Buildings with deep pits for manure storage are considered to be the greatest emitters of odorous gases as compared to building types. Thus odor emission measurements in similar deep pit buildings with different age pigs would provide data useful for helping establish the odor emission factor for the new setback guideline.

Objectives

1. Develop and validate a simple parametric guideline for determining scientific odor impact distances for swine facilities based on site-specific factors.
2. Determine appropriate odor emission factors for nursery and finishing pigs.
3. Educate swine producers about how location, design, and management influences odor impact area around their facilities.

Literature Review

Separation distances between animal facilities and neighboring residencies and businesses should be determined in a scientific way to ensure sufficient dilution by atmospheric dispersion. Many of the extensively used industrial dispersion models are based on Gaussian equations, and some of them have been used for agricultural pollutant studies. Important features that make agricultural odor different than industrial pollutants have been delineated (Mejer and Krause, 1986; Smith, 1993; Zhu *et al.*, 1998). Many researchers have questioned the validity of the assumptions used with the Gaussian models related to sampling time, emission rate calculations, and meteorological stability classifications (Turner, 1994, Gryning *et al.*, 1987; Smith, 1993; Fritz *et al.*, 1998; Zhu *et al.*, 1998).

Setbacks adopted by Ontario, Holland, Iowa, Illinois and South Dakota (Kohl and Lorimor, 1997; Illinois, 1997) for livestock buildings depend roughly on animal type, land use, and total animal body weight and range from 0.14 to 1.5 miles. County setbacks are as high as four miles. Setback guidelines have been developed in Germany, Holland, Switzerland and Great Britain. According to Klarenbeek and van Harreveld (1995), the Dutch guidelines were established and validated with odor emission measurements, dispersion modeling, neighbor surveys and "experience" (Klarenbeek and van Harreveld, 1995). Separation distances are a function of the rate of pollution (odor emission rate), usually power functions with exponents between 0.3 and 0.5.

The Warren Springs Laboratory in the United Kingdom derived an empirical equation to estimate minimum nuisance setback based on odor emissions from many sources including chicken and pig houses (Williams and Thompson, 1985). The equation is: Setback distance (ft) = $7.2\ (E)^{0.6}$, where E is the building odor emission rate, OU/s.

The Austrian guideline improves upon established guidelines from Germany, Holland and Switzerland, all of which are at least partially based on scientific odor measurements and neighbor surveys. This guideline considers facility size, local topography, wind frequency, some building design and management features, and some odor abatement techniques (Schauberger and Piringer, 1997). The guideline estimates the strength of the odor source and the dispersion of odors from the source as follows:

Setback distance (feet) = $82 \times f_d \times f_l \times (O)^{0.5}$

where: O = odor number = $N \times f_a \times f_t$

N = number of animals

f_a = animal factor

f_t = technical factor based on ventilation, manure treatment and feeding

= fv [0.1 to 0.5] + f_m [0.1 to 0.3] + f_f [0.05 to 0.20]

f_d = odor dispersion factor [0.6 - 1.0]

f_l = land use factor [0.5 - 1.0].

The dimensionless odor number (O) representing the strength of the odor source is calculated by multiplying the number of animals (N) by the animal factor (A) and the technical factor (T). The animal factor depends on animal type and body weight. The technical factor is the sum of a ventilation factor (V), a manure management factor (M), and a feed factor (F). For example, a ventilation factor of 0.10 is assigned to vertical exhaust systems (not common in the U.S.) and 0.45 to horizontal exhaust systems.

Odor impact distance from the source is estimated by considering annual wind distribution and influence of obstacles and land slopes. The surrounding topography is assigned a score from zero to 70 points in each of eight directions which is then added to the wind frequency to obtain the "total score". The odor dispersion factor is 0.6, 0.7, 0.8, 0.9 and 1.0 for total scores of 0-10, 11-30, 31-50, 51-70 and >70, respectively. The directional land use factor (L) ranges from 0 to 1 with 0 for "full tolerance" zones, 0.5 for commercial areas and 1.0 for "purely residential areas." Thus, site-specific information is used to estimate setback distances.

Procedure

Measurements of Odor Emissions from Nursery Buildings

Odor emission measurements were conducted in two mechanically ventilated commercial nursery rooms. Both rooms were equipped with wire floors over 6 ft deep manure storage pits, one pit ventilation fan, and one or two wall ventilation fans. Room A (21 x 35 ft.) had one pit fan and two wall fans facing east, a heater on the west side, and a doorway entrance at the south end, Figure 1. Room B (18 x 32 ft) had both fans facing north, with a heated hallway along the south endwall, Figure 2. The ventilation system in each room was controlled by an integrated environmental control system. The sampling locations for Room A included the outlet of the pit ventilation fan and the east and west slotted air inlets, Figure 1. Air sampling locations for Room B consisted of the pit fan, the vent panel opening to the pre-heated hallway, and the air inlet to the recirculation fan, Figure 2.

Five odor sampling visits were made to each nursery between March and May 1999. Data collection consisted of the following procedures: 1) record and manually set the variable-speed fan voltage using the FanCom environmental control system. 2) record time, 3) measure indoor and outdoor temperature and relative humidity with a motorized psychrometer, 4) record manure pit depth, 5) record pig number and weight, 6) collect nine or ten air samples in 0.35 ft^3, Tedlar bags, 7) measure exhaust fan airflow rates with a hot-wire anemometer, 8) reset the environment control system to automatic mode based on temperature, and 9) return to campus and evaluate odor samples.

Odor detection threshold values were determined by a dynamic dilution, forced-choice olfactometer using eight trained panelists. Odor detection threshold is the concentration of an odor in air at which it is just barely sufficient to detect the presence of odorous materials in the air. Odor dilution ratio is the concentration of the original odor sample divided by its concentration in the diluted sample when the latter is at the odor detection threshold (ASTM, 1978). Odor emission rate is expressed in terms of odor units per second (OU/s) and is the product of the odorous dilution ratio and the total volumetric emission rate from the exhaust fan(s).

Measurement of Odor Emissions from Finishing Buildings

Odor emission rates from four, identical, 1,000-head, mechanically ventilated swine finishing houses (Heber et al., 1998) were used to establish baseline emissions for finishing buildings. Each building had long-term manure storage beneath a fully slatted floor, two sidewall curtains, a curtain on the west endwall, four pit ventilation fans, and five exhaust fans in the east endwall.

Odor samples were collected in 2.8 ft^3 Tedlar bags and sent overnight to Iowa State University for analysis of concentration using dynamic dilution olfactometry with four to six trained panelists. A measurement of odor in the building consisted of the average concentration of one to four sample replications depending on the air sampling protocol and number of good samples. A total of 31, 29, 22 and 26 odor concentration measurements were conducted in the four buildings. Pit fan ventilation rates were measured with full-size airflow rate sensors (FanCom FMS 50) and recorded every minute. Odor emission calculations were performed a total of 78 times.

Setback Guideline

A new setback guideline was developed based on literature review, odor emission measurements, dispersion modeling and review and study of existing setback guidelines, particularly the one developed by Schauberger and Piringer (1997) upon which the new guideline was primarily based. Building design and management and odor abatement factors in the new guideline were introduced to replace the Austrian guideline "technical factor". Geometry-based factors and outdoor manure storages were also incorporated into the guideline. The new interactive setback guideline was installed on the World Wide Web at http://danpatch.ecn.purdue.edu/~odor.

Results

Objective 1: Develop and validate a simple parametric guideline for determining scientific odor impact distances for swine facilities based on site-specific factors.
The new guideline combines features of Austrian and British setback guidelines (Schauberger and Piringer, 1997; Williams and Thompson, 1985) and incorporates new features developed in this research. The guideline is as follows:

Setback distance in feet = $20\ F \times L \times T \times V \times (A_E E + A_S S)^{0.5}$

where: F = wind frequency factor [0.75 to 1.00],
- L = land use factor [0.5 to 1.00],
- T = topography factor [0.8 to 1.00],
- V = orientation and shape factor [1.00 to 1.15],
- E = building odor emission, N x P x B, OU/s
  - N = number of pigs,
  - P = odor emission factor, OU/s-pig, [1 to 15, Table 2],
  - B = building design and management factor = M-D,
    - M = manure removal frequency [0.50 to 1.00],
    - D = manure dilution factor [0.00 to 0.20],
- S = odor emission from outdoor storage, OU/s, C x G
  - C = odor emission factor for outside liquid manure storage, 50 OU/s-AU
  - G = animal unit, AU=1,100 lb of pig weight.

A_E = odor abatement factor for buildings [0.30 to 1.00],
A_S = odor abatement factor for outside liquid manure storage [0.30 to 1.00]

Wind Frequency Factor, F

The expected frequency of wind directions are required since this guideline estimates setback in eight directions. Regional wind frequencies in 16 directions are available from the National Climatic Data Center (828-271-4800). The frequencies are calculated for each of 8 directions, converted to decimal fractions, and added to 0.75. The result is the wind frequency factor. For example, the wind frequency factor is 0.90 for a wind frequency of 15%. The wind frequency factor is 1.00 for all wind frequencies equal to or greater than 25%.

Land Use Factor, L

Setback distance should be higher for a direction that is recreation or residential area than one that is industrial area. Therefore, land use factors range from 0.5 for areas that need lower protection from odor to 1.0 for areas that are very sensitive to odor.

Topography Factor, T

The surrounding topography and landscape influence odor dispersion and dilution from the sources. Dispersion conditions are favorable if the odor source is located on flat land with very limited obstacles in the vicinity. For a source that is located in a valley, neighbors at in the same valley but at lower elevation might receive more odorous air than if the land was flat especially at night during temperature inversions. Factors for topography range from 0.8 to 1.00, Table 1.

Orientation and Shape Factor, W

Odor emission sources may include an array of points (exhaust fans), lines (building side with curtain or doors opening) and areas (outdoor lagoons or other storage). A swine production facility may have several buildings and waste storage or treatment facilities that emit odors. All of the odor emission sources at a given production site should be grouped and encompassed spatially with a rectangle as shown in Figure 3. A building length to width ratio (L/W) is used to describe the shape of the encompassing rectangle and a direction is used to give the orientation of the rectangle.

The orientation, shape (L/W) and distance between the odor emission source and the neighbors determine the exposure angle factor (W), Figure 4. For a long and narrow odor emission source that is oriented north-south, the likelihood of receiving odor are greater for a neighbor to the north than a neighbor to the east of the facility because of a larger exposure angle. However, the downwind odor concentration will be greater when the wind blows along the length of the facility, Figure 5, but the exposure angle is smaller.

A sensitivity test was conducted with a 10,000-head swine finishing facility and a 170 ft diameter "neighbor" to study the interactive effects of the L/W ratio and the wind exposure angle on downwind concentrations at a distance of 4,400 ft. The line source Gaussian dispersion model was used to predict downwind gas concentrations with all combinations of wind speeds and stability.

The pig facility covered a total area of 161,400 ft^2. A set of actual weather data from Dayton, Ohio was used to determine realistic frequencies of wind speed and stability combinations. Downwind concentrations and percent exceedances of any predicted concentration higher than an arbitrary threshold concentration were predicted for L/W ratios between 2 and 20.

The results showed that percent exceedance increased with L/W ratio for directions parallel and perpendicular to the odor source. However, orientation and shape did not have a significant effect in the NW, NE, SE and SW directions. Based on this study, the following odor source orientation and shape factors were developed: V = 1.00 for L/W < 2, V= 1.05 for L/W > 2 and < 4, V=1.10 for L/W > 4 and < 8 and V=1.15 for L/W >8.

Building Odor Emission, E

The following factors are used to quantify the odor emission from buildings. The ratio of odor emission rates of the finishing pig to the nursery pig was 5:1 = 5.0 (see results under objective 2). This corresponds to the ratio of pig weights in lb (153/30 = 5.1) and more importantly to the ratio of fresh manure production in lb/day (9.8/2.0 = 4.9). Since reliable odor emission data is not yet available for other types of pigs, odor emission factors were assigned based on the amount of fresh manure production as compared to the nursery and finishing pigs while also considering space per pig in the buildings, Table 2. Odor emitted by stored manure on a per head basis is larger for pigs with more space per pig such as sows with litters. Thus, the odor emission factors assigned to boars, gestating sows, and sows and litters were 8, 6, and 15 OU/s-head, respectively.

Odor Abatement Factor for Buildings, A_E

Some swine facilities utilize one or more odor reduction or treatment methods to reduce odor emission such as biofilters, pit additives and diet manipulation. An odor abatement effectiveness factor (A_E) is used to account for the reduction in odor emission. The allowable reduction of odor emission ranges from 0 to 70%. The odor abatement factor is calculated as (1-R/100) where R = the percent reduction of odor. For example, the factor is 0.70 for an effectiveness of 30%.

Building Design and Management Factor, B = M – D

The total odor emission from a swine building is influenced by the frequency of manure removal (M) from the building and the final dilution (D) of the stored manure. There is no data that provides the reduction of odor emission due to manure removal frequency. Some data is available on reductions in ammonia emissions but it is very likely that reductions in odor emissions are less than reductions in ammonia emissions.

Odor emission is reduced with higher frequency of manure removal. Estimations based on expertise and experience are necessary until research is conducted to determine the odor reductions. All percentage reductions were based on long term underfloor storage with no dilution water. The manure removal factor is 0.40 for daily manure removal and 0.50 for manure removal every 3 days. Manure removal factors are 0.70, 0.80 and 0.90 for weekly, biweekly and monthly manure removal, respectively. The factor is 1.0 for manure storage times longer than one month.

Odor emission from swine buildings is also reduced by dilution of stored manure. The dilution ratio is defined as the amount of recharge water added to the pit divided by the amount of fresh manure produced by the animals during an accumulation cycle. For example, the dilution is 1:1 if three inches of recharge water were added to the pit at the beginning of the cycle and three inches of manure accumulated in the pit during the cycle. The dilution ratio is 10:1 if 20 inches of water is added to a recirculation flush pit and 2 inches of manure accumulated before emptying the pit. The manure dilution factors are 0.20, 0.15, 0.10, 0.05 and 0.0 for dilution ratios of 10:1, 5:1, 2:1, 1:1 and 0:1, respectively.

Odor Emission from Outdoor Storage, S = C x G

The total odor emission rate from outdoor storage is the product of animal units (C) and odor emission rate per animal unit (G) which is 50 OU/s-AU for any type of liquid storage. The animal unit is calculated by dividing the total animal weight by 1,100 lb. Odor emission rates of 87 and 110 OU/s-AU from two first-stage anaerobic lagoons were measured using a buoyant convective flux chamber at an artificial wind speed of 2.5 mph (Heber and Ni, 1999; Heber, 1998a). The lagoons, located in Oklahoma and Utah, were 0.6 and 3.2 acres in surface area, respectively. These measurements were conducted during late spring when lagoons typically emit greater amounts of odor. Therefore, a lower odor emission of 50 OU/s-AU was selected to characterize outdoor liquid manure storage. According to Nicolai (1999), earthen storage basins which are typically 20% the size of anaerobic lagoons emit five times as much odor per unit area. Thus, the odor emission rate of 50 OU/s-AU is reasonable for storage basins as well.

The odor abatement factor for outside liquid manure storage A_S is used to characterize the reduction in odor emission as compared to open liquid storage. Surface aeration of anaerobic lagoons is an example of odor reducing technology. The odor emission from a 2.5 acre anaerobic lagoon in Oklahoma with surface aeration was 24 OU/s-AU (Heber et al. 1999). The lower emission factor can be accounted for by assigning an appropriate value to the odor abatement factor, A_S.

Benefits to Swine Industry

Setbacks that depend on building design and management and odor abatement methods benefit swine producers needing smaller setbacks because of proximity to neighbors. Producers and other interested parties will be able to access the interactive guideline on the web. County zoning and planning boards now have access to a reliable tool to determine setbacks for swine facilities.

Objective 2: Determine appropriate animal factors for nursery and finishing pigs.

Finishing Pigs

The mean odor concentrations measured in four buildings were 235, 260, 321, and 339 OU/m^3, respectively. Overall odor concentrations (109 samples) ranged from 12 to 1586 OU/m^3 with a geometric mean of 142 OU/m^3. The 95% confidence interval around this mean was 109 to 185 OU/m^3. Mean odor emission rates measured in the buildings were 73, 85, 137 and 81 OU/s per AU (animal unit = 1,100 lb of pig weight). The geometric mean of the odor emission rate was 36 OU/s per AU and the 95% confidence interval was between 27 and 55 OU/s per AU. The odor emission rate for finishing pigs (153 lb average) is 5 OU/s-pig based on these measurements.

Nursery Pigs

The odor concentration of nursery building air ranged from 93 to 635 OU with a geometric mean of 190 OU (Lim et al., 1999). Outdoor odor concentration ranged from 7 to 85 OU and averaged 18 OU. The mean odor emissions from rooms A and B were 20 and 82.7 OU/s-AU, respectively. The geometric mean odor emission rate from two nursery rooms was 36 OU/s-AU or 0.20 OU/s-ft^2. An appropriate animal emission factor for nursery pigs (30 lb average weight) is therefore 1 OU/s-pig as compared to 5 OU/s-pig for the finishing pigs.

Odor emissions were apparently related to total pig mass in the nursery rooms, Figure 6. Sampling visits 1 and 2 for both rooms were conducted near the end of one growth cycle of nursery pigs, and visits 3, 4 and 5 were conducted during a subsequent growth cycle. It is reasonable to assume that larger pigs produce more manure and excretion, which contribute to higher odor concentration.

Benefits to Swine Industry

Scientific measurements of odor emission from nursery and finishing buildings have provided important baseline data. The effects of diet manipulation and other alternatives can be tested and compared to these baseline emissions. The measurements aided the development of odor emission factors for the interactive setback guideline.

Objective 3: Educate swine producers about how location, design, and management influences odor impact area around their facilities.

Several educational activities were carried out during the course of this research project. A presentation on odor impact distance from swine facilities was given at a national conference (Heber, 1998b). An extension publication on methods and practices for reducing odor from swine facilities was written (Heber et al., 1999). This publication includes information about odor impact distances. An article was written for the Pork'98 magazine, which provided information about odor concentrations and air quality in finishing facilities during warm weather in the summer.

A conference paper on the setback guideline was accepted for Air Pollution 2000, the Second International Conference on Air Pollution from Agricultural Facilities in Louisville, Kentucky in October 2000. The setback guideline is the dissertation topic for Mr. Teng Lim who plans to graduate around December 2000.

The setback guideline has been used several times with swine producers to calculate the setback distance for their facilities. He regularly uses the setback guideline in workshops and other extension presentations to educate producers on the impacts of site-specific factors on odor impact area. The Indiana Pork Producers Council is sponsoring the second odor emissions workshop by Dr. Heber in December 1999.

The Purdue odor and air quality WWW page has been accessed over 800 times since July 1999. The interactive setback guideline on this page

http://danpatch.ecn.purdue.edu/~odor/setback.htm/ has been used frequently by these users but access to the guideline has not been monitored. However, it is expected that producers will be educated by using the final setback guideline on the web in the future.

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Table 1. Directional topography and landscape categories.

Factor	Topography and landscape situation
0.80	No vegetation, buildings or other obstacles
0.85	Dispersion reduced by obstacles
0.90	Hillside or valley with upward flowing wind
0.95	Hillside or valley with downward flowing wind
1.00	Very narrow valley with downward flowing wind

Table 2. Animal odor emission factors.

Type	Space per pig, ft^2	Manure production, lb/day	Emission factor, OU/s-head
Nursery, 30 lbs	3.5	2.3	**1**
Grower, 65 lbs	5.0	4.2	**2**
Finishing, 150 lbs	8.0	9.8	**5**
Gestating	16	9.0	**6**
Sow and litter	30	22.5	**15**
Boars	40	11.5	**8**

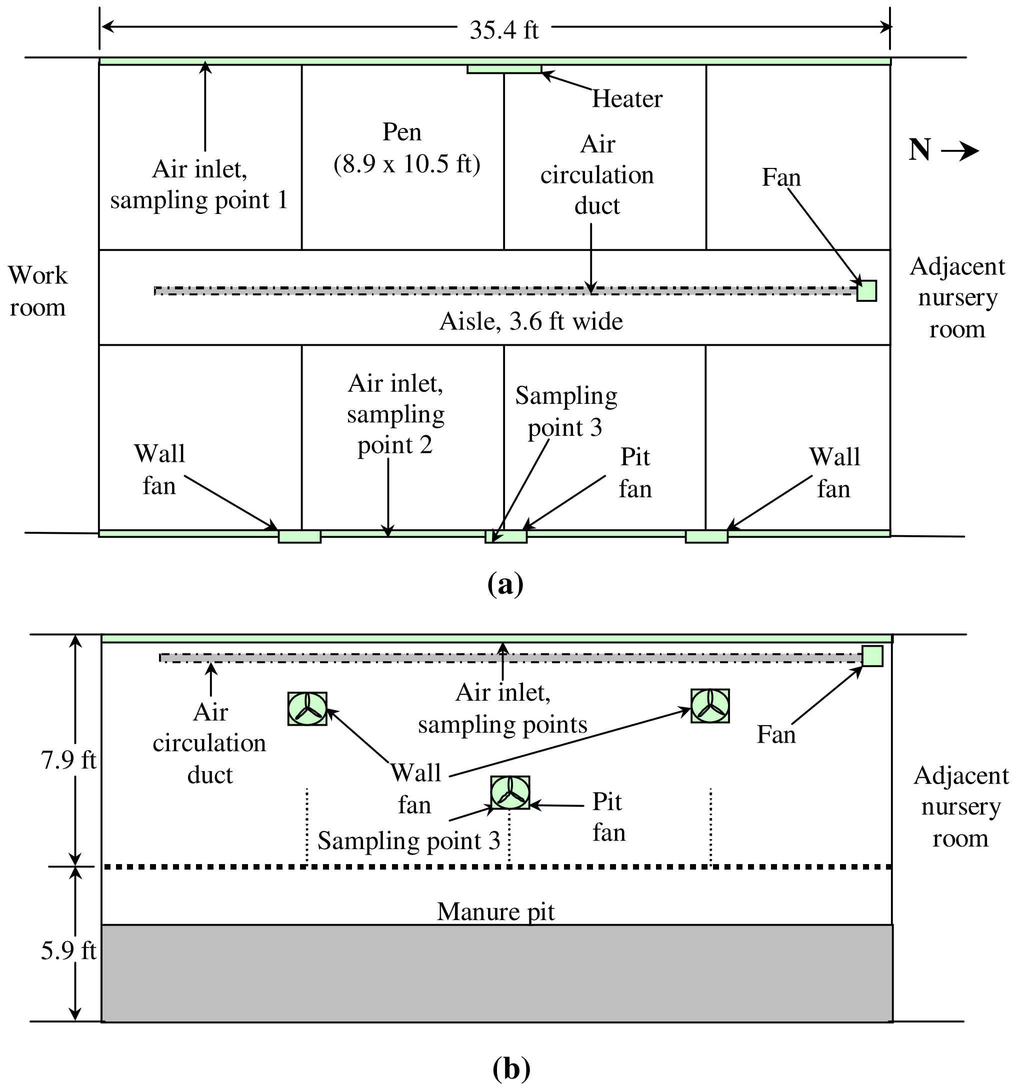

Figure 1. Floor plan (a) and side view (b) of room A.

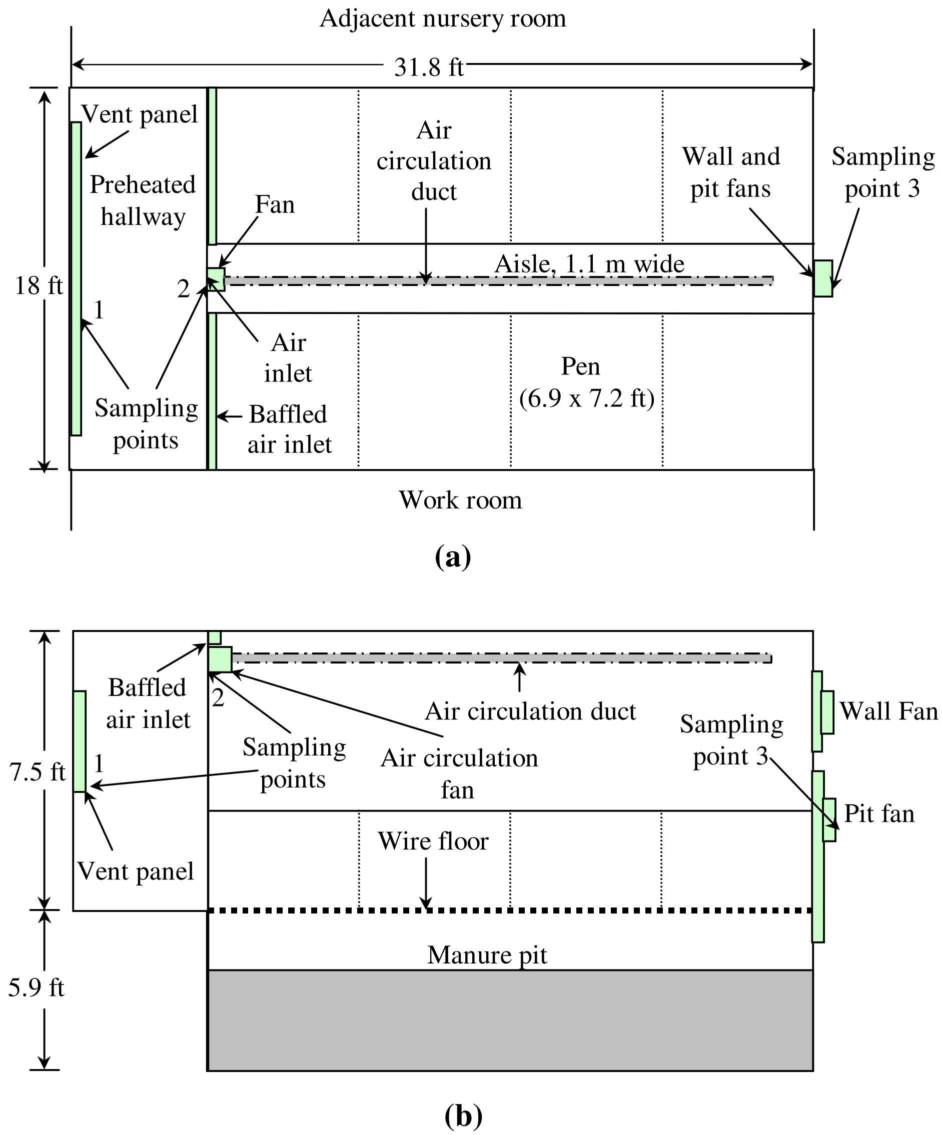

Figure 2. Floor plan (a) and side view (b) of room B.

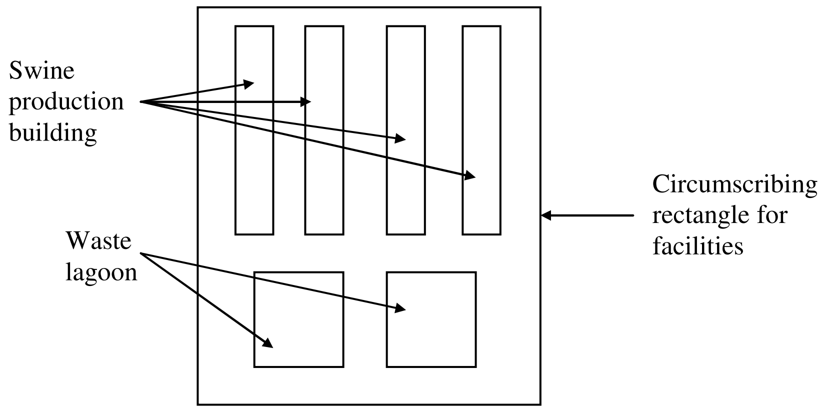

Figure 3. Circumscribing the facilities at production site.

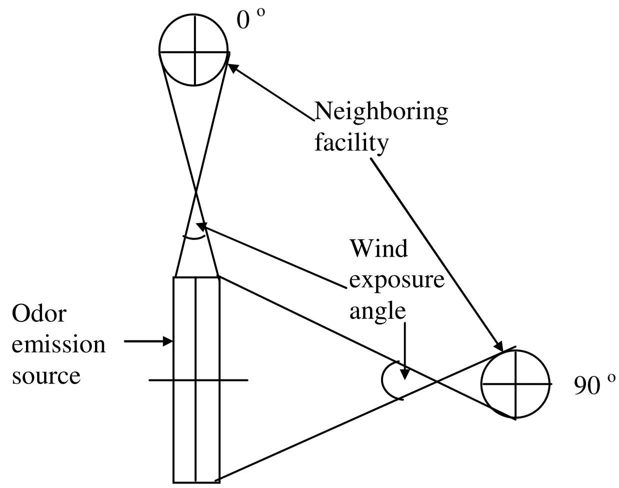

Figure 4. Wind exposure angle depends on the orientation, shape and distance between odor emission source and neighboring facilities.

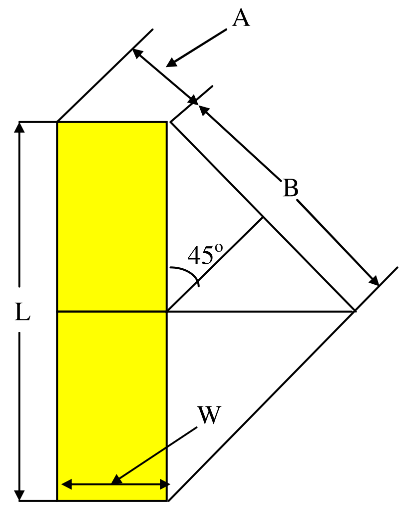

Figure 5. Odor concentration depends on the total length of line A and B when wind is blowing from SW.

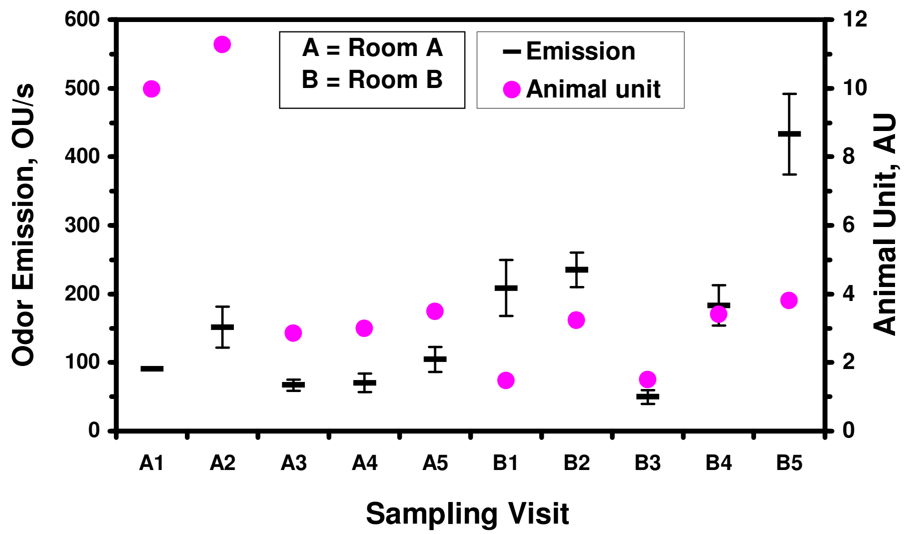

Figure 6. Odor emissions and total pig body mass for each session.