Measurements and Simulation of Climatic Conditions in the Animal Occupied Zone in a Door Ventilated Room for Piglets

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ABSTRACT. Climatic conditions in the animal occupied zone (AOZ) of a pig room are important for animal health, comfort and performance. Both practical measurements and numerical simulations could be used to assess the climatic conditions in the AOZ. The objective was to test the possibilities for using pig location patterns based on the real time monitoring as a thermal boundary condition in a numerical simulation model and to gain insight in the distribution of air velocity, air temperature and CO_2 concentration in the AOZ. Measurements were performed in a door ventilated room for weaned piglets. Animal lying locations were recorded. The geometry of the air space including models for the pigs was constructed in AutoCad and imported in the numerical simulation program (Fluent 5). The measurements of three 1-hour periods were considered to be static situations, and are compared with numerical simulations.

Measured and simulated airflow direction in the AOZ did correspond, but in air velocity magnitude there were differences. The simulations agree with measurements in a preceding study, that show that the height above the solid floor is of crucial importance for the local air velocity. Both measurements and simulations showed a tendency for decreasing pen temperature when the distance to the door increased, but the measured temperatures were in general higher than the simulated. Adding radiation heat transfer in the simulations might decrease the difference. The differences between measured and simulated CO_2 concentration were relatively large, this could be caused by chosen simplifications in the simulations that influence the calculated airflow pattern and CO_2 distribution, such as not including the feeders in the model and assuming homogeneous conditions in the air inlet.

In the study it is proved to be possible to include boundary conditions obtained from conditions with live pigs, but some adaptations in the presented simulation model are necessary. Regarding the door ventilation system, the study confirmed that the air distribution is inhomogeneous especially at high ventilation rates. The study confirms the expectation that numerical simulation has the potential to become an important tool for designing and improving ventilation systems for livestock rooms.

Keywords. Pig housing, air velocity, numerical simulation, air quality, air distribution, CFD.

A.van Wagenberg, B. Bjerg, and G. Bot. "Measurement and Simulation of Climatic Conditions in the Animal Occupied Zone in a Door Ventilated Room for Piglets". Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Manuscript BC 03 020. April, 2004.

INTRODUCTION

Air velocity, air temperature and contaminant concentration in the animal occupied zone (AOZ) of a pig room, are important for animal health, comfort and performance. The actual values depend on many factors, of which an important factor is the ventilation system design (Zhang et al. 2001; Van Wagenberg and Smolders, 2003). To assess the performance of ventilation systems, information on climatic conditions in the AOZ is needed.

Both practical measurements and numerical simulations could be used to gain insight in the climatic conditions in the AOZ. Measuring climatic conditions in the AOZ has been done in preceding studies than concentrated on air velocity in the AOZ and on fresh air supply to the AOZ based on gas concentrations (Van Wagenberg and De Leeuw, 2003; Van Wagenberg and Smolders, 2003). There are three disadvantages of practical measurements. A practical building is needed before the design of a ventilation system can be evaluated. Secondly it considers local measurements which complicates the handling of heterogeneity within the AOZ. Finally, practical measurements demand expensive equipment and long-term experiments.

In a numerical simulation the room volume is divided into a cell structure (grid). Per cell a momentum, energy and a mass balance is expressed in differential equations. Between cells there is momentum, heat and mass transfer. Under given boundary conditions, this method can be used to simulate three-dimensional airflow, temperature and gas concentration distribution. For this, software packages are available. Numerical simulations have the potential to predict the climatic conditions in the AOZ. A number of numerical simulation studies have focused on the influence of room dimensions and inlet conditions in prediction of isothermal airflow in mechanical ventilated full scale livestock test rooms (e.g. Harral and Boon, 1997, Bjerg et al., 1999, Bjerg et al., 2002a, Bjerg et al., 2002b). Numerical simulation of buoyant airflow above a simulated pig is reported by Zhang et al (1999). Bjerg et al (2000) investigated numerical simulation methods to predict airflow in a mechanical ventilated test room with and without thermal pig simulators and pen partitions. However, the complex environment of an actual occupied pig room, has not yet been reported. It is known that the presence of live pigs in a room has substantial effect on the characteristics of the airflow around them (Smith et al., 1999).

In this paper, practical measurements in a door-ventilated room for weaned piglets are described and compared with numerical simulation results. The objectives were to test the possibilities for using the boundary conditions obtained from conditions with live pigs in a numerical simulation model and to achieve the information on the distribution of air velocity, air temperature and CO_2 concentration in the AOZ. The level of agreement between measurements and simulation will illustrate the required further development of the numerical simulation technique. This paper thereby contributes to development of the simulation technique to an efficient tool in the design of practical ventilation systems.

MATERIALS AND METHODS

EXPERIMENTAL SET-UP

The experimental data were collected during three 1-hour periods during two subsequent days (2 hours during first day and 1 hour during second day). The periods were considered to be static situations: however, animals did move in the pens during the hour. Measurement results were compared with the numerical simulation. During the periods no persons entered the room, the feed system was inactive and the light was on for video recording of animal locations.

DESCRIPTION OF ROOM AND ANIMALS

A door-ventilated room, in which fresh air enters the room through an opening in the lower part of the door, was used in this research (fig. 1). Next to the operator walkway are solid pen partitions (0.6 m height). Fresh air fills the operator walkway and flows slowly over the pen partitions into the pens. This ventilation system is commonly used in the Netherlands. The experimental room was located at the experimental farm in Raalte, The Netherlands. The room was built as a representative copy of the door ventilation system most applied in practice for housing of piglets from 7 kg bodyweight to approximately 23 kg bodyweight. In figure 1 a plan and a cross section of the room is shown. In the room there were 5 pens on each side of the operator walkway, each for 9 animals. Each pen had 50% solid floor and 50% metal tribar slatted floor. The air inlet in the door was 0.58 m by 0.92 m (0.534 m^2). Initial measurements, with an ultrasonic anemometer located in the air inlet, have shown that airflow direction for all ventilation levels is perpendicular to the central alley. The exhaust air was removed from the room by a ventilator in a ventilation shaft, directly behind the door at 2.1 m height. For measuring and controlling the ventilation rate a measuring fan and an automatic valve were mounted in the ventilation shaft.

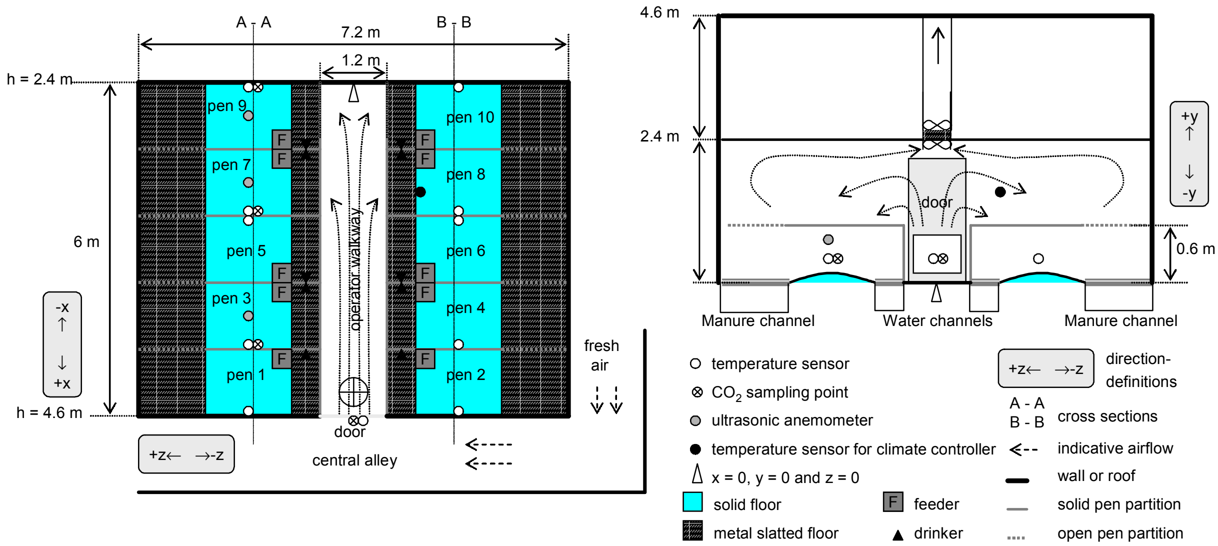

Figure 1. Plan and cross section of the compartment for weaned piglets, the measuring locations - the defined x, y and z axis are indicated.

A coordinate system was used in the room, figure 1. This coordinate system was based on the positioning of the ultrasonic anemometers and in such a way that the expected airflow directions in pens 3, 7 and 9 were positive.

Earlier work in the same room and in other door ventilated rooms has shown that air distribution over the pens is not homogeneous (Van Wagenberg and Smolders, 2003 and Van Wagenberg and De Leeuw, 2003). At higher ventilation rates air is known to flow over the operator walkway to the back of the room before it flows over the pen partition. Much fresh air enters in the pens in the back of the room, resulting in effective removal of contaminants and heat from those pens, but increasing the risk for high air velocities in those pens. In the pens located near the front of the room there is less fresh air supply and air velocities are lower.

Three dimensional air velocity patterns in pen 3 and 9 of the experimental room were measured before. This was done by moving an ultrasonic anemometer over a grid within the AOZ. The method and the results are described by Van Wagenberg and De Leeuw (2003). The results of these measurements are plotted in graphs and are shown in figure 2.

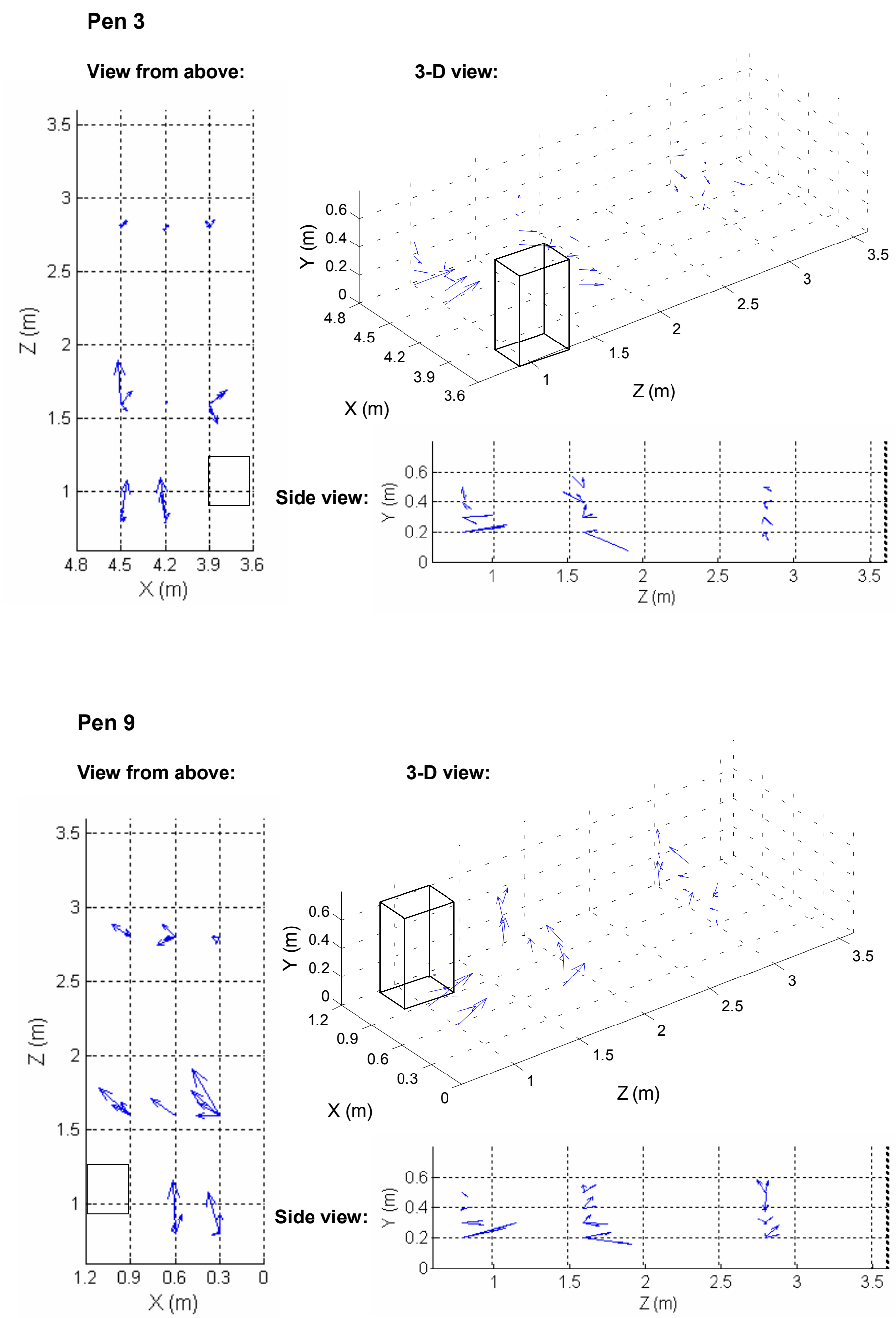

Figure 2. 3-D air velocity distribution in pens 3 and 9 in experimental room as measured in earlier research (numbers on axis in meters; x, y and z as in figure 1; arrow length of 0.5 m on axis ≈ 0.15 m/s; open box = feeder; average bodyweight piglets 8 kg; ventilation 340 – 490 m^3/h)

It was clear that air velocity and airflow direction in pens 3 and 9 depend on the location. In the front of both pens air velocity was higher than in the back. In the vertical velocity-profile above the solid floor (side view, Z= 1.6 m, measuring height Y varies from 0.2 to 0.5 m.), air velocity near the floor was highest and directed towards the back of the pen. In pen 3 the airflow direction changed direction at a height between 0.3 and 0.4 m and flowed to the front of the pen.

The measurements described in this paper were taken during days 18 and 19 in the production period. The average bodyweight of the piglets in the room was 13.1 kg. Feed intake was 650 gram/animal per day and the heat production was calculated at 55 W per animal, of which 38 W was sensible heat (Van Ouwerkerk, 2000). The ventilation was at minimal rate at a room temperature lower than 24.4° C, at higher temperature the ventilation increased automatically; the minimum and maximum ventilation levels were 5.0 and 18.0 m^3/h per piglet. The temperature range between minimum and maximum ventilation was 4° C and there was no additional heating.

MEASUREMENTS AND RECORDINGS

Air velocity measurements were performed with 3 ultrasonic Anemometers (Gill, Windmaster 1086M) protected by a cage and located in pens 3, 7 and 9, 1 m behind the front pen partition, 0.6 m from the side pen partition and 0.3 m above the solid floor. Time averaged air velocities were determined by averaging over 300 s with 1 Hz sample frequency. The accuracy was 0.01 m/s. A detailed description of the measuring system and strategy has been published before (Van Wagenberg and de Leeuw, 2003).

Air temperature measurements were performed with Pt100 sensors (accuracy < 0.1ºC). Sensors for pen temperatures were located in the middle of the solid floor in all pens, at 0.15 m height and at 0.05 m distance from the pen partition, figure 1. The intake air temperature was measured in the inlet and the room temperature was measured at 1.5 m height halfway the room above pen 8, the latter was used by the climate controller. The room temperature was assumed to be equal to the air temperature in the outlet and used for the calculation of heat loss by ventilation. This assumption is checked with the cfd simulation, this is presented in the results section of this paper. All temperature data were recorded every 10 minutes.

The ventilation rate was measured by a measuring fan in the ventilation shaft measured ventilation in the room (accuracy < 50 m^3/h). The data were recorded every 10 minutes.

Carbon dioxide concentration was measured in the inlet air, in pens 3, 7 and 9 during two of the three selected hours. This was done from outside the room with a manual CO_2 sensor (Anagas CD 98, accuracy circa 50 ppm). After each other air samples were extracted from the room with a Teflon tubing system. Figure 1 shows the locations of the sampling points in the pen.

Video cameras were used to record animal lying locations in all pens. The pig location patterns were used to determine the locations of the sources of heat and carbon dioxide for the simulations.

NUMERICAL SIMULATIONS

Livestock test rooms used in published numerical simulation studies have usually been equipped with small air inlets that implied inlet velocities about 20 times higher than the velocities in the AOZ. Simulation of airflow in such rooms requires an intensive grid resolution in the air inlet zone (Bjerg et al., 2002a). Since the demand for computer power and calculation time highly depends on the used number of cells in the grid, it is important to be able to control the grid density in the different parts of air volume. A structured hexagonal grid (Bjerg et al., 2002a) includes a good possibility to control the grid resolution in different parts of the air volume. In the door ventilation system differences between inlet velocities and velocities in the AOZ are small and, consequently, the ability to control the grid distribution in different parts of the room is not as important. Therefore the simulations in this study were based on an unstructured grid. The possibility to control the grid resolution is limited but the unstructured grid that is able to handle air spaces with a complicated geometry.

The commercial Computational Fluid Dynamic program Fluent 5 (Fluent Inc) was used to perform the numerical simulations. To account for the effect of turbulence the k-epsilon turbulence model (Launder and Spalding, 1974) was chosen. This widely used model is relatively stable and it has proven to function well for simulations concerning indoor airflow. Both steady state and transient simulations were carried out. Time steps of 1 or 10 s and 5 or 10 iterations per time step were used in the transient calculations.

Geometry and grid construction

The geometry of the air space was constructed as a solid volume in the AutoCAD construction program from Autodesk. The geometry of a pig was represented by a half sphere (0.15 m radius), see figure 3. Using a model for each pig made it possible to adjust the location and magnitude of heat and carbon dioxide production to the actual conditions in each pen. The spherical shape had the advantage that the heat production could be distributed to only one surface per animal and it limited the risk of creating narrow air volumes between pig models requiring a locally high grid density. A plane surface on top of each pig model was used as inlet boundary for carbon dioxide, see figure 3. The area of the carbon dioxide inlet on the pig model was relatively large (0.009 m^2) which reduced the need for locally high grid resolution. The location of pig models was based on video recording of the pens. Figure 3 shows the location of pig models in case 3. Figure 5 shows location of pigs in all three cases. More details on the locations of pigs are given in the results section.

The pen partitions above the slatted floor close to the sidewalls consisted of 6 horizontal bars with 0.045 m spacing in between. A geometric modeling of these openings would be rather complicated and requires a local high grid density. Consequently it was modeled as a face with a defined flow resistance. To support the control of grid density the air volume above the pens was divided into three internal volumes (fig. 3) so it became possible to specify a finer resolution close to the surfaces compared to the middle of the room.

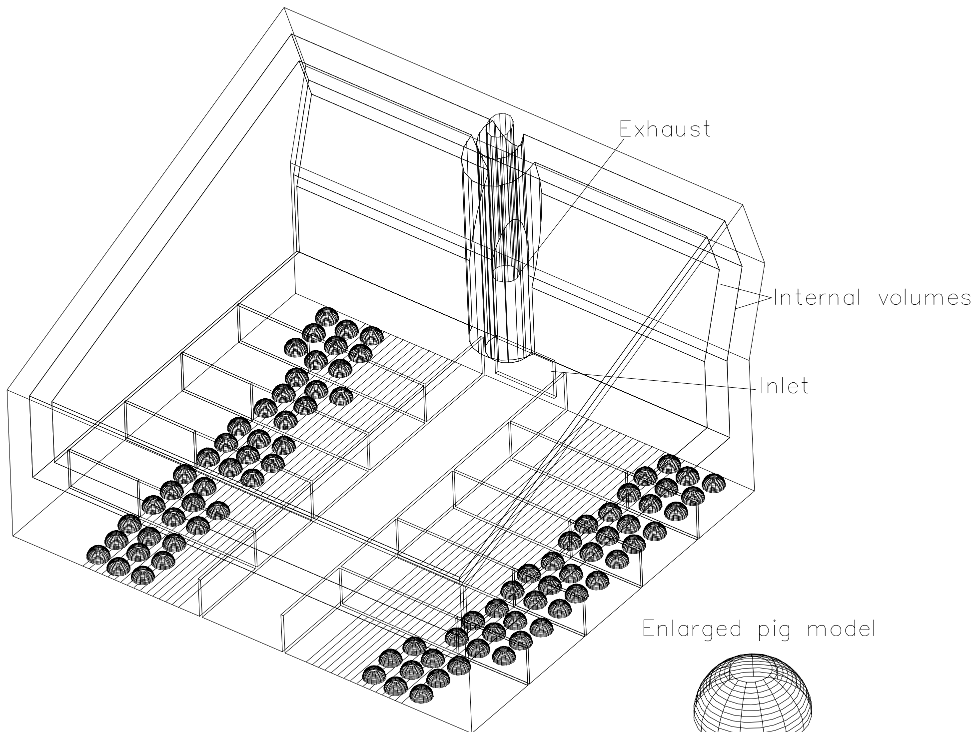

Figure 3. Geometry of air volume with location of pig models used in case 3.

Using the ACIS format the geometry was exported from AutoCAD to the Gambit preprocessor from Fluent Inc. The preprocessor was used for boundary specifications and automatic grid construction. In each of the three cases the three-dimensional grid consisted of approximately 155 000 tetrahedral cells. Near the pens and close to the building surfaces the maximum cell dimensions were 0.15 m. In the middle of the air space the maximum cell dimension was 0.3 or 0.6 m. Figure 4 shows the grid distribution at one sidewall and in the symmetric plane of the room. The significance of grid distribution was not investigated in this study. The theoretical way to do this is to refine the grid until the solution no longer changes. But the practical possibilities to do so are restricted by computer power limitations.

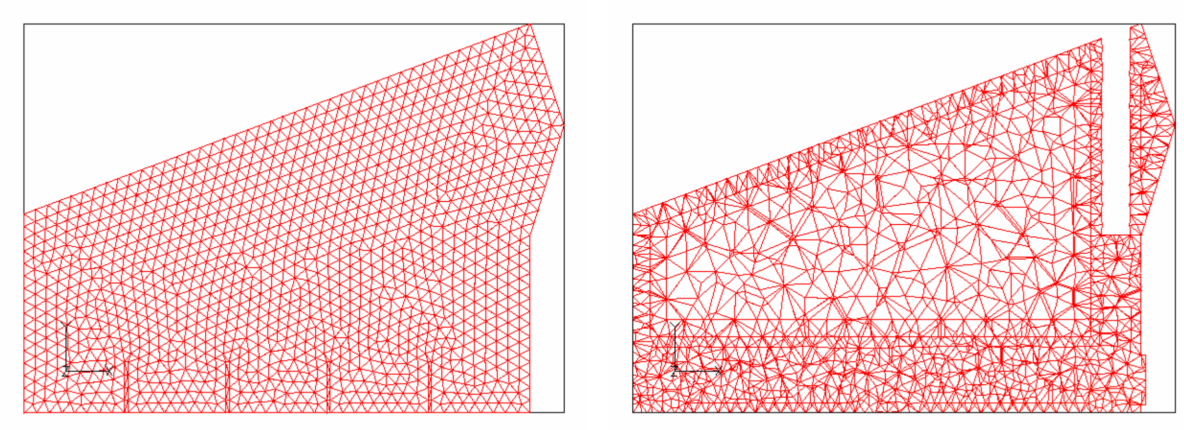

Figure 4. Grid distribution in the room, left at one side wall and right in the symmetric plane.

Heat balance

The airflow in the room was assumed to be driven mainly by the inlet air and the convective heat from animals. Consequently radiation from animal to room surfaces and heat transfer through building construction was not taken into account. There was no additional heating during the experiment. The heat balance was maintained by assuming that the convective heat from the animals was equal to the heat removed by ventilation, which was computed based on the measured inlet air temperature, the room temperature and the ventilation rate. The applied convective heat appears from table 1 and is in the magnitude of 40% of the expected total sensible heat production (calculated at 38 Watt, see earlier section in this paper) from the animals, the rest of the sensible heat loss is mainly radiation.

Table 1. Initial values and boundary conditions for simulation in case 1, 2 and 3.

	Case 1 27/5/2002: 10.30 – 11.30	Case 2 27/5/2002: 15.30 – 16.30	Case 3 28/5/2002: 6.00 – 7.00
Ventilation (m^3/h)	649	912	449
Air inlet velocity (m/s)	0.338	0.475	0.234
Inlet air temperature (° C)	17.6	19.8	16.9
Heat supply from animals (W)	1634	1873	1067
Heat supply (W/animal)	17.0**	21.5	12.3

** to compensate for solar radiation 25 W extra was added to three pigs in each of the two pens close to the windows.

Boundary conditions

Air intake was specified as inlet air velocity homogeneously distributed over the inlet area and calculated from the ventilation rate as given in table 1. Carbon dioxide concentration in the inlet air was set to 300 ppm. Air outlet was modeled as *pressure outlet* and all surfaces were assumed to be impermeable for air and adiabatic (solid wall function). Animal convective heat supply was specified as heat flux (W/m^2) at the spherical surface area of the animal models. To compensate for observed solar radiation through windows, 25 W of extra heat supply was added to each of three pigs in the two pens nearest to windows (pen 9 and 10) in case 1. The 25 Watt was roughly estimated based on the sun-lighten surface (circa 0.3 m^2 per pen), on the direct solar radiation (at 27/5: 11.00 in The Netherlands this is circa 500 W/m^2) and on radiation losses of 50% in the dirty window. The flow resistance of the open pen partition near the side walls was determined in a separate numerical simulation model. Based on the simulated pressure drop Δp (Pa), the pressure discharge coefficient, C defined by: $\Delta p = C½\rho v^2$ (Fluent, 1998) was determined to be 1.76 where ρ air density (kg/m^3) and v air velocity (m/s),

CO_2 production from each animal was calculated as 16.3 liter/h of CO_2 per 100 W total heat production (CIGR, 1984). For the actual average pig weight of 13.1 kg CO_2 production was calculated at 9 liter of CO_2 per hour per animal. This quantity of CO_2 was added as a velocity inlet into the air volume at the top of each of the 87 pig models in the simulation.

RESULTS AND DISCUSSION

MEASUREMENTS

Results of the measurements on air velocity, air temperature, ventilation rate and CO_2 concentration at the measuring positions (fig. 1) in the three periods are presented in table 2.

Table 2. Average of temperature, air velocity, ventilation rate and CO_2 concentration measurements and standard deviation.

		Case 1 27/5/2002: 10.30 – 11.30 Average	Stdev	Case 2 27/5/2002: 15.30 – 16.30 Average	Stdev	Case 3 28/5/2002: 6.00 – 7.00 Average	Stdev
Ventilation (m^3/h)		649	70	912	52	449	0[1]
Air velocity (m/s)							
Pen 3	x-direction	-0.04	0.02	-0.03	0.01	-0.03	0.01
	y-direction	0.02	0.01	0.02	0.01	0.02	0.01
	z-direction	0.10	0.01	0.10	0.01	0.12	0.01
	Omnidir.	0.11	0.02	0.11	0.01	0.12	0.01
Pen 7	x-direction	-0.01	0.02	0.02	0.02	0.00	0.02
	y-direction	0.03	0.02	0.02	0.01	0.01	0.01
	z-direction	0.08	0.01	0.10	0.01	0.09	0.02
	Omnidir.	0.09	0.01	0.11	0.01	0.09	0.02
Pen 9	x-direction	0.03	0.01	0.02	0.02	0.02	0.01
	y-direction	0.01	0.01	0.03	0.03	0.02	0.01
	z-direction	0.06	0.03	0.12	0.03	0.06	0.01
	Omnidir.	0.07	0.02	0.13	0.03	0.07	0.01
Temperature (° C)							
Outside		18.0	0.7	22.6	0.7	13.0	0.2
Inlet		17.6	0.2	19.8	0.2	16.9	0.1
Climate controller		25.1	0.2	25.9	0.1	24.1	0.1
AOZ	Pen 1	23.2	0.2	24.2	0.3	22.7	0.1
	Pen 2	23.4	0.3	24.3	0.1	23.3	0.1
	Pen 3	24.2	0.6	25.0	0.3	22.8	0.2
	Pen 4	24.2	0.4	24.9	0.2	23.4	0.1
	Pen 5	23.5	0.6	24.5	0.2	22.6	0.1
	Pen 6	23.4	0.4	24.6	0.2	23.3	0.2
	Pen 7	23.3	0.3	24.6	0.3	22.0	0.1
	Pen 8	23.1	0.5	24.6	0.2	23.5	0.1
	Pen 9	21.4	0.2	22.5	0.4	22.2	0.1
	Pen 10	22.7	0.5	23.9	0.2	23.0	0.3
Increase CO_2 concentration (ppm)							
	Pen 3	268	155	431	104	n.a.	n.a.
	Pen 7	313	161	523	256	n.a.	n.a.
	Pen 9	185	38	206	98	n.a.	n.a.

[1]ventilation was constant
n.a. = not available

In all three pens air velocity in the z-direction contributed most to the air velocity magnitude. Air velocity in pen 3 was similar for the three periods, despite differences of the ventilation rates. Air velocity in pen 9 varied the most within the 1-hour periods and between the 3 cases. In case 1 and 2, the calculated increase in CO_2 concentration compared to the inlet was lowest in pen 9 and highest in pen 7.

In case 1 the outside temperature during the 1-hour period raised almost 2° C. The room temperature raised 0.6° C and ventilation rate increased by 170 m^3/h. Surprisingly, the air velocities in the three pens reduced during the 1-hour period, which means higher ventilation resulted in a lower air velocity at the measuring positions in the pens. In case 1 there was some direct solar radiation in pens 9 and 10 during the first 40 minutes. In case 1 and 2, the warmest pens were pens 3 and 4. In case 3 the temperatures in the pens on the right side of the operator walkway were somewhat lower than on the left side. This was caused by the location of the animals as they lay further to the back of the pen on the slatted floor (fig. 5). In case 3 the ventilation was constant and at minimum level.

Video recordings were analyzed to determine locations of the animals. The results are presented in figure 5 in the next section. In case 1 most of the piglets in all pens were lying on the back part of the solid floor. In pens 9 and 10 they had a preference for lying in the area with solar radiation. In pen 7 they were in the front of the pen, on the solid floor. In case 2 the piglets were more active. For pens 7, 8 and 10 it was not possible to indicate any specific location for the animals, so the heat and CO_2 sources are randomly distributed in the simulations. In case 3 the piglets in pens on the left side of the walkway were lying on the back side of the solid floor and on the slatted floor. On the right side of the walkway they were lying more on the solid floor.

NUMERICAL SIMULATION

The steady state simulations did not converge into stable solutions and therefore the presented results are based on the transient simulations that gave stable solutions with both 1 and 10-second time steps and both 5 and 10 iterations per time step.

The simulated airflow pattern 0.3 m above the floor (fig. 5) shows that the airflow in the AOZ was mainly z direction from the operator walkway to the sidewalls. Figure 5 shows that the variations in inlet velocity, heat supply and locations of pigs resulted in different airflow patterns in some of the pens, e.g. the airflow direction in pen 1 changed 180 degrees from case 2 to case 3. In case 3 the airflow in all pens is orientated parallel away from the walkway.

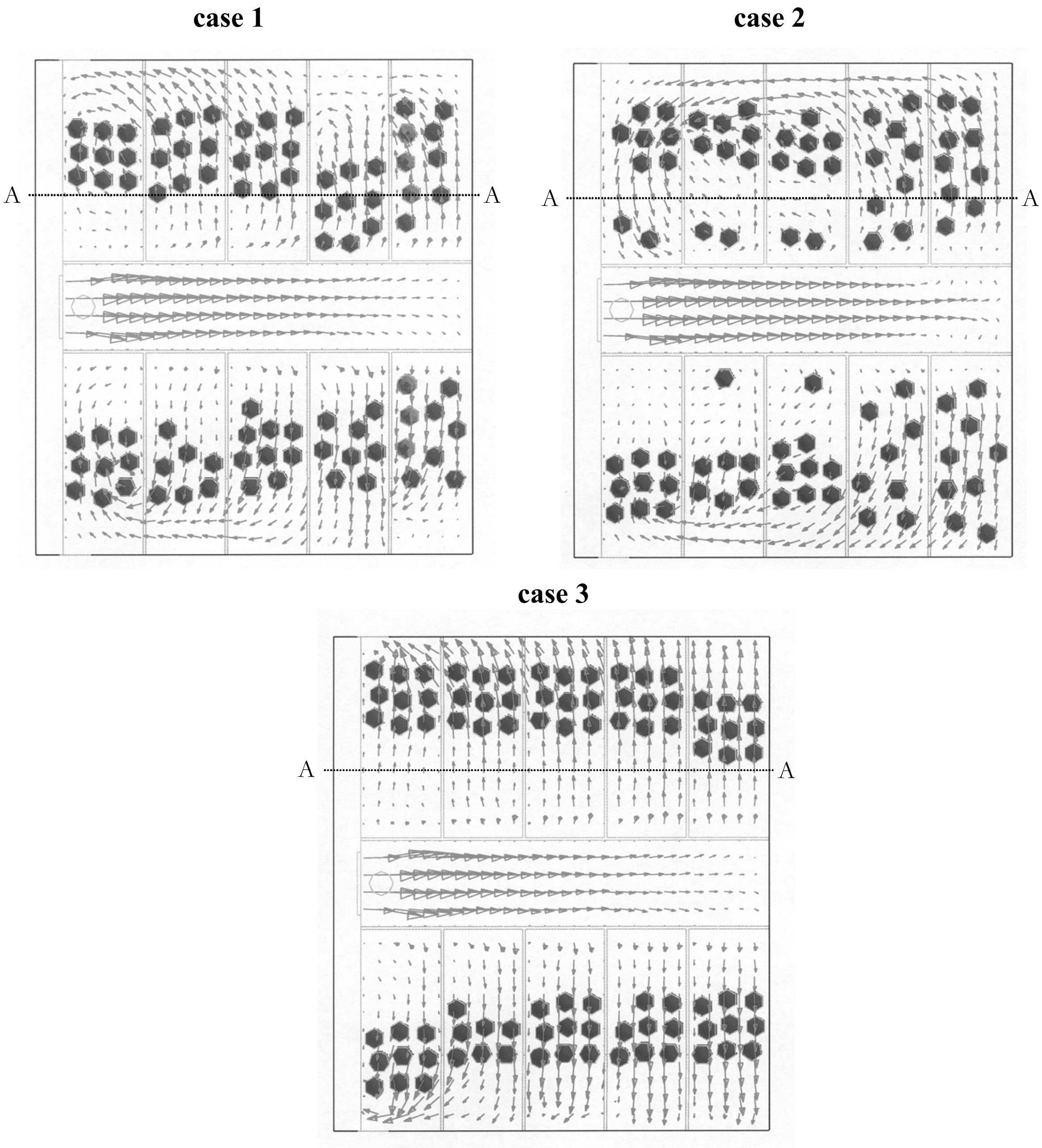

Figure 5. Location of pig models and simulated airflow 0.3 m above the floor in case 1, 2 and 3.

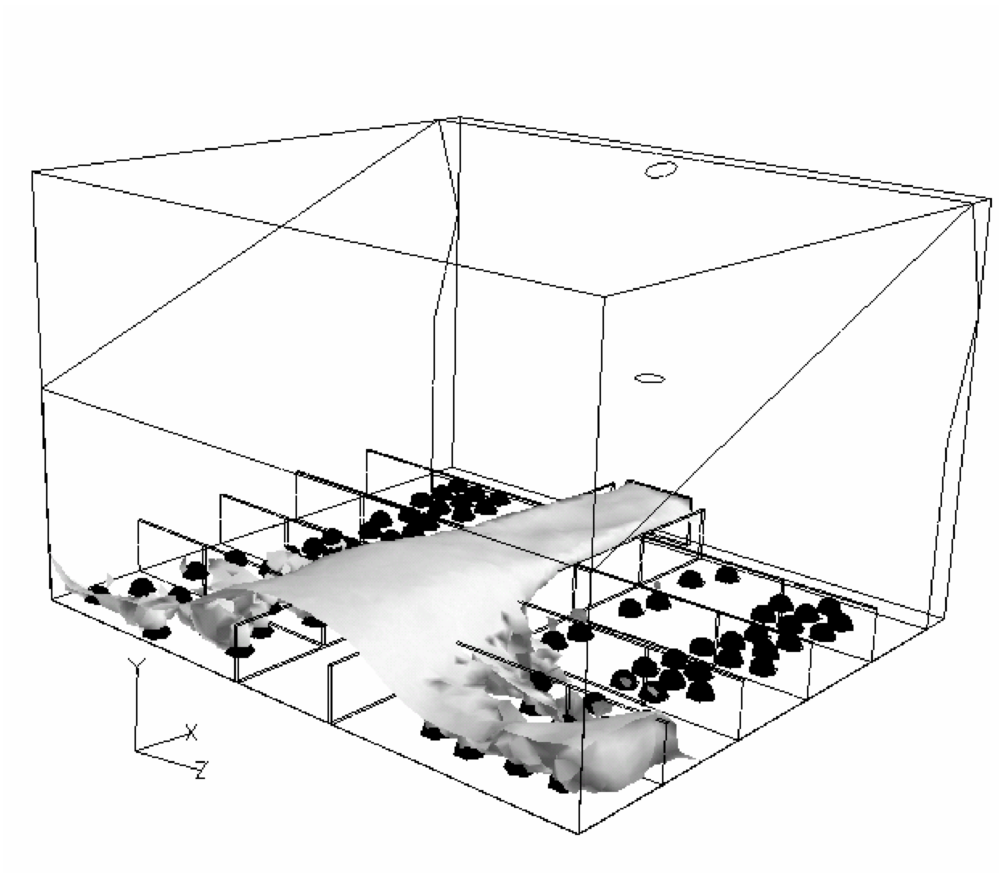

Figure 6. Simulated CO_2 concentration in case 2. The iso-plane shows the 700 ppm level (400 ppm above inlet concentration)

Figure 6 shows the calculated 700 ppm carbon dioxide 3-dimensional iso-plane in case 2. The CO_2 concentrations were lower than 700 ppm under the iso-plane, and higher than that above the iso-plane. Figure 6 illustrates that in pens 9 and 10 the CO_2 concentration was lower than in the other pens, which indicates that most of the fresh air enters the pens farthest from the door inlet.

COMPARISON OF SIMULATION AND MEASUREMENTS

Air velocity

Both measurements and simulation showed that the airflow at the measuring points in pens 3, 7 and 9 in all three cases was oriented in the direction from walkway towards the side wall of the room. The air velocity in this direction (positive z) contributed most to the air velocity magnitude in all the measurements and in the simulated air velocities at the measuring points in all the cases.

The measured air velocity in the z direction and the calculated vertical velocity profiles around the measuring points are showed in figure 7. It shows that the simulated velocities agree with measurements in pen 7 in case 2 and in pen 9 in case 3. For the rest the differences were larger, and reached up to a substantial 0,05 m/s. In case 2 the simulation shows that there is much difference in air velocity between the pens contrary to the measurements.

An explanation for the differences could be that objects in the pen are not taken into account in the model. The first thing to add is probably the feeder. In addition, it is possible that the air velocity profile is shifted upward or downward because of airflow obstruction caused by standing animals. This has a pronounced effect on the air velocity at 0.3 m height, the simulated vertical air velocity profile indicates a large velocity gradient above the floor and shows that the airflow direction changes at approximately 0.5 m above the floor and becomes directed towards the operator walkway. This gradient agrees very well with the velocity profile as measured in the experimental room in earlier research (Van Wagenberg and De Leeuw, 2003), as is described in de materials and methods section in this paper. This similarity in air velocity profile illustrates that simulations can predict realistic values for air velocity in the AOZ.

Due to the big spatial variation for air velocity within the AOZ, sensors used for validation experiments should be located in such way that patterns can be visualized and compared with the simulation rather than unstructured point measurements.

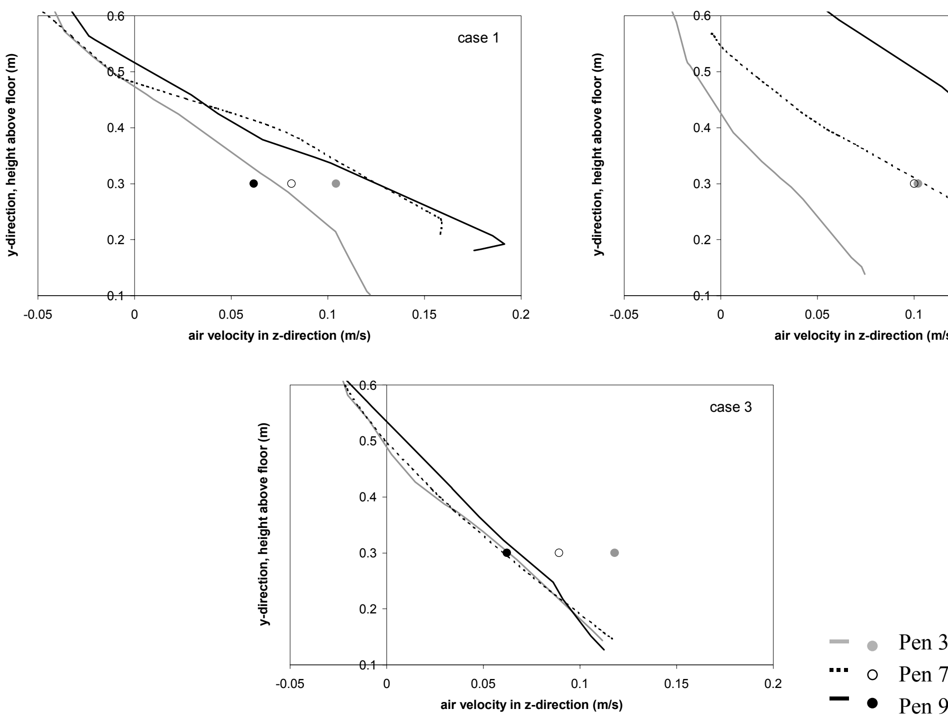

Figure 7. Comparison of three simulated air velocity profiles (lines) (pen 3: x = 4.2 m, y = 0 – 0.6 m and z = 1.6 m; pen 7: x = 1.8 m, y = 0 – 0.6 m and z = 1.6 m; pen 9: x = 0.6 m, y = 0 – 0.6 m and z = 1.6 m) and three local air velocity measurements.

Temperatures

In table 3 some results of temperature recordings and simulation are shown. The simulated temperature differences between the location of the climate controller temperature sensor and the outlet were small (0 – 0.2° C). This is important for the simulations in which those temperatures were assumed to be equal.

Table 3. Results of temperature measurements and simulations.

	Temperature (° C)		
	Measured by sensor climate controller	Simulated at location climate controller	Simulated in outlet
Case 1	25.1	24.2	24.3
Case 2	25.9	25.3	25.3
Case 3	24.1	23.1	23.3

Table 3 also shows that the simulated temperatures in the outlet were lower than the measured temperatures by the climate controller. This difference was surprising, because the heat supply in the model was based on the measured heat removed by ventilation. The explanation seems to be that the heat supply in the model was smaller than assumed because the grid generation converted the spherical pig models to edged figures with smaller surface areas.

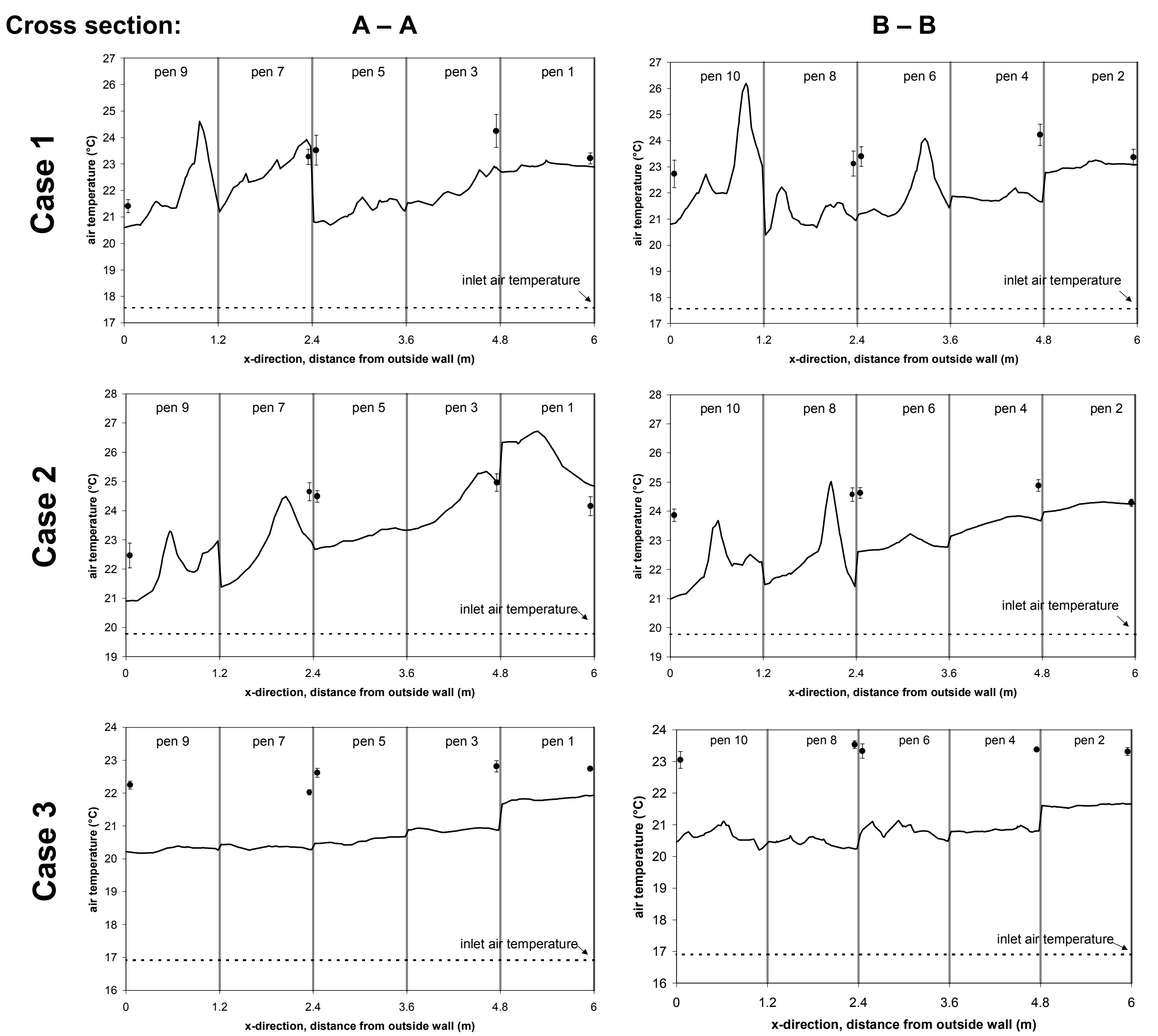

Figure 8. Comparison of two simulated temperature profiles (black line) in the cross sections A-A and B-B (see figure 1) at y = 0.15 m with local temperature measurements with standard deviation (Ī) and temperature of the inlet air.

In figure 8 simulated temperature profiles and measured temperatures at y=0.15 m in the AOZ are shown. In most cases the simulated AOZ air temperatures are equal or lower than the measured temperatures. A minor reason for this difference might be the difference between the assumed and the effective heat supply area. Another reason is probably due to the radiation heat transfer was neglected in the simulations by assuming all surfaces to be adiabatic. In the real room the animals transmit radiation heat to the pen partitions and building surfaces. The building surface, especially the ceiling, retransmits some of this heat to the relatively cold floor areas in and close to the walkway. Pen partitions and floor surfaces also transfer convective heat to the entering air, before it reaches the location of the temperature measurements.

Generally the simulated temperature increases from the pens 9 and 10 to pens 1 and 2, which agrees with figure 6 that indicates that most of the fresh, cold air enters the pens farthest from the door inlet. However, in the measurements the temperatures in pens 1 and 2 were lower than in pens 3 and 4. A possible explanation for this difference is that the surface temperature of the wall next to the central alley is relatively low due to a low degree of insulation. Consequently the air in pens 1 and 2 deliver heat to the wall, which is not accounted for in the simulation.

The comparison between simulations and measurements is relatively poor. This indicates that the further development of the simulation model with the suggested items is necessary to improve the quality of the predicted temperatures in the AOZ.

CO_2 concentrations

Figure 9 compares simulated and measured carbon dioxide concentration 0.15 m above the floor in the AOZ (z=1.6). In case 3 there were no measurements. The shown profile is located very close to the release area of carbon dioxide from some of the pig models especially in cases 1 and 2 (see cross section A – A in figure 5). Consequently very high carbon dioxide concentration was predicted close to these models and the value is not shown in figure 9. The comparison shows that the simulated values are higher than measured, in case 1 and in case 2 in pen 3. But it is not possible to decide whether the measurements or the simulation is the main source for this deviation. In all cases the simulated carbon dioxide concentration increased from the pens close to the outside wall to the pens close to the opposite wall. A higher ventilation rate resulted in an increased difference of the concentration between the pens. This relationship between inlet velocity and air distribution between pens in the door ventilation system agrees with earlier experimental work reported by Van Wagenberg and Smolders (2003).

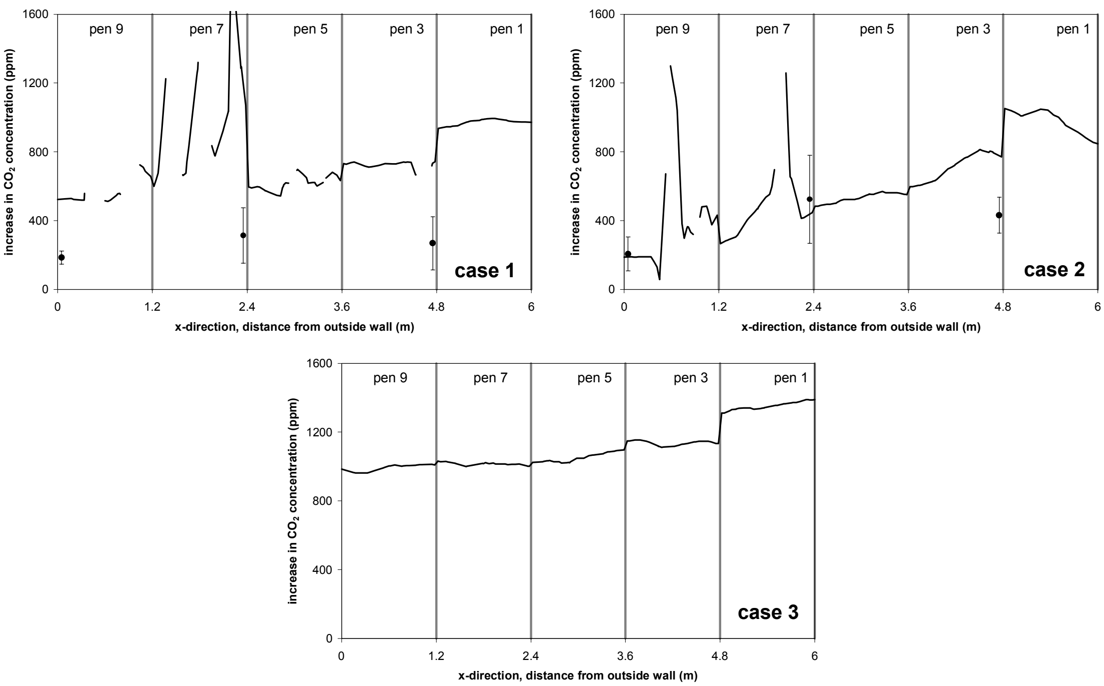

Figure 9. Comparison of simulated carbon dioxide profiles (black line) in the cross section A-A (see figures 1 and 5) at y = 0.15 m with local carbon dioxide measurements with standard deviation ( ), the simulated CO_2 values close to the pig simulators are removed.

CONCLUSION

Measurement of one-hour average air velocity, air temperature and carbon dioxide concentrations in a room with live pigs can generate data for validation of numerical simulation based on stationary boundary conditions. The used unstructured grid construction method was an appropriate way to handle the complicated geometry (including a model of each animal) in the door ventilation system.

The simulated air velocity profile above the solid floor agreed fairly well with expectations based on earlier research, comparison of the locally measured and simulated air velocities showed some good correspondences as well as some substantial differences. Adding the feeder in the model is expected to give an improvement. Due to the big spatial variation for air velocity within the AOZ, sensors used for validation experiments should be located in such way that patterns can be visualized and compared with the simulation rather than unstructured point measurements.

For temperature in the AOZ the differences between simulation and measurement were substantial. Including exchange of heat radiation is expected to be an important improvement of the simulation model. Other improvements could be a more detailed specification of inlet condition, e.g. including a space in front of the inlet, see Bjerg et al (2002a) or using a significantly denser grid which dramatically would increase the needed computer power and calculation time.

The study confirms the expectation that numerical simulation has the potential to become an important tool for designing and improving ventilation systems for livestock rooms. In connection to the door ventilation system the study confirms that the air distribution is inhomogeneous especially at high ventilation rates. In the pens closest to the door the CO_2 concentration and temperature is highest. Numerical simulation can be used to improve the air distribution in a further development of this ventilation system.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the funding provided for this project by the Dutch Product Boards for Livestock, Meat and Eggs and the Dutch Ministry for Agriculture, Nature Management and Fisheries. The authors thank Mr. Mark de Leeuw, Researcher Engineer at the research Institute for animal Husbandry, for his technical assistance during the project.

REFERENCES

Bjerg, B., K. Svidt, S. Morsing, G. Zhang and J.O. Johnsen. 2002a. Modeling of a Wall Inlet in Numerical Simulation of Airflow in Livestock Buildings. CIGR Journal of Scientific Research and Development. Manuscript BC 01 001. Vol. IV, March 2002.

Bjerg, B, K. Svidt, G. Zhang, S. Morsing, J.O. Johnsen. 2002b. Modeling of air inlets in CFD prediction of airflow in ventilated animal houses. *Computers and Electronics in Agriculture* 34(1-3): 223-235.

Bjerg, B, K. Svidt, G. Zhang, S. Morsing, S. 2000. The Effects of Pen Partitions and Thermal Pig Simulators on Airflow in a Livestock Test Room. *J. Agric. Eng. Res.* 77(3): 317-326.

Bjerg, B., S. Morsing, K. Svidt, G. Zhang. 1999. Three-dimensional airflow in a livestock test room with two-dimensional boundary conditions. *J. Agric. Eng. Res.* 74(3): 267-274.

CIGR, 1984. Climatization of animal houses. Report from working group. Scottish Farm Buildings Investigation Unit, Aberdeen, 116 p.

Fluent, 1998. Fluent 5, User's Guide Volume 1. Fluent Incorporated.

Harral A. J., C. R. Boon 1997. Comparison of predicted and measured air flow patterns in a mechanically ventilated livestock building without animals. *J. Agric. Eng. Res.*66(3): 221-228.

Launder, B., D. B. Spalding. 1974. The numerical computation of turbulent flows. *Computer Methods of applied Mechanical Engineering* 3: 267-274.

Smith, J.H., C.R. Boon, A,J,F. Webster and C.M. Wathes. 1999. Measurements of the effects of animals on airflow in an experimental piggery. *J. Agric. Eng. Res.* 72(2): 105 – 112.

Van Ouwerkerk, E.N.J. 2000. ANIPRO klimaat- en energiesimulatiesoftware voor stallen [ANIPRO climate and energy simulation software for animal houses] (in Dutch). Nota V 99 – 109 IMAG, Wageningen, The Netherlands

Van Wagenberg, A.V., M.A.H.H. Smolders. 2003. Contaminant and heat removal effectiveness of three ventilation systems in nursery rooms for pigs. *Transactions of the ASAE 45*(6): 1985 – 1992.

Van Wagenberg, A.V., M.T.J. de Leeuw. 2003. The use of an ultrasonic anemometer in the Animal Occupied Zone of pig facilities. *Applied Engineering in Agriculture* 19(4): 499 – 508.

Zhang, G., K Svidt, B. Bjerg and S. Morsing. 1999. Buoyant flow generated by thermal convection of a simulated pig. *Transactions of the ASAE* 42(4): 1113 – 1120.

Zhang, Y., E.M. Barber and J.R. Ogilvie. 2001. Commissioning Livestock Buildings: The Needs and Challenges. *Transactions of the ASAE* 44(1): 129 – 136.