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Simulation of airflow in pig fattening houses with different air supply systems

For the assessment of different air supply systems in pig fattening houses the knowledge of the airflow pattern in the barn is of major importance. In addition to indoor climate measurements at the Landesanstalt für Schweinezucht (LSZ) in Boxberg computational fluid dynamics (CFD) studies were conducted in two pig fattening compartments. In particular, a compartment with air supply through a porous ceiling and one with underfloor air inlet were examined under summer and winter ventilation conditions. Aim of the CFD simulations was to get a deeper insight into the airflow pattern of the compartments. Results show major differences in the airflow pattern between the compartments and reveal potential for optimisation of the ventilation systems.

Keywords

Computational Fluid Dynamics (CFD), porous ceiling, underfloor air inlet, fattening pigs

Abstract

Landtechnik 68(2), 2013, pp. 89–94, 6 figures, 1 table 11 references

Detailed reproduction of airflow patterns through recordings within livestock housing is extremely difficult to achieve. For interpreting results of barn climate measurements and for understanding the flow diagrams within different ventilation systems, three-dimensional modelling of the airflow process is required. A suitable method for this is numerical airflow simulation. Nowadays this approach is applied increasingly due to the higher computing capacities available and improved solvers - including application for the generation of simulations in agricultural engineering research [1–5].

At the Landesanstalt für Schweinezucht (LSZ) in Boxberg barn climate measurements were undertaken over a period of two years for comparison of different fresh air intake and cooling systems in four fattening pig barn compartments [6]. Complementing the measurements airflow simulations were carried out for a barn compartment with porous ceiling air intake and another compartment with underfloor air intake. The aim hereby was not to achieve exact reproduction of the airflows during the research period but to achieve instead a representation of typical examples of airflows under both air inlet systems. Additionally, simulations were carried out towards optimising airflow routes. Also, methodical investigations were carried out into modelling of the porous ceiling and into the influence of heat production from animals on the airflow streams so that these factors could be reproduced as realistically as possible.

Presented in this report are the barn models applied, the three-dimensional mesh and boundary conditions as well as selected results from the simulations for summer and winter situations.

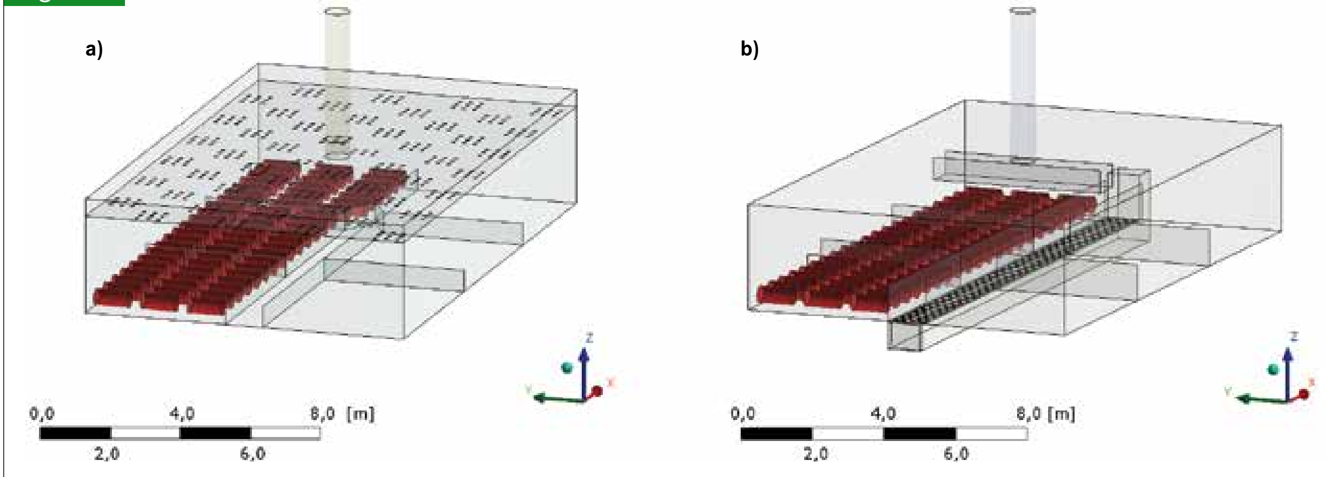
Material and methods

The software Ansys Fluent 14.0 (Ansys Inc.) was used as solver for the airflow calculations. The setting-up of models and mesh, as well as evaluation of results, was done through application of DesignModeler, Meshing and CFD-Post in the Ansys Academic Research CFD Package (Ansys Inc.).

The compartments under observation are inside the research barn for conventional pig feeding at LSZ Boxberg. Interior area is 16.0 m by 9.53 m. Every compartment is divided into 6 pens, each with space for 21 animals (approx. 1.0 m^2/animal). Ceiling height in the porous ceiling compartment is 2.85 m and 3.00 m for the underfloor air intake compartment.

For modelling of barn compartments the following simplifications were undertaken to ease meshing and to limit calculation times. In each case only the fluid volumes of the compartments were calculated (**Figure 1**). The underfloor slurry storage and the slatted flooring were not considered. Only the closed parts of pen walls were integrated in the models (0.63 m and 1.03 m high). For setting-up the mesh for the simulation, and for the numerical airflow calculations, the barn models were halved, with a plane of symmetry applied along the middle of the centre passage. For this reason only the left half of the com-

Fig. 1



Model of the compartment a) with porous ceiling and b) with underfloor air inlet

partment, as shown with animal models in **Figure 1**, was accounted for in the explanation of the meshing and results.

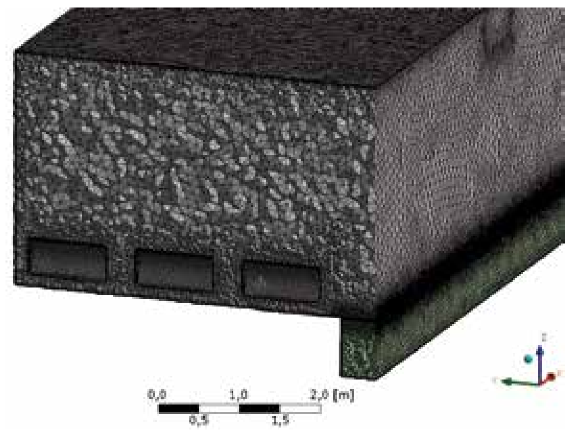
In the porous ceiling compartment intake air flowed from the under-roof area. The ceiling comprised closed tiles and perforated tiles laid in a chessboard pattern. With the underfloor compartment the inlet air was flowing in summer through the underfloor canal system (shown in the front elevation of the model) as well as through a shaft on the outer side of the compartment into the air supply canal under the centre passage of the compartment. From there, air is rising through the slatted flooring of the passage and into the animal area over the pen walls. In both compartments the air is drawn out of the barn via the centre passage by a fan situated within the exhaust air extraction shaft. For construction reasons, the extraction fan is situated 0.6 m behind the compartment middle. In the underfloor air supply compartment an exhaust air box is fitted beneath the shaft. The box is designed to prevent a short-circuit with the upward flowing intake air. In the model for the porous ceiling compartment this aspect is ignored in that, for this particular ventilation system, it had only a very limited influence on the airflow. A detailed description of both ventilation systems can be found in [6].

The porous ceiling, as well as the slatted floor in the central passage of the underfloor compartment, were greatly simplified for the simulations. Thus, the perforated area in the porous tiles was based on just nine openings instead of the actual 180 openings per tile in order to limit the number of mesh elements. The number of openings in the slatted floor was also reduced, from 21 to 6 per slat element. In the same way the underfloor canal system, through which the fresh air is flowing before entering the compartment, was not integrated in the model.

For modelling the animals 21 cylinders were equidistantly distributed at 0.15 m above barn floor level [7]. Each cylinder's size was based on a calculation of body surface area according to the liveweight of the penned pigs [8].

For calculating airflow streams via CFD, discretisation of the fluid volume is necessary. Hereby, the airflow area is subdivided into a finite number of control volumes over which the solver then creates, and then works out, equation systems for the conservation equations (mass, impulse, energy and turbulence factors). For this, a tetrahedron mesh was created, to a great extent automatically. Illustrating the situation for each compartment is a detail (**Figure 2**) of the mesh used for the underfloor intake air compartment in the summer situation. For resolving the airflow in the boundary layers at the walls (dimensionless distance from wall $y^+ < 1$), eight prismatic layers were integrated in the mesh on the walls, the ceiling, and the floor areas of the compartments as well as on the walls of the underfloor canalisation, on the slatted flooring and on the surface areas of the animal models. The height of the first cell layer on the walls was 1 mm. Within the interior the cell size was limited to a maximum 0.12 m. Thus the mesh in the different models contained between 8.6 and 12.6 million cells. Mesh

Fig. 2



Detail of the mesh in the model of the compartment with underfloor air inlet quality was controlled via the characteristic orthogonal quality (measure of variation in optimal tetrahedron form) and aspect ratio (measure of element elongation) [9]. All meshes had a minimum orthogonal quality larger than 0.11 and a maximum aspect ratio smaller than 105. These are acceptable values. However, values larger than 0.15 and smaller than 100 are to be aimed for because this increases the precision of simulations.

Data bases and boundary conditions

Selected as bases for simulation of winter and summer conditions in the compartments were two ten-minute measurement intervals each including 20 single measurements (13.02.2011: 00:55–01:05 and 04.07.2011: 13:55–14:05). The measurement points were in the under-roof space, in the underfloor canal, in the compartments and exhaust air shafts, as well as in the exterior air at a height of 3.2 m. The medians of the recorded data served as boundary conditions for the inlet air temperature and volume flow as well as for differential pressure between compartment and exterior atmosphere (**Table 1**). In part, measurement data were slightly adjusted for the simulations. The volume flow was established in the simulations through accepting a fixed air velocity at the exit point for exhaust air shaft. As air intake with appropriate air temperature served the upper surface of the roof interior space as indicated in **Figure 1** in the porous ceiling compartment, or the inlet surface areas of the underfloor canal. The pressure difference between barn and exterior atmospheres was simulated with the help of so-called porous jumps (defined pressure loss) on the perforated areas of the porous ceiling, in the slatted floor of the centre passage of the underfloor air intake compartment and at the entrance of the underfloor canal (**Table 1**). The pressure difference in the barn could in this way be depicted with a precision of 1 to 4 Pa which approximately represented manometer readings.

Based on liveweight (lw) on trial days, the convective heat from the animals was calculated according to the model [8]. The advantage of this model was that, contrary to the calculation [10], it enabled a separate determination of convective heat emission and of radiation heat emission – although, to reduce calculation time, the latter was not considered in the simulations. For both compartments under summer conditions, an animal weight of 91 kg was assumed with resulting convective heat output of 45.5 W per animal. In the winter situation the heat output per animal in the underfloor air intake compartment was 35.1 W (51 kg lw). These data were integrated into the simulations as constant heat flow on the upper surface of the animal models. Other heat sources were not considered in that, even during the February test day, the heating was not on in both compartments.

Solver and convergence criteria

A pressure based solver was used for calculations with application of the SIMPLE algorithm. The variables were interpolated using the second order upwind scheme. Only simulation of the winter situation in the underfloor intake air compartment was carried out with application of the first order upwind scheme. This led to a somewhat reduced precision of results. Selected as turbulence model was the realisable k-ε-model. For simulation of thermal convection air density calculation according to the ideal gas law took place with regard to the otherwise incompressible airflow field calculation [11]. As convergence criteria were established a decline in the residual of the energy equation by six powers of ten, a decline in the residuals of the remaining conservation equations by three powers of ten, and the presence of a balanced energy and mass balance in the entire airflow area.

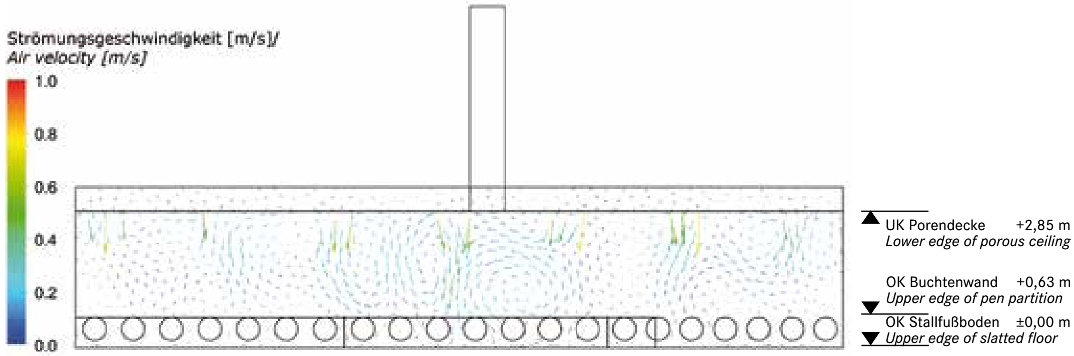
Table 1

Boundary conditions of the CFD simulations

Parameter/*Parameter*	**Porendeckenabteil/*Compartment with porous ceiling***	
	Sommer/*Summer*	**Winter/*Winter***
Einlasstemperatur/*Inlet temperature* [°C]	22.1[1)]	4.2
Volumenstrom/*Ventilation rate* [m³/h]	10 351[2)]	2795
Druckverlust Porendecke/*Pressure loss porous ceiling* [Pa]	-37.7[3)]	-5.6[3)]
	Unterflurzuluftabteil/*Compartment with underfloor air inlet*	
	Sommer/*Summer*	**Winter/*Winter***
Einlasstemperatur Unterflurkanal/*Inlet temperature underfloor canal* [°C]	19.1	8.6
Einlasstemperatur außen/*Inlet temperature outside* [°C]	22.1	-
Volumenstrom/*Ventilation rate* [m³/h]	11 228	1857
Druckverlust Spaltenboden/*Pressure loss slatted floor* [Pa]	-15.2[3)]	-2.2[3)]
Druckverlust Unterflurkanal/*Pressure loss underfloor canal* [Pa]	-2.0[3)]	-0.5[3)]

1) Abweichung vom Messwert +0,1 °C/*deviation from measurement +0.1 °C.*
2) Abweichung vom Messwert -125 m³/h /*deviation from measurement -125 m³/h.*
3) Berechneter Druckverlust des porösen Sprunges/*calculated pressure loss of the porous jump.*

Fig. 3



Air velocity in the longitudinal section of the compartment with porous ceiling (summer), vectors 15-fold extended

Selected results and discussion

Summer situation in the porous ceiling compartment

Depicting the airflow velocity vectors in longitudinal section of the compartment (middle of pens) showed a fine-structured area flow that was very slow in many localities (**Figure 3**). Along the length of the compartment there were eight to nine smaller eddies to be seen, most of which initiated from one of the porous ceiling tiles. The average flow velocity in the animal area at 0.8 m height was 0.14 m/s and in the entire barn area there was an average of 0.15 m/s. The average temperature in the animal area was 24.1 °C.

Methodical research with different models of porous ceilings indicated that influence of the air intake openings on airflow pattern in the model applied was greater than in reality. A further reduction of air intake openings is therefore desirable for future simulations. Despite these reservations, the simulation results agreed with the measured data very well overall. At the measurement point for air temperature and velocity in the middle of the first pen at 80 cm height the difference between simulation and measurement results was only -1.6 °C and +0.05 m/s.

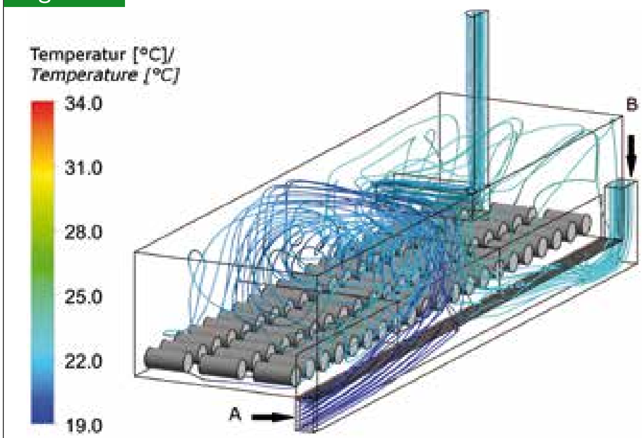
Summer situation in the underfloor air intake compartment

Airflow velocity and air temperature in the underfloor inlet air compartment were very strongly influenced by the inlet flows in the simulation of the summer situation. Hereby, the air from both inlet openings met in front of the exhaust air box (**Figure 4**). The cooler air from the underfloor canal system (A) collected in the front area of the compartment while the warmer outdoor air from the second air inlet (B) remained in the rear part. Additionally, air in the front and rear pen areas in the vicinity of the compartment walls was less mixed compared with the air in compartment middle. In the barn interior the average airflow velocity was 0.23 m/s, in the animal area 0.19 m/s. Airflow velocity at the entrance of the underfloor canal was 2.3 m/s at the front opening and 2.1 m/s at the rear opening. The mean temperature in the animal area was 22.3 °C.

A comparison with measurement data from the compartment sensor was only possible to a limited extent with this simulation because the model was unable to realistically characterise pressure loss at inlet air entry. Fog tests showed that both air inlet flows in reality met behind the exhaust air boxes. This caused a completely different airflow pattern in the front pen where the compartment sensor was positioned compared to that shown by the simulation. The average airflow velocity in the animal area, however, was in the range of the values determined by a thermo-anemometer in supplemental measurements. The simulation also showed two disadvantages for this ventilation system. Firstly, the central positioning of the exhaust air shaft can, despite exhaust air boxes, lead to direct removal of fresh air through the exhaust air suction. The fitting of two exhaust air openings on the outer walls of the barn, similar to classic feed passage ventilation layout, would be an improvement here. Secondly, high-volume flows through application of the rear inlet air openings mean that an uneven temperature distribution in the compartment has to be accepted because uncooled exterior air is sucked-in at this point.

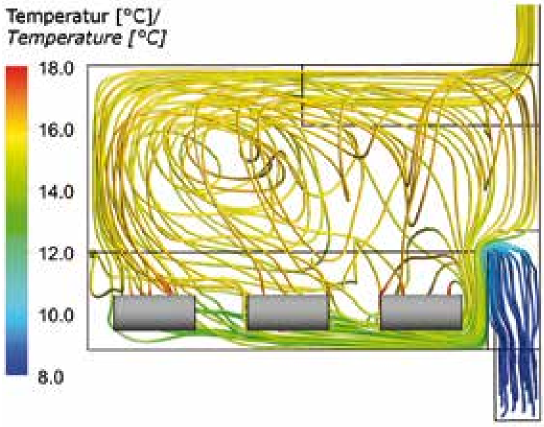
For better ventilation of the compartment outer areas, it would be recommendable to influence airflow by fitting deflector plates. This will be looked into in further simulations.

Fig. 4



Streamlines and air temperature in the compartment with underfloor air inlet (summer), A: inlet air from underfloor system, B: inlet air from outside

Fig. 5



Streamlines and air temperature in the cross section of the compartment with underfloor air inlet (winter)

Fig. 6

Fog-test in the compartment at similar ventilation rate
(Foto: Joachim Threm)

Winter situation in the underfloor air intake compartment

Contrary to the summer situation, the inlet air in the winter situation is only drawn into the barn from the underfloor canal. Simulation of the winter situation in the animal area resulted in a very low average airflow velocity of 0.04 m/s. In the diagram of the airflow streams in cross-section (middle of foremost pen) the airflow pattern of this ventilation system indicates a warming of the intake air during its rise into the centre passage and subsequent fall into the animal area (**Figure 5**).

A comparison of results with fog trials in the compartment (**Figure 6**) emphasised the good diagrammatical reproduction of the flow patterns through the simulation. A weak point, however, was that the air temperature was not depicted correctly. Also, in the other simulations for the summer and winter situations the compartment temperature was underestimated by 3–5 °C. This can be traced back to the ignoring of radiation heat from the animals. However, there was a very limited influence on the depicted flow pattern by this factor which made this simplification an acceptable one.

Conclusions

The results of these trials indicate that numerical simulations can offer a deeper insight into airflow in pig feeding barns and into the resultant optimisation potential. General statements over the airflow pattern of the observed inlet airflow variants are possible using the available material. However, a precise validation of the simulated results is definitely necessary for more detailed results. For future simulations the underfloor slurry storage should be integrated in the models and the mesh optimised. Heat radiation should also be taken account of in calculations.

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