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Measurement of Air Velocity in Animal Occupied Zones Using an Ultrasonic Anemometer

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Abstract. *The air velocity in the animal occupied zone (AOZ) of a pig facility influences the thermal comfort of pigs and is affected by the ventilation system in the building. Little is known about the relationship between the air velocity in the AOZ and the ventilation system design. This article describes the development and a practical test of an air velocity measuring system in the AOZ using ultrasonic anemometers.*

The anemometers were protected by a wire protection cage, which resulted in a lower air velocity *measurement that was corrected by a linear correction factor of 0.83. A suitable aggregation interval for time-averaged air velocity measurements in occupied pens was 300 s. The effect of animal activity on the measured air velocity was minimal and therefore neglected, but the location of the anemometer in a pen was deemed important. A representative location was above the resting place of the animals over the solid floor. The presence of an anemometer in a pen resulted in some minor changes in the lying behavior of the animals.*

In the experimental door-ventilated room with weaned piglets there was a clear (0.04 m/s) and significant difference in average air velocity between pens 3 and 9 ($P < 0.001$). The maximum air velocity of 0.15 m/s advised was exceeded in 21% of the time a pen in the back of the room. In a pen closer to the door, air velocities appeared to be too high less than 2% of the time.

The measuring system described in this article can be combined with air quality and temperature measurements in the AOZ for determination of the performance of ventilation systems and comparison of ventilation systems.

Keywords. Air velocity, Ventilation system, Pig facilities.

Air velocity in the animal occupied zone (AOZ) of a pig facility influences thermal comfort, behavior, and production of pigs. Therefore, air velocity in the AOZ in livestock buildings is one important aspect of the building performance (Zhang et al., 2001). Several ventilation systems are commonly used in pig rooms. Fresh air supply to the AOZ depends on the ventilation system design (Van Wagenberg and Smolders, 2003). However, little is known about the relationship between the ventilation system design and the air velocity in the AOZ. Only some experimental data are available. One experiment with simulated pigs showed that for ventilation systems with a high slot-inlet, the air velocity in the inlet is an important factor for the air velocity in the AOZ, especially under warm summer conditions (Randall, 1980). A slot ventilated building with the air inlet located in the sidewall affected air velocity in the AOZ along with inlet height and distance from the inlet (Hoff, 1995). No experimental data are available on air velocities in the AOZ under practical conditions with occupied pig rooms or with other ventilation system designs.

Airflow patterns and air velocity distribution in rooms with different ventilation systems can be predicted by numerical simulation models as long as it considers empty test rooms without obstacles (Harral and Boon, 1997; Bjerg et al., 1999). Both numerical simulations and lab measurements show that the effect of pen partitions and simulated animals in rooms reduce the air velocity in the AOZ compared to an empty room (Bjerg et al., 2000). The complex environment of an occupied pig room where animal presence and animal activity significantly affect airflow pattern characteristics has not been simulated yet (Smith et al., 1999).

For determination of the performance of a ventilation system as part of building performance, the quality of the climate in the AOZ is an important factor, besides other factors, such as energy consumption and operational costs. Quality of the climate in the AOZ can be characterized by air quality variables, such as contaminant concentrations, and variables affecting thermal comfort, for example air temperature and air velocity. Contaminant concentration and temperature measuring systems are available and have been reported in literature (Aarnink and Wagemans, 1997; Van Wagenberg and Smolders, 2003).

Several sensor types are available to measure air velocity, but not all sensor types can be used under practical conditions in occupied pig rooms. Some sensors are impractical in swine houses, due to the expected low air velocities in the AOZ, the presence of ammonia, and/or possible dust deposition on the sensor. An ultrasonic anemometer is a suitable sensor for measuring air velocity in the AOZ. In this study, a measuring system with this sensor type has been tested under practical conditions and a procedure for data processing is proposed. At the same time the system was used to gain insight into occurring air velocities in the AOZ in a door-ventilated room for weaned piglets, the animal category that is the most sensitive to discomfort in indoor climate.

Objective

The objective of this research was manifold. The first objective was testing the measuring system, which consisted of determining the effect of a wire protection cage around the anemometer. The second objective concerned data processing, and dealt with determining of the best suitable aggregation interval for time-averaged air velocity measurements and determining turbulence intensity. The third objective was related to the use of the anemometer in an occupied pig pen and was subdivided into: determining the effect of pig activity on the air velocity measured; determining the effect of the location of the anemometer in a pen on the measured air velocity; determining the effect of presence of an anemometer in a pen on the resting locations of the animals; and using the measuring system during one batch in a door-ventilated room for weaned piglets (in two pens).

Material and Methods

Anemometers and Effect of Wire Cage

Air velocity measurements were performed with ultrasonic anemometers (Gill, Windmaster 1086M), which each consisted of three acoustic transmitters and three acoustic receivers at 0.11 m distance. The speed of propagation of sound from the transmitter to the receiver depended on the one-dimensional air velocity between the transmitter and the transducer. The anemometers measured three one-dimensional air velocities, which were components of the omnidirectonal air velocity. The total height of the anemometers was 0.75 m and the diameter of the construction that holds the transmitters and receivers was 0.24 m. The measuring range was 0 to 45 m/s, the resolution was 0.01 m/s, and the accuracy for the omnidirectional air velocity was ? 0.01 m/s (stated by the manufacturer). The maximum measuring frequency was 1 Hz. Because the deviation could vary per sample, averaging air velocities over many samples reduced the chance of over or underestimation of the air velocity.

A wire cage (fig. 1) protected the anemometers. The openings in the cage were 20 • 20 mm, and the steel wire was 2.5 mm in diameter. The height of the cage was 0.77 m and the diameter was 0.27 m. The anemometer was mounted in the cage such that there was a space of 20 mm between the anemometer and the bottom of the cage.

Figure 1. Air velocity anemometer in a wire cage in the middle of the pen.

To determine the effect of the wire cage under different flow directions an anemometer was placed in a wind tunnel in two positions, and air velocity in the wind tunnel was varied stepwise between 0 and 2 m/s. During each step (500 s) air velocity was measured with and without the cage. Measurements were done with the anemometer placed perpendicularly (90?) on the z-direction of the airflow and with the anemometer placed at an angle of 40? of the z-direction of the airflow (fig. 2). These positions were chosen because it was expected that in the AOZ most of the airflow would vary between these directions. The effect of the cage on the turbulence intensity was also determined. Turbulence intensity (I_t) was defined as the standard deviation of the average omnidirectional air velocity divided by the average omnidirectional air velocity (Smith et al., 1999).

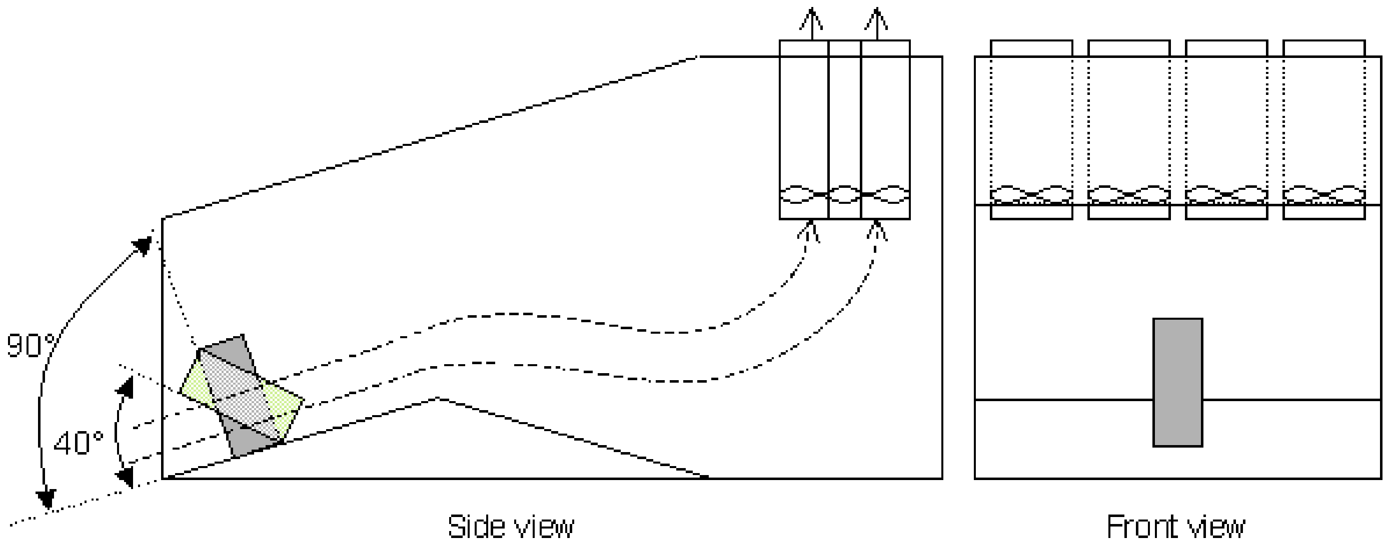


Figure 2. Anemometer positions in the wind tunnel experiment (- - -> = airflow).

Description of Room

The experiments were carried out in one room for weaned piglets at the experimental farm in Raalte in The Netherlands. The room was designed for housing of piglets from 7 kg of bodyweight to about 23 kg. Then they were moved to a finishing room. The room was door ventilated, and built as a representative copy of actual door-ventilated rooms.

Figure 3 shows a plan and a cross-section of the room. The room had five pens (for nine animals each) on each side of the operator walkway. In the pens 50% of the floor was solid concrete with a spherical shape and floor heating, and 50% was a metal tribar slatted floor. At the front of the pen there was a water channel of 0.40 m. Feed was supplied in a dry feeder, water in a separate drinker. Ventilation air entered the room from the central alley, where the air was preheated up to 5?C. Through an opening in the door (0.58 • 0.92 m) the air entered the room and flowed over the operator walkway to the back of the room (door ventilation). Air was removed from the room by a ventilator in a ventilation shaft, directly behind the door at a height of 2.10 m. In the ventilation shaft an automatic valve and a measuring fan were placed for controlling the ventilation rate. Control of ventilation was based on the inside temperature and on the settings in the climate controller (table 1). Heating in the room was available by a hot water pipe mounted against the surrounding walls and a radiator in the back of the operator walkway. Lights were on in the room between 6:00 a.m . and 4:00 p.m . (unless differently stated). The pens in the compartment were numbered according to figure 3.

In rooms with door ventilation, air distribution over the pens was uneven (Van Wagenberg and Smolders, 2003). At higher ventilation rates air flows over the operator walkway to the back of the room before it flowed over the pen partition. Much of the fresh air entered the pens in the back of the room, resulting in effective removal of contaminants and heat from these pens, but increasing the risk for high air velocities. Toward the front of the room there was less fresh air supply and possibly lower air velocities.

Fresh air entered the pens from the operator walkway; in the pens the airflow was expected to be directed towards the back of the pen. Due to heat production in the pen (animals, floor heating) air will rise and less fresh air will reach the back of the pen.

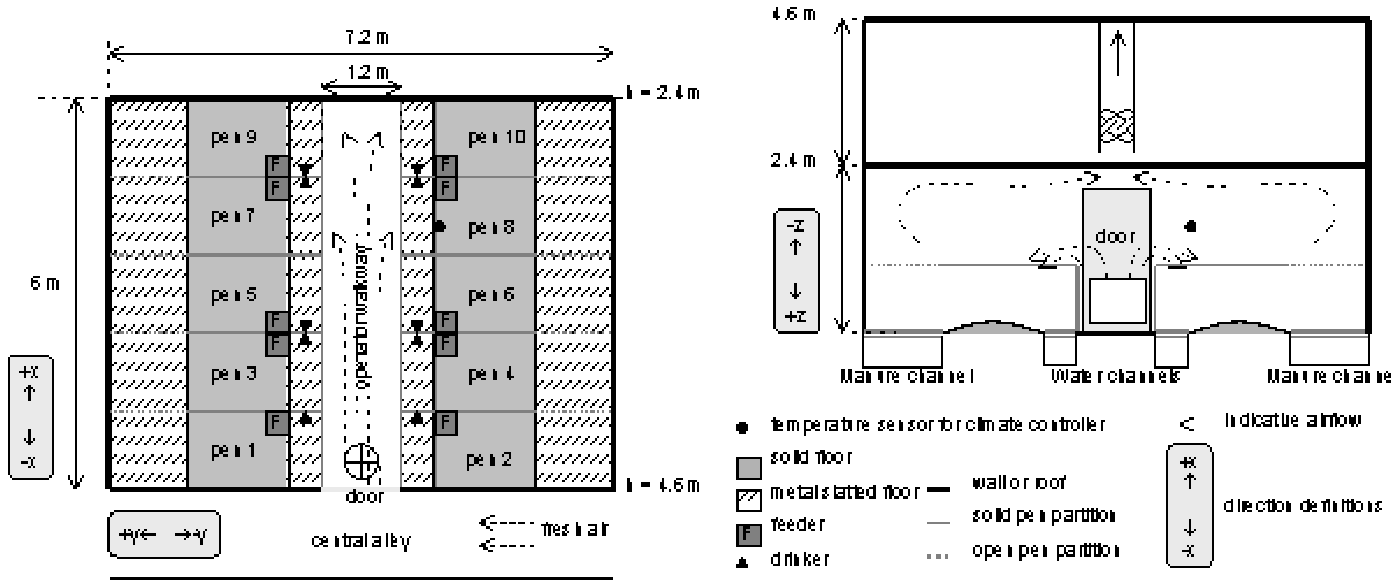


Figure 3. Plan and cross-section of compartment for weaned piglets (h = height).

Table 1. Climate settings in room.

Day No.	Temperature (?C)			Ventilation per Piglet (m ^{3} /h) [a]	
	Heating	Floor Heating	Setting Point Ventilation	Minimum	Maximum
2	28	40	30	4	10
4	25	40	27	4	11
8	24	35	26	5	13
21	18	25	21	5	20
28	18	25	21	6	25
49	17	20	20	6	25

[a] Temperature range between minimum and maximum ventilation 4 ? C.

Measurements in the Room

After testing the measuring system in the wind tunnel the anemometers were placed at different locations in pens 3 and 9 of the experimental room. These two pens were selected because they were positioned on one side of the operator walkway and because it would give insight into the expected differences in microclimate between a pen at the front and at the back of the room. Possible anemometer locations within the pens were defined and numbered as indicated in figure 4. The letter a indicates that no specific number in the location notation is meant. In pen 3 the feeder was placed in zone 1-3-a, in pen 9 the feeder was placed in zone 1-1-a. Details on the measuring time and location are addressed later in this article.

Ventilation rate was measured with a measuring fan in the ventilation shaft (accuracy < 50 m ^{3} /h) and recorded every 15 min. Outside temperature, temperature of the floor heating water, and room air temperature (location indicated in fig. 3) were recorded every 15 min.

Animal behavior was recorded with a video system and analyzed later. Details on the recording time, frequency, and animal behavior categories are described later in this article.

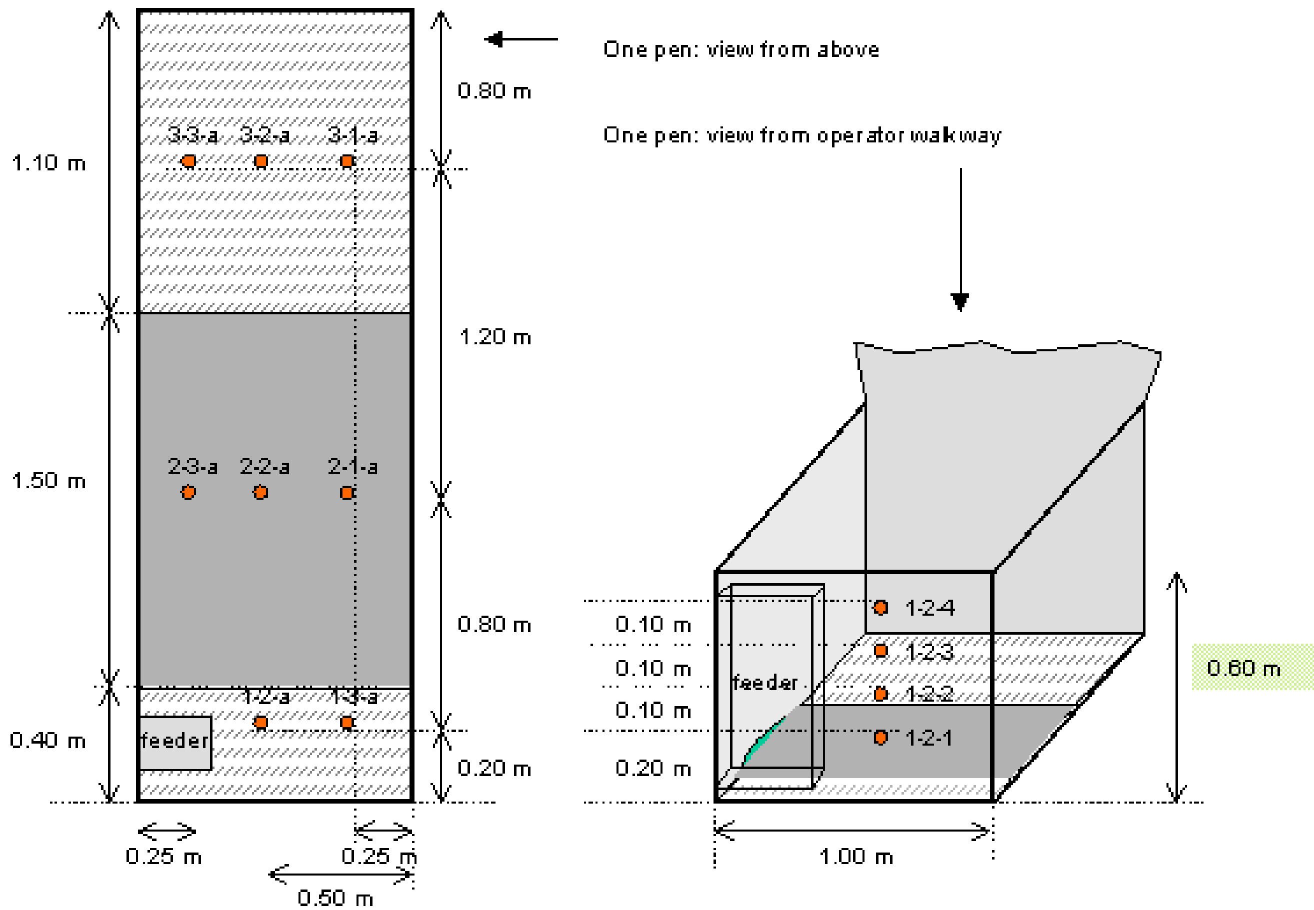


Figure 4. Zones within a pen and the notation of the different anemometer locations in the pen. The letter ? a? indicates that no specific number in the location notation is meant.

Aggregation Interval and Turbulence Intensity

Air velocity was measured with a 1-Hz sample frequency. This smallest possible sample interval (with the anemometer used) was chosen to take the smallest turbulences into account in the measurements. To get workable data files over long-term measurements, for example during one batch of weaned piglets, aggregation to time averaged air velocities is necessary. For determination of the most suitable aggregation interval, two analysis methods were used for three air velocity data sets. The data sets were collected at daytime, with the anemometer located at location 2-2-2.

For the first analysis method the air velocity signals were aggregated over 60-s intervals. Fourier analysis (Jenkins and Watts, 1969) was used for the original as well as for the aggregated data. Let N the number of recordings or aggregates be even, i.e. $N = 2n$. The signal was written as a finite Fourier series, i.e. weighted sum of first up to n th harmonic functions, such that the finite Fourier series coincided with the velocities observed at the measuring points. By computing and plotting the percentage of variance accounted for by the first up to j th ($j = 1 \ldots n$) harmonic function against the harmonic function cycle length, the impact of harmonic functions was displayed. The plot was used to decide which higher order harmonic functions could be ignored. A suitable aggregation interval was based on the lowest order harmonic function to be ignored. The analysis was performed using the software package Genstat (1993).

In the second analysis the directional air velocities (x, y, and z) of the three data sets were aggregated over several intervals DT, between 2 and 600 s. The time averaged omnidirectional air velocity was calculated as the root mean square (RMS) using equation 1.

$$U_{DT} = \sqrt{(\overline{x_{DT}})^2 + (\overline{y_{DT}})^2 + (\overline{z_{DT}})^2} \quad (1)$$

where x_{DT}, y_{DT}, and z_{DT} are the time averaged directional air velocities over an aggregation interval DT (s), resulting in a time averaged omnidirectional air velocity U_{DT}. The second analysis was carried out because it was expected that the value of U_{DT} would decrease with increasing aggregation interval DT. Changes in airflow direction within interval DT would result in lower values for x_{DT}, y_{DT}, and z_{DT}, and therefore in lower U_{DT}. By plotting U_{DT} against the aggregation interval DT, this effect was shown.

The three original data sets were also used to calculate turbulence intensity I_t in the AOZ.

Effect of Pig Activity on Anemometer Measurements

It was expected that pig activity would result in higher momentary values for air velocity. This effect was determined using air velocity measurements (1-Hz sample frequency) and animal activity observations. These measurements were done simultaneously in pen 3, during a period of 2 h, between 11:30 a.m . and 1:30 p.m . (data set 1 in table 3). Animal activity was recorded continuously. The recordings were analyzed and the momentary values of the air velocity were linked to one of the six defined categories for pig activity: no contact between pig and anemometer cage; pig sniffing the anemometer cage; pig rubbing against the anemometer cage; pig lying under anemometer cage; pig running in pen; pig bumping against anemometer cage.

Effect of Location in Pen on Air Velocity, Airflow Direction

It was expected that there would be heterogeneity in air velocity and airflow direction within a pen. To quantify this heterogeneity, one reference anemometer was located at location 2-2-2, and another movable anemometer was located at one of the other 28 sampling locations (fig. 4). The location of the reference anemometer was chosen to be close to the resting area of the animals, but in such way that the floor area under the cage was still accessible for the animals. Measurements with both anemometers started simultaneously and lasted 15 min (sample frequency 1 Hz, aggregation interval 300 s). After this period the movable anemometer was placed in another location. The average air velocity and airflow direction in both the reference location and the other sampling location were determined, as well as the difference in air velocity between the two locations. The experiment was carried out in pens 3 and 9, both with eight animals with low weight in the pen (an average weight of 8 kg) and with eight heavier animals (an average weight of 20 kg). The ventilation rates during the experiments are presented in the results section.

Air velocity values in the front (zone 1-a-a) in the middle (zone 2-a-a) and in the back (zone 3-a-a) of the pen were compared using two-sample t-tests. The representatives of the reference anemometer was determined by comparing average air velocity values per zone (1-a-a, 2-a-a, and 3-a-a) with the air velocity at the reference location using two-sample t-tests.

Effect of Presence Anemometer on Resting Locations of the Piglets

At location 2-2-2, the bottom of the wire cage was located 0.20 m above the solid floor (measuring height 0.30 m). This presence of the cage might affect the resting locations of the piglets in the pen. Resting locations were analyzed to assess this possible effect. During one batch, two periods were analyzed during which the lights were on continuously. The first period was from days 1 to 11 in the batch (light animals) and the second period was from days 29 through 34 (heavy animals). Each hour a video picture was recorded of pens 1 and 3 and pens 7 and 9 (24 hours per day). The pictures were analyzed as to percentage of the animals standing and resting on the slats above the manure channel and in the rest of the pen. Pens 1 and 3 were compared, as well as pens 7 and 9 using a two-sample t-test.

Air Velocity in AOZ during Batch

The air velocity in pens 3 and 9 was measured continuously during one batch, except for the first week of the batch (20 February until 28 March 2002). Experimental conditions are shown in table 2. The anemometers were in both pens located at location 2-2-2 (1 Hz, sample frequency, 300-s aggregation interval). Air velocities were plotted against day number and ventilation rate. Air velocities in pens 3 and 9 were compared using a two-sample t-test.

Table 2. Experimental conditions during batch with air velocity measurements in AOZ (period 20 February ? 28 March 2002).

	Floor Temperature (? C)	Room Temperature (? C)	Ventilation (m^3/ h)
Minimum	26.8	20.2	450
Average	29.6	22.4	576
Maximum	43.0	25.0	1263

Results and Discussion

Effect of Wire Cage

The effects of the wire cage on the wind tunnel measurements are presented in figure 5.

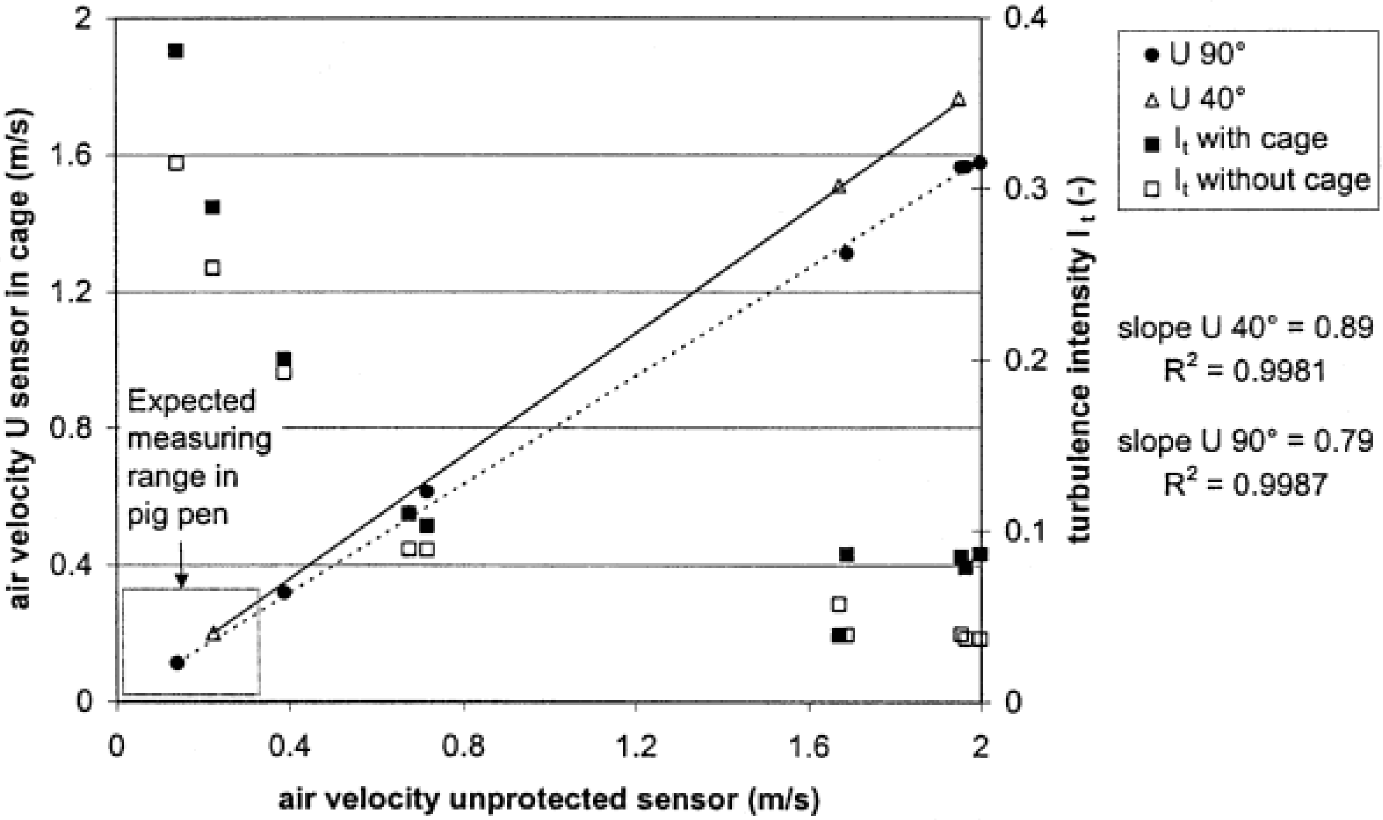


Figure 5. Effect of wire cage on turbulence intensity and on air velocity measured in wind tunnel with two anemometer positions.

The air velocity in the wind tunnel was in most cases higher than the expected measuring range in a pigpen. The effect of the cage for low air velocities in the wind tunnel (lower than 0.5 m/s) proved to be equal to the effect of the cage for the higher air velocities (using a two-sample t-test). This result indicates that, in the air velocity range tested, the air velocity did not influence the effect of the cage.

There was linearity between the air velocity measured by the unprotected and the protected anemometer. For the 90? position, the ratio was 0.79, for the 40 ? position, the ratio was 0.89. The difference in ratio between the two positions indicates that the effect of the cage on the air velocity depends on the direction of the airflow and proved to be significant using a two-sample t-test ($P < 0.001$). However, considering the relatively small difference and the expected measuring range, only one omnidirectional correction factor was used. This factor was 0.83, the average ratio between the air velocity in the wire cage and the air velocity around the wire cage in the wind tunnel measurements. A direction-dependency for this correction factor was not expected to increase the reliability of the air velocity measurements in the AOZ.

Turbulence intensity [(Std.dev.U_{DT})/U_{DT}] was increased by 10% to 20% by using a cage around the anemometer. This result was unexpected, since Smith et al. (1999) found that there was a small reduction in turbulence when an anemometer was placed in a wire cage. The different effects can be due to the differences in cage construction.

Aggregation Interval and Turbulence Intensity

Characteristics of the three datasets used to determine the most suitable aggregation interval and the turbulence intensity are presented in table 3.

Table 3. Characteristics of the three data sets used for the Fourier analyses, aggregation analyses, and determination of turbulence intensities. [a]

Data Set	Pen No.	Average Animal Weight (kg)	Average Ventilation Rate (m^3/h)	No. of Air Velocity Recordings (N)	Average Air Velocity (m/s)			
					X	Y	Z	Omni. Dir
1	3	14	1497 (106)	7600	0.04	0.07	0.06	0.11 (0.04)
2	3	11	702 (22)	5842	0.02	0.05	-0.01	0.08 (0.03)
3	9	11	702 (22)	5842	-0.01	0.14	0.03	0.16 (0.05)
[a] SD in parentheses.								

The result of the Fourier analyses as to the three data sets is shown in figure 6. There are four graphs, for the three directions and the omnidirectional air velocity signal. The cycle length of the harmonic function contributing to the signal is on the horizontal axis and the percent of variance accounted for by the harmonic function with cycle length equal to or bigger than *t* (*t* in seconds) is on the vertical axis.

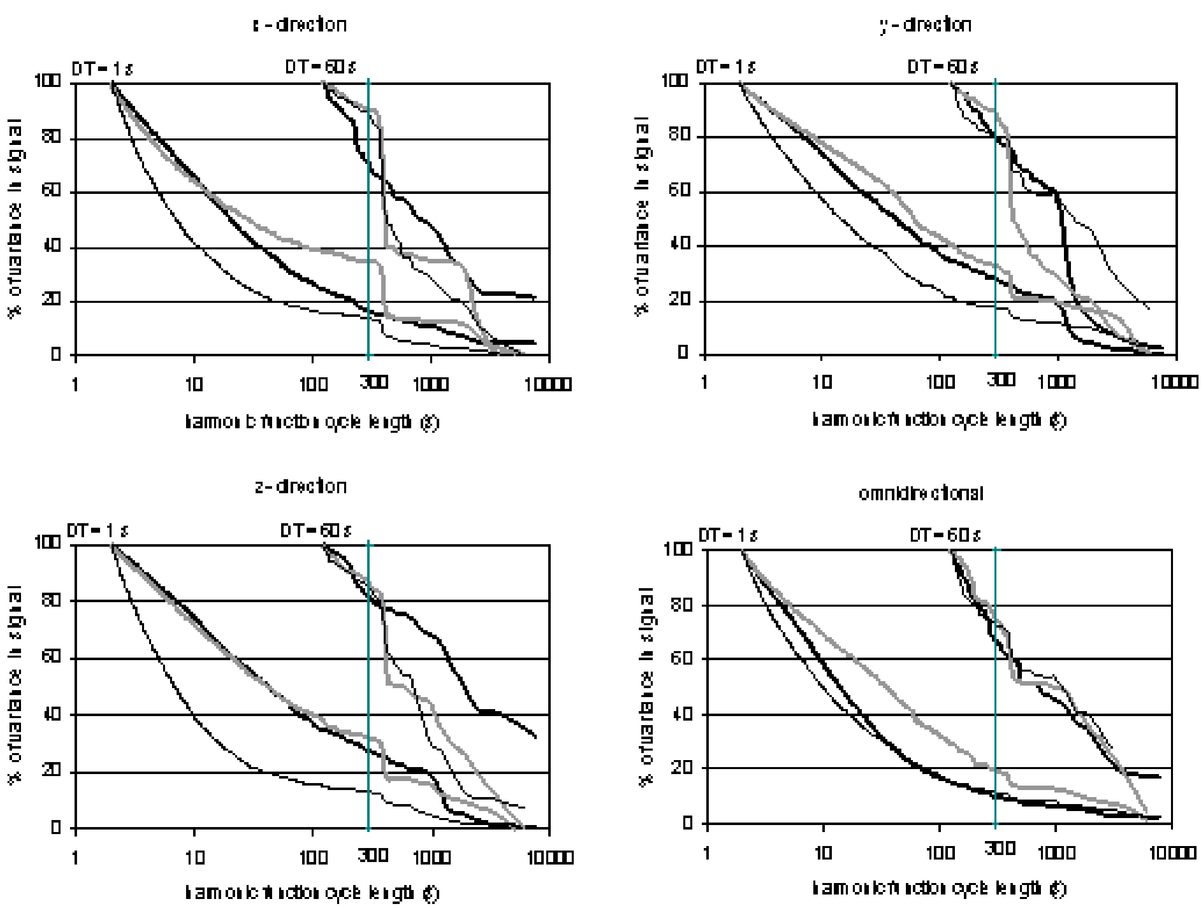


Figure 6. Result of Fourier analyses of three data sets (

[redacted]

data set 1,

data set 2,

[redacted]

data set 3) per direction and omnidirectional for the non aggregated data (DT = 1 s) and aggregated data (DT = 60 s); on the horizontal axis the cycle length of the harmonic function (t) and on the vertical axis the percent of variance accounted for by the harmonic function with cycle length equal to or bigger than t s.

The harmonic functions contribute to 100% of the variance in the signal when the cycle length of the function equals 2 • DT , what is logical because aggregating the signal filters out harmonics with a shorter cycle length. In the y-direction and in the z-direction for data set 1 a relatively large percentage of variance in the signal consists of harmonic functions with a cycle length of more than 1000 s. For data sets 2 and 3 in the x-and z-direction, what is clear at cycle length of 400 s. This effect can be caused by the delay in the ventilation control, assuming that ventilation rate and air velocity in the AOZ are related. The delay in ventilation control is determined by the time constant of the temperature sensor used. This sensor was mounted in a small metal tube (by the manufacturer). It takes some time for the sensor to register a temperature change. To include this effect a suitable aggregation interval is shorter than 400 s. Based on these results an aggregation interval of 300 s and a measuring frequency of 1 Hz were adequate for the level of turbulence encountered. The recorded average air velocity per direction (x, y, z) was used to determine the omnidirectional air velocity for the 300-s interval. This aggregation interval is a quarter of the interval used by Smith et al. (1999) for handling air velocity measurements in AOZ; animal weight in that experiment was 40 kg. Hoff (1995) used an aggregation interval of 180 s for an unoccupied test room.

Figure 7 shows the effect of the length of the aggregation interval (DT) on the omnidirectional air velocity.

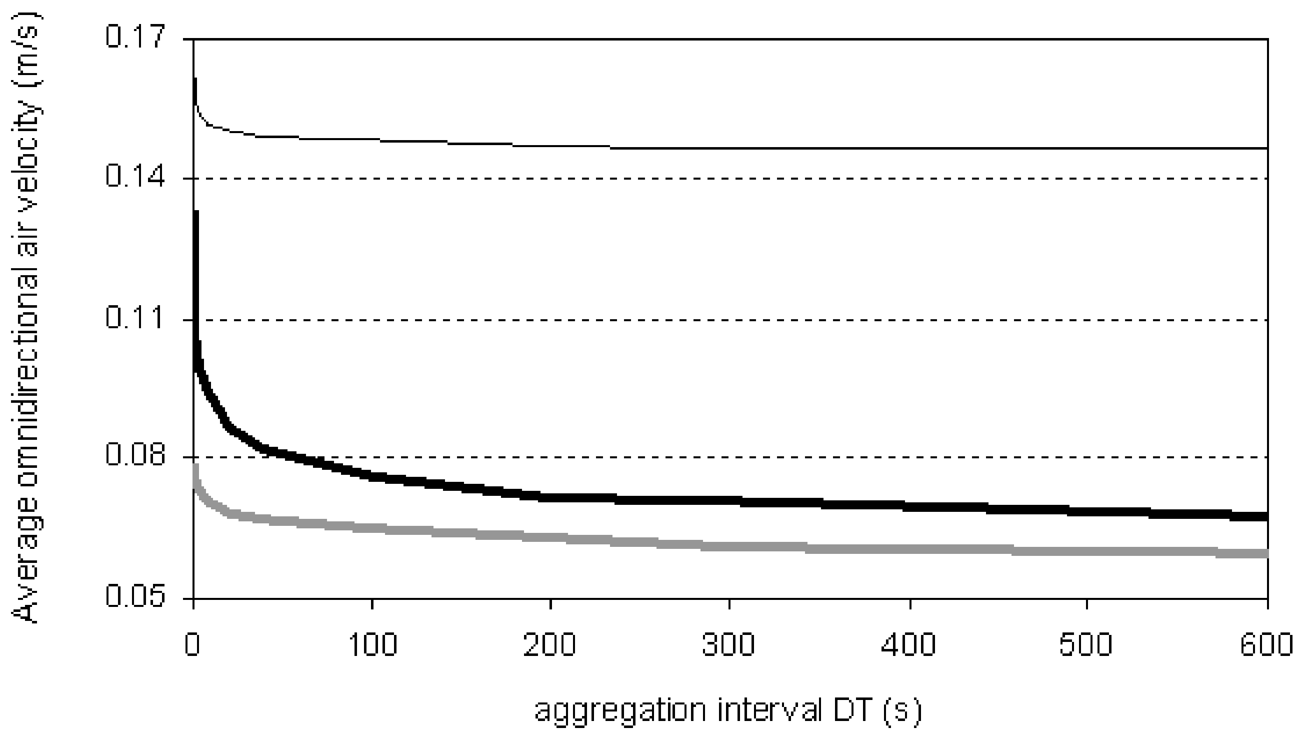


Figure 7. Effect of aggregation interval DT on average omnidirectional air velocity for three data sets (

data set 1,

data set 2,

data set 3).

For all three datasets the omnidirectional air velocity is reduced by increasing the aggregation interval DT from 1 and 100 s. Data set 1 demonstrates the greatest effect. At a 300-s aggregation interval, the air velocity seems to be stable for all three data sets, which indicates that the measurements will show the net airflow at the measurement location.

Turbulence intensity [(Std.dev.U_{DT})/U_{DT}] was 0.41 for data set 1, 0.44 for data set 2, and 0.34 for data set 3. These values are of the same magnitude as the values found by Smith et al. (1999) in occupied pigpens.

Although there are indications that quick fluctuating airflow, or turbulence, causes an unpleasant feeling for the piglets (Smith et al., 1999), turbulence measures were not pursued further for two reasons. First, the dataloggers were not able to process the data before storing the data at a 1-Hz sample and store frequency the memory capacity was less than 1 day. Second, it was not known what the appropriate sample and aggregation interval was for calculation turbulence such that it was the best indicator for thermal comfort of piglets.

Effect of Pig Activity on Anemometer Measurements

Pig activity had minor effect on the average momentary air velocity (table 4). In the 2-h observation period during daytime, when most activity was expected, 71% of the time there was no contact between the pigs and the anemometer. The effect of the small air velocity increase, only 29% of the time, was minimal. A statistical analysis of the differences as well as correction of the measured air velocity for this interaction was considered to be unnecessary.

Table 4. Effect of pig activity on the momentary air velocity in pen 3 with pigs of 14.5 kg. [a]

Kind of Interaction between Pig and Anemometer	Duration (s)	% of Time	Avg. Momentary Air Velocity (m/s)
No contact	7709	71	0.11 (0.04)
Sniffing	872	8	0.13 (0.06)
Rubbing	112	1	0.11 (0.05)
Lying under anemometer	1758	16	0.11 (0.04)
Running in pen	280	3	0.13 (0.05)
Bumping against anemometer	55	1	0.12 (0.05)
[a] SD in parentheses.			

Effect of Location in Pen on Air Velocity and Airflow Direction

The impact of location on the measurements is shown (table 5) with values averaged over 15 min and 8 (1-a-a and 2-a-a) or 12 (3-a-a) anemometer locations. Positive and negative values in table 5 refer to the airflow direction (fig. 3). The SD was determined using the average air velocities at the locations.

Table 5. Directional ($\bar{x}$, $\bar{y}$, $\bar{z}$) and omnidirectional air velocity (U) at different locations within pens 3 and 9 with light and heavy animals. [a]

		Air Velocity (m/s)			
		$\bar{x}$	$\bar{y}$	$\bar{z}$	U [b]
Pen 3 light	Front (1-a-a)	0.00 (0.01)	0.03 (0.04)	0.01 (0.01)	0.04 (0.03) a
	Middle (2-a-a)	0.01 (0.01)	0.01 (0.04)	-0.01 (0.02)	0.04 (0.02) a
	Back (3-a-a)	0.00 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01) b
Pen 3 heavy	Front (1-a-a)	-0.01 (0.02)	0.05 (0.02)	0.01 (0.02)	0.05 (0.02)
	Middle (2-a-a)	0.01 (0.01)	-0.01 (0.03)	-0.02 (0.02)	0.04 (0.02)
	Back (3-a-a)	-0.04 (0.02)	-0.01 (0.02)	-0.01 (0.02)	0.05 (0.02)
Pen 9 light	Front (1-a-a)	0.00 (0.01)	0.03 (0.03)	0.00 (0.01)	0.04 (0.03) ab
	Middle (2-a-a)	-0.04 (0.01)	0.03 (0.03)	-0.01 (0.01)	0.05 (0.02) a
	Back (3-a-a)	-0.01 (0.01)	0.00 (0.01)	0.00 (0.01)	0.02 (0.01) b
Pen 9 heavy	Front (1-a-a)	-0.03 (0.02)	0.04 (0.02)	-0.01 (0.01)	0.06 (0.02) c
	Middle (2-a-a)	-0.08 (0.02)	0.05 (0.02)	-0.02 (0.03)	0.10 (0.02) d
	Back (3-a-a)	-0.01 (0.01)	0.00 (0.01)	-0.02 (0.01)	0.02 (0.01) e

[a] SD in parentheses.

[b] a,b,c,d,e, different letters indicate a significant difference in air velocity between front, middle and back of the pen (a,b =P < 0.05; d,e,c = P < 0.001)

At the front of pen 3 at the locations 1-a-a (especially 1-1-1 and 1-2-1) air velocity was relatively high in the y-direction, air flowed from the front to the back of the pen close to the floor. Air velocities in the x and z-directions were lower at the front of the pen. At the back of the pen with light animals, air velocity was very low in all directions. With heavy animals airflow was directed towards the door at the back of the pen (direction ?x).

At the front of pen 9 airflow was directed towards the back of the pen, in the y-direction. In the middle of the pen the airflow direction was strongest in the x-direction toward the door, especially with heavy animals. At the back of the pen air velocities in all directions were relatively low.

In table 6 the average differences in air velocity among zones in the pen (front, middle, and back) and location 2-2-2 are shown. Negative values in table 6 mean that the air velocity at location 2-2-2 is higher; positive values the reverse. The results show that even in the small pens used in this research, there were significant differences within the pen sometimes up to 0.07 m/s (pen 9, heavy animals). The air velocity was lowest at the back of pen 9, above the slats. With heavy animals, also the air velocity at the front pen 9 was lower than at location 2-2-2. This may be explained by fresh air entering the pen from the operator walkway, then flowing over the pen partition and falling on the slats at the front of the pen without reaching the anemometer that was located 0.20 m behind the pen partition. The airflow was then directed to the back of the pen, resulting is some upward flow caused by obstruction of the pigs and heat produced in the resting area. This airflow pattern resulted in a comparatively higher air velocity at the locations 2-a-a. In pen 3 the fresh airflow from the operator walkway was smaller, and therefore the differences in air velocity within the pen were smaller.

Table 6. Average difference in air velocity between location 2-2-2 in the pen and other zones in the pen, for pens 3 and 9 with light and heavy animals. [a]

	Ventilation Range (m^3/h)	Average Difference in Air Velocity (m/s) [b]		
		Front (1-a-a)	Middle (2-a-a)	Back (3-a-a)
Pen 3 light	340 ? 460	-0.01 (0.04)	0.01 (0.02)	-0.01 (0.01) [a]
Pen 3 heavy	550 ? 1370	0.03 (0.02) [a]	-0.01 (0.02)	-0.01 (0.03)
Pen 9 light	440 ? 490	0.01 (0.04)	0.00 (0.03)	-0.05 (0.02) [b]
Pen 9 heavy	620 ? 740	-0.05 (0.02) [b]	-0.02 (0.03)	-0.07 (0.02) [b]

[a] SD in parentheses.

[b] a, b different letters indicate a significant difference in air velocity between the reference location 2-2-2 and the front, middle or back of the pen (a = $P < 0.01$; b = $P < 0.001$).

It is impractical to locate anemometers at several locations in one pen, so one *best suitable* location should be chosen. Table 6 shows that the air velocity measured at location 2-2-2 shows no significant differences in air velocity with the space-average air velocity in the middle of the pen (2-a-a) above the resting area. Therefore location 2-2-2 was chosen as the standard measurement location.

Effect of Presence of Anemometer on Resting Locations of the Piglets

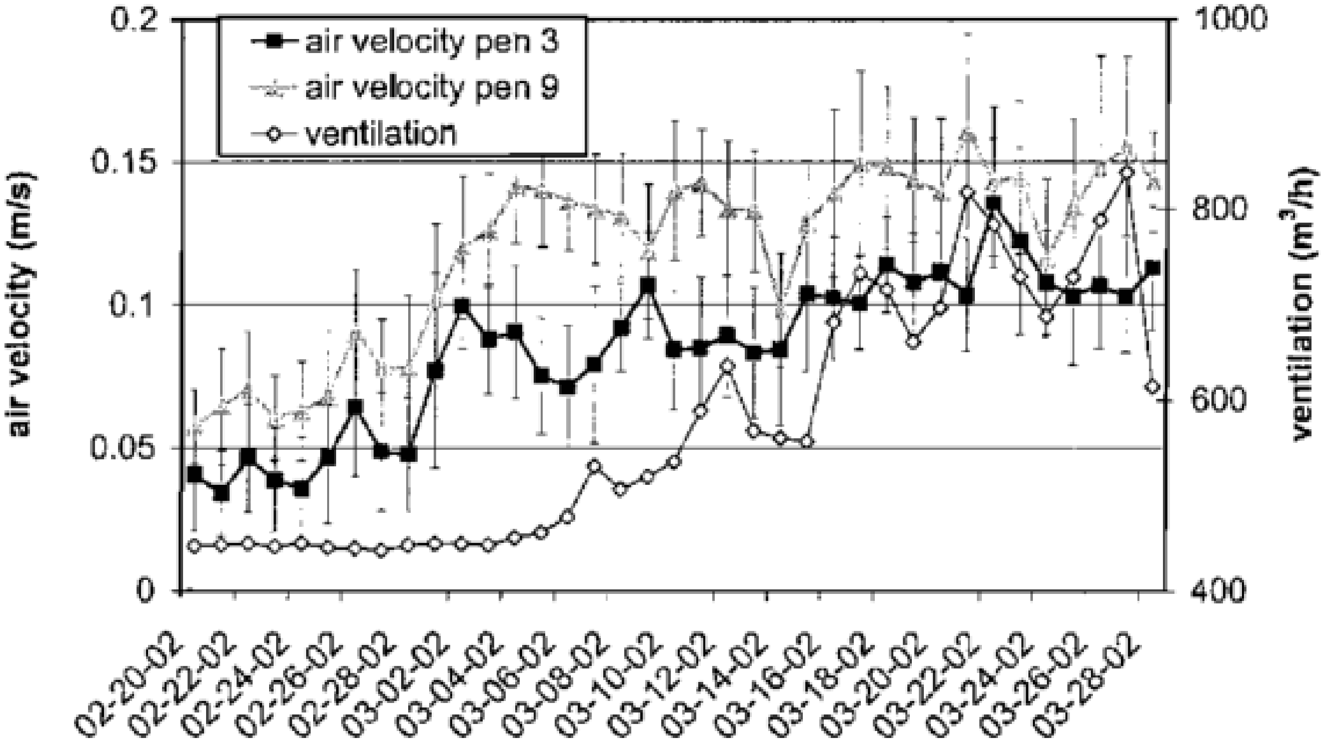
Results of the comparison of the resting locations in pens 1 and 3, and pens 7 and 9 are presented in table 7. In this experiment there was a possibility of interactions of the pen-effect with the anemometer presence-effect. Changes in percentage of animals lying on the solid floor were considered to have the largest effect in animal welfare and animal production. For light animals, there was no significant difference. For heavy animals there was some difference (9% between pens 7 and 9), what can be explained by the fact that it was more difficult for heavy animals to use the floor area under the sensor. However, the significant differences were relatively small and the general pattern did not change. It can be concluded that measuring air velocity in the AOZ results in minor changes in resting locations in the pen.

Table 7. Average percent of animals lying and standing on the solid floor/water channel and on the slats in pens with and without anemometer. [a]

	Pen 1	Pen 3	Pen 7	Pen 9
Presence of anemometer	No	Yes	No	Yes
Day 1 to 11 light animals				
Lying on solid floor or water channel	76	80	84	78
Standing on solid floor or water channel	15	14	11 ^{b}	18 ^{b}
Lying on slats	0	0	0	0
Standing on slats	9 ^{a}	6 ^{a}	5	5
Day 29 to 34 heavy animals				
Lying on solid floor or water channel	67	65	75 ^{c}	66 ^{c}
Standing on solid floor or water channel	12	12	11 ^{a}	17 ^{a}
Lying on slats	11 ^{c}	16 ^{c}	6	9
Standing on slats	9	8	8	9
[a] $^{a, b}$ different letters indicate a significant difference (^{a} = P < 0.05; ^{b} = P< 0.001; ^{c} = P< 0.01)				

Air Velocity in AOZ

The air velocity in pens 3 and 9 was measured during one batch (except for first week). In figure 7 the course of the daily average air velocity is shown. The air velocity measured in pen 9 was higher than in pen 3. During the batch the air velocity increased in both pens, but not in proportion to the ventilation rate. During the period 20 February to 6 March 2002 there was only a minor increase in daily average ventilation, but there was an important increase in air velocity in the pens. Most of the time the air velocities in both pens show the same fluctuations, but on day 9 March 2002, the air velocity in pen 9 was relatively low, while in pen 3 the air velocity was relatively high.



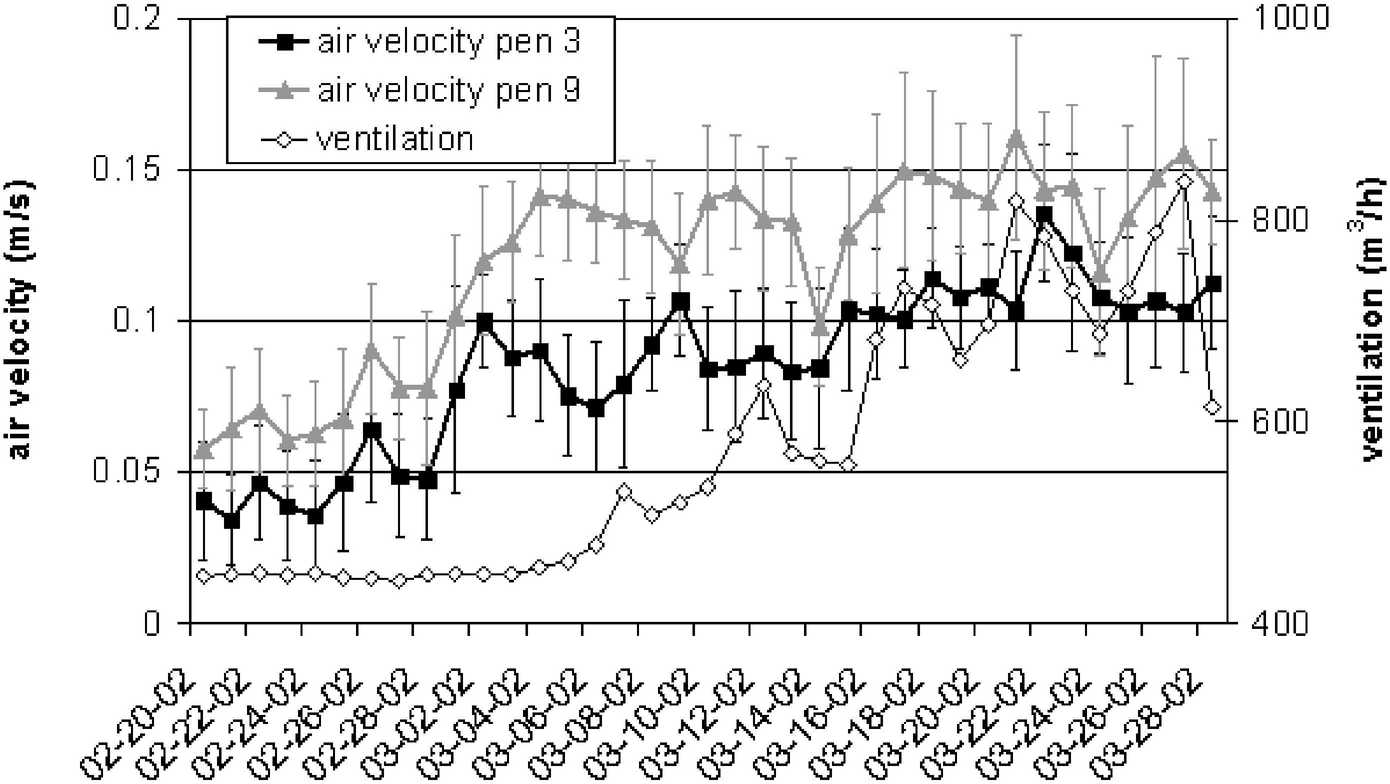
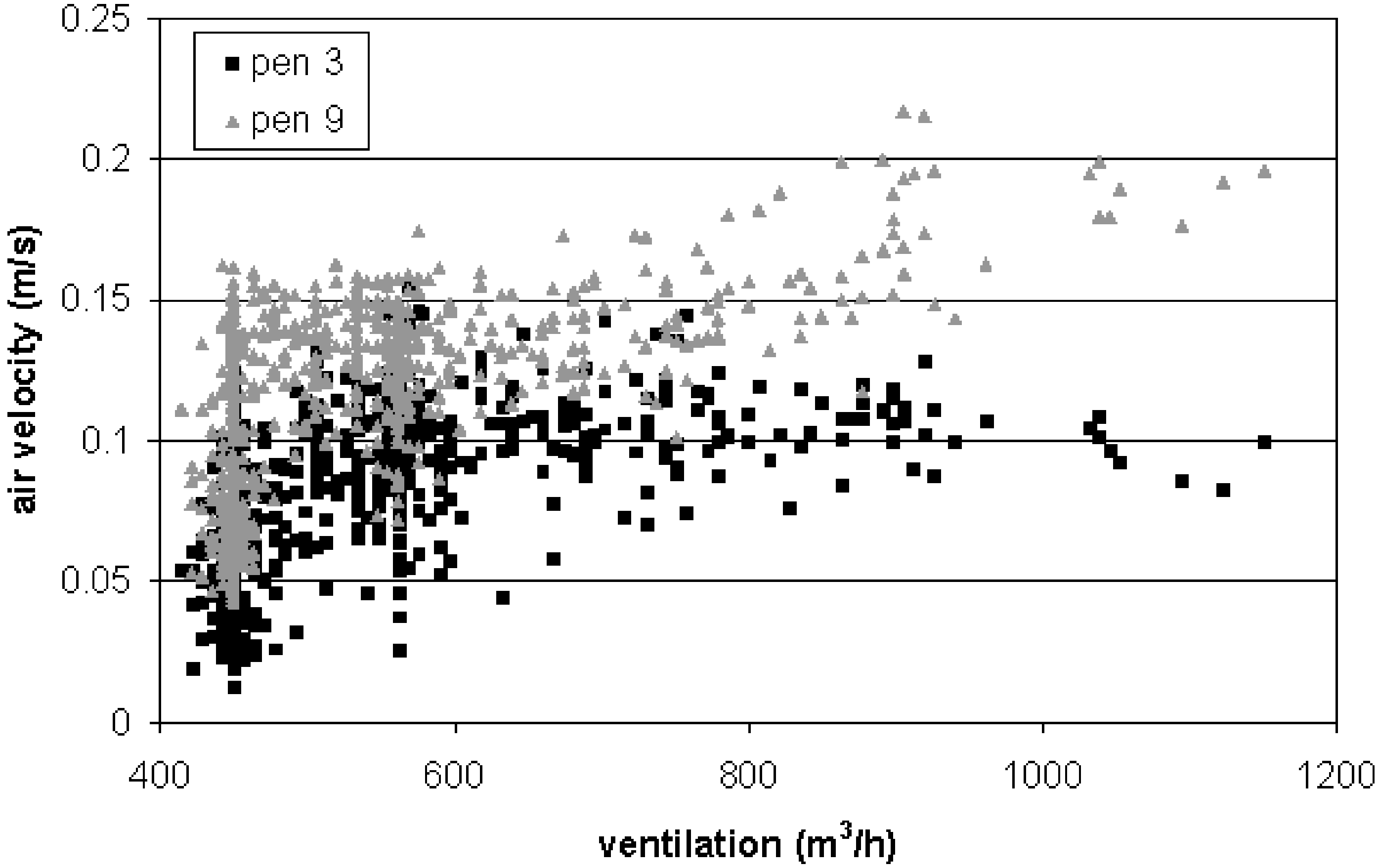


Figure 8. Daily average ventilation and air velocity (range indicates standard deviation) at location 2-2-2 in pen 3 and pen 9 during one batch (except for first week) of weaned piglets in experimental room.

In figure 9 the air velocity measured is plotted against ventilation rate. Higher ventilation rates increase the air velocity, especially in pen 9. At low ventilation rates (between 400 and 600 m ^{3}/h) there is much variation in air velocity in both pens. The analysis of the air velocities during the batch as presented in figure 8 and 9 cannot explain all the variation encountered.



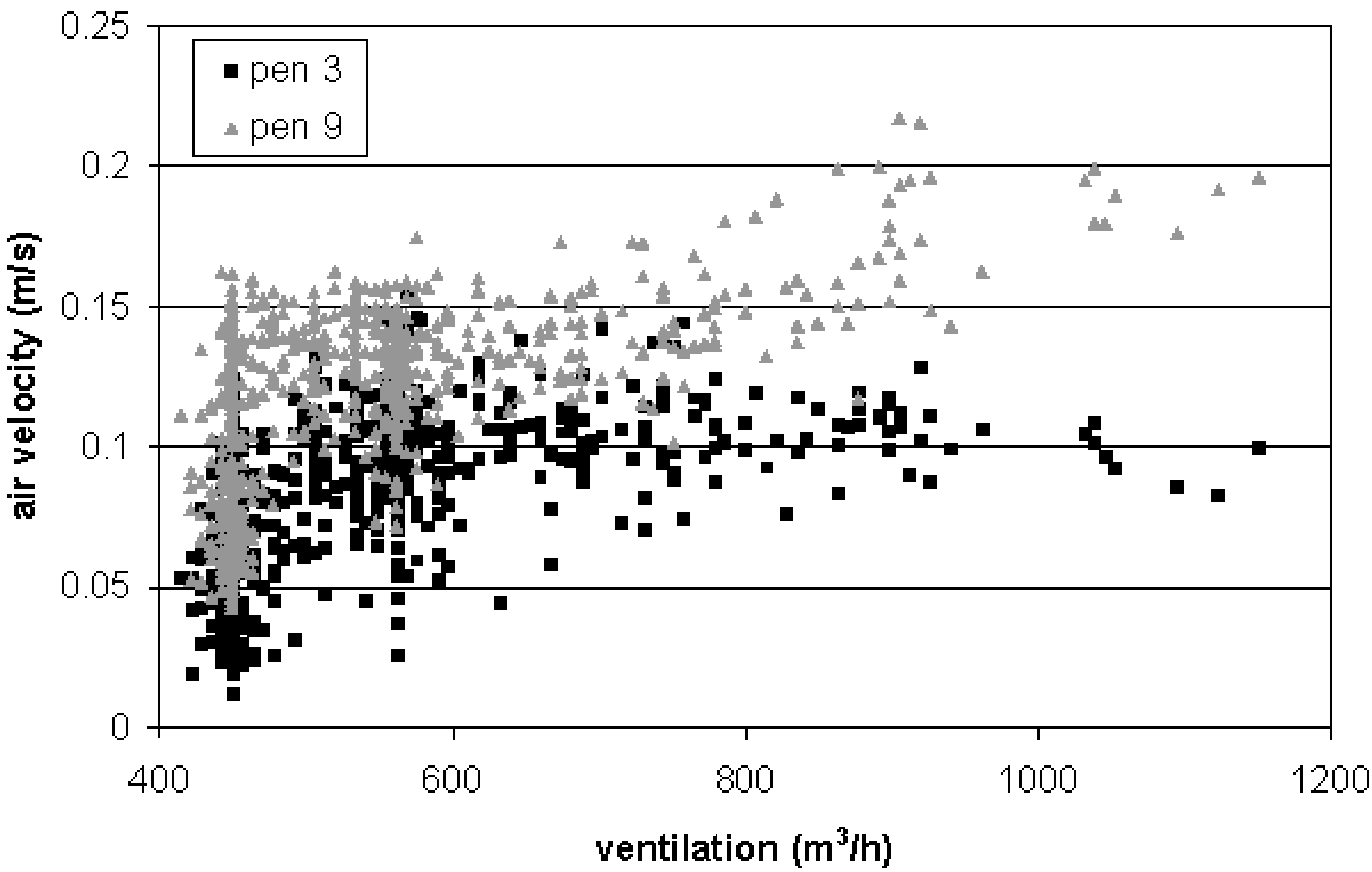
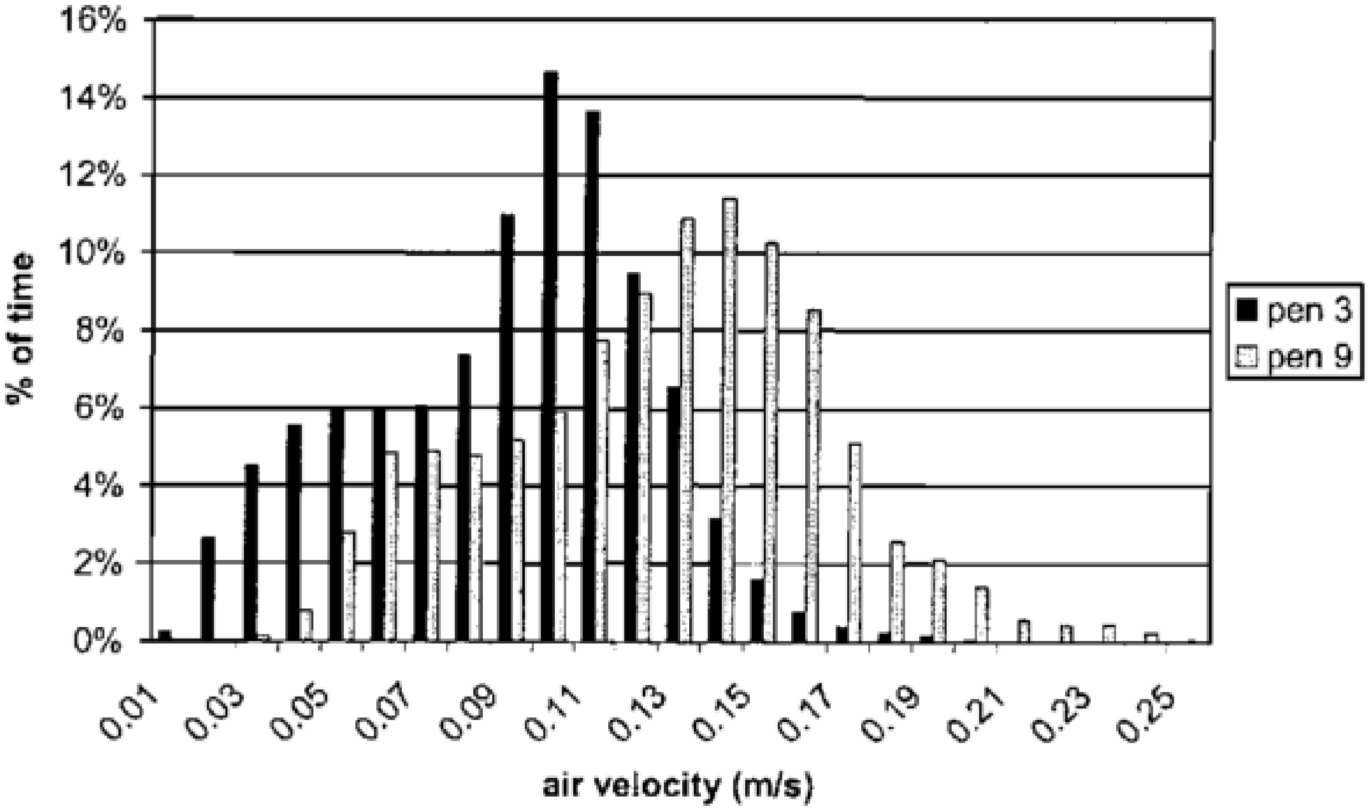


Figure 9. Effect of ventilation rate on air velocity at location 2-2-2 in pen 3 and pen 9 during one batch (except for first week) of weaned piglets in experimental room (hourly averages).

The distribution of the air velocities during the batch is shown in figure 10. There was a clear and significant difference in average air velocity between pens 3 and 9 ($P < 0.001$). The average difference was 0.04 m/s. The recommended maximum value for air velocity in the AOZ for weaned piglets is 0.15 m/s (Van ?t Klooster et al., 1989). The air velocity in pen 9 was higher 21% of the time; in pen 3 it was higher about 2% of the time.



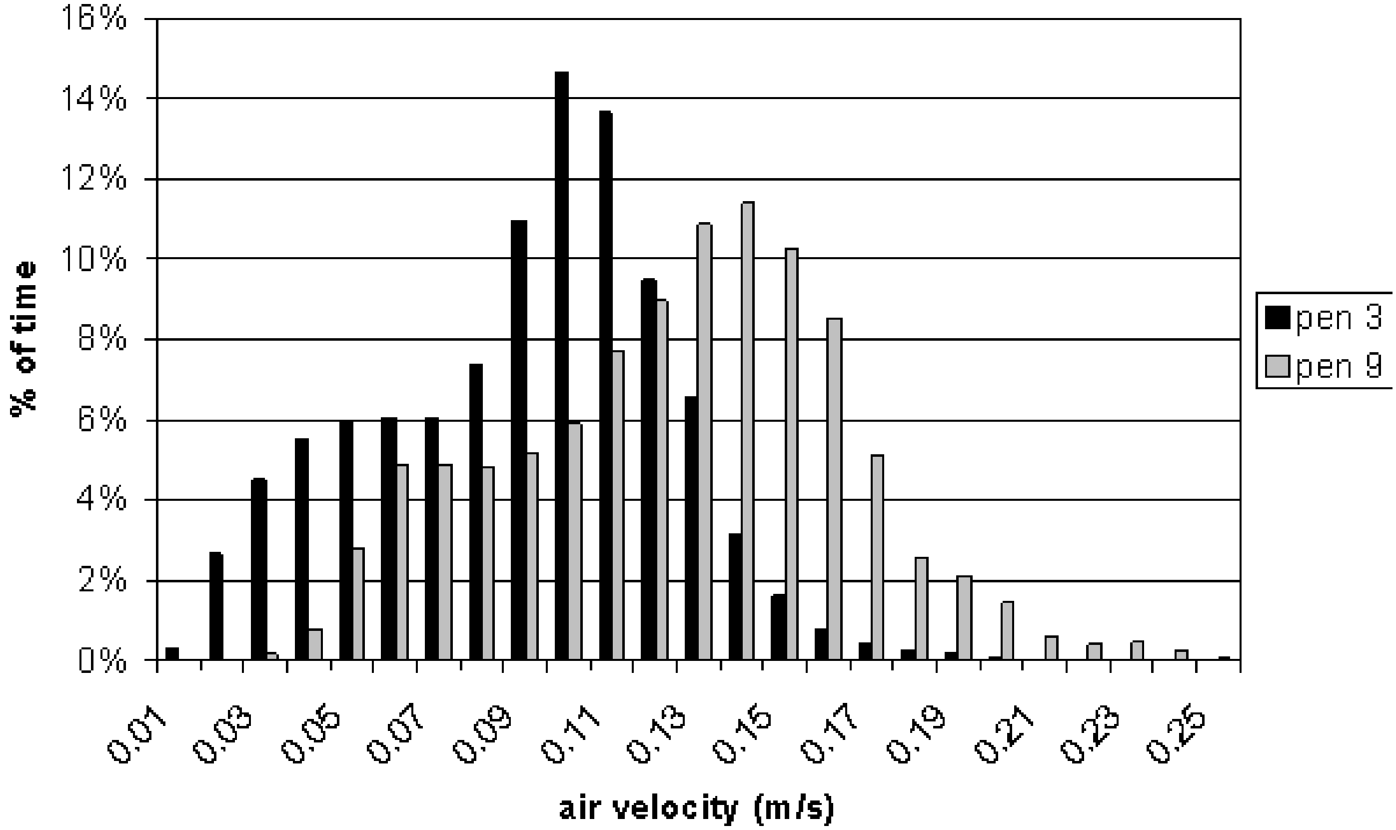


Figure 10. Distribution of air velocity measurements (300-s averages) at location 2-2-2 in pens 3 and 9 during one batch (except for first week) of weaned piglets in experimental room.

Besides differences in air velocity, there will be more climatic differences between pens 3 and 9 that might result in differences in animal production, animal health, and animal welfare. The fresh air supply in pen 9 was better than pen 3. Only the combination of air quality aspects, air velocity, and air temperature gives information about the quality of the climate in the AOZ, and thereby on the performance of the ventilation system. The measuring system described in this article can be combined with those for air quality and temperature in the AOZ as described in earlier work (Van Wagenberg and Smolders, 2003). This system can be used to determine the performance of ventilation systems and to compare ventilation systems.

Conclusion

Air velocity in the AOZ of occupied pig rooms can be measured using ultrasonic anemometers. A wire protection cage is necessary, but does affect the air velocities measured. To determine the time averaged air velocities a standardized calculation method, sample frequency, and aggregation interval can be used. A 1-Hz sample frequency and a 300-s aggregation interval are proposed for rooms for weaned piglets. Within the AOZ there will be differences in air velocity, and therefore the measurement location needs to be determined in a preliminary study to find a representative location for the occurring air velocity in the resting area of the pigs. Animal resting locations were essentially unaltered by the presence of a static anemometer, and animal activity had little impact on the air velocity measured. In a door-ventilated room the air velocity in pens at the back of the room was 0.04 m/s higher than in a pen closer to the door, resulting in differences in microclimate between the different pens within one room.

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