FLOW SIMULATION FOR DESIGN OF VENTILATION SYSTEMS IN ANIMAL HOUSES

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ABSTRACT

In livestock farming the climate within an animal house is a dominant factor for animal welfare. There are threshold values or recommendations for the most important climate parameters. Temperature, humidity, CO_2 and NH_3 gas concentrations, germs, dust, odour and air flow velocity have to be observed. Unfortunately the necessary ventilation of livestock buildings leads to emissions, too. So an important aim is to develop ventilation systems that produce

1. good climate conditions for the animals,
2. but also minimize emissions.

The Leibniz-Institute for Agricultural Engineering (ATB) carries out climate-specific investigations to develop suitable ventilation systems for animal houses, supported by flow simulations of the Federal Agricultural Research Centre, Institute of Technology and Biosystems (FAL).

INDEX TERMS

Flow simulation, Ventilation systems, Emission, Animal houses, Micro climate

INTRODUCTION

The climate in livestock buildings is an important factor for livestock management. The animal health and performance are influenced by climate parameters and the condition of the building. It is necessary to force a fresh air stream through the livestock building. The necessary mass stream of fresh air depends on the kind of animals, their weight, the construction of the building, and the climate outside the building. The ventilation of animal houses leads to emissions and air-borne pollution in the surroundings of these buildings. Dust, germs and gases are emitted together with the used air. Odours caused by certain gases can lead to annoyance in residential areas. Some gases, such as N_2O and CH_4, are known to increase the greenhouse effect. Furthermore, ammonia can cause damage to plants in the immediate surroundings of livestock buildings, directly. Emissions should therefore be minimized. Both the micro-climate inside the live-stock building and the emission flow rate are strongly influenced by the ventilation system. Consequently an important aim in climate design of animal houses is to develop ventilation systems that produce good climate conditions for the animals, but also minimize emissions. The type of ventilation system (mechanically or naturally ventilated housing), the location and the design of the air inlets, and the velocity of the incoming air influence the indoor air quality and the emission flow rate. Knowledge about the connections between the ventilation system, the climate in the livestock building and emissions is a prerequisite for developing suitable ventilation systems. Such knowledge is acquired by means of

a) numerical models,
b) physical models and
c) experiments in real livestock buildings.

Basic research on the field of air flow in livestock buildings is carried out in collaboration between the Institute of Agricultural Engineering Bornim (ATB) and the Federal Agricultural Research Centre Braunschweig-Völkenrode (FAL). The numerical flow field is simulated by FAL. The numerical and physical models are used especially to investigate the air flow pattern inside the building and to work out design guidelines for natural ventilation systems. The investigations with real livestock buildings are conducted by ATB in various animal houses to analyse the effect of different ventilation systems. To this end the air temperature, humidity, gas concentrations and air velocity are measured inside the animal houses. To determine the emission stream it is necessary to measure the concentration in the fresh air, the concentration in the exhaust air and the air flow rate. There are many possible ways to determine the air flow rate. Problems in livestock buildings are the size of the building, in many cases a high air flow rate, complicated flow relations and many different air inlets and outlets. The so-called tracer gas method, based on the measurement of concentration, proves to be best. In some cases SF_6 is applied as tracer gas – especially for run measure-

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ments. But in most cases the radioactive gas Krypton 85 is used as tracer gas. The following report mentions problems of dimensioning ventilation systems for animal houses. The application of forced ventilation and natural ventilation systems is explained and discussed. Selected results are presented gained with different investigation methods regarding climate design in livestock buildings and the influencing of emission streams by the ventilation system.

DIMENSIONING OF VENTILATION SYSTEMS FOR ANIMAL HOUSES

Dimensioning of the heating and ventilation system in livestock buildings is based on the heat and mass balance. The different sources and sinks of heat and substances (especially H_2O, CO_2 and other gases) are the animals, the floor with wet areas, slurry channels and manure and the building. To solve balance equations mass and energy we need information about the building, the animal species and animal age, the management system, the required indoor climate conditions and the outdoor climate conditions. In Germany the standard work "DIN 18910 – Wärmeschutz geschlossener Ställe – Wärmedämmung und Lüftung; Planungs- und Berechnungsgrundlagen (in translation: Thermal insulation for closed livestock buildings; Thermal insulation and Ventilation; Principles for Planning and Design)" applies for both the necessary indoor climate parameters and the values for heat, moisture and CO_2 production by the animals. The problem is that the production values of the animals depend on different parameters such as indoor climate and animal activity (Pedersen and Sällvik 2002).

The design of the ventilation system (forced and natural ventilation) must on the one hand guarantee the animal welfare, but on the other hand ensure that the emissions are minimized (for example with low air velocity near the emission sources). Experiences are available for the design of openings for naturally ventilated livestock buildings (Albright 1990, Müller 1992, Team of Authors 1987). But the mere balance calculation is not sufficient. There is an inhomogeneous distribution of flow and concentration fields in animal houses. The air flow conditions have an important influence on the micro climate inside the room. Therefore it is recommended to analyse the air flow behaviour in the room with numerical and physical models.

RESEARCH METHODS

To design new ventilation systems the following investigation methods can be applied, to get a deeper insight into the mass transport phenomena within ventilated rooms of animal production:

a) Numerical flow simulation

The simulation technique (incompressible flow with k-ε turbulence model for finite volume) allows a survey of the complete field of interest, ammonia e.g.. The concentration field as a result of 3D-simu-lation of the mass, energy and momentum balance is inhomogeneous, see Figure 1. In practice control systems (climate computer) refer to spot measurements of the scalars (ammonia concentration e.g.). There is a lack of feed back to the results of fluid mechanics (Desta et al., 2004). All control systems handle with the transported concentrations of special substances but not with the responsible flow field because of the complexity of the algorithms (Janssens et al., 2004). Our aim is to find a simplified access to the mass transport phenomena on a firm physical basis.

b) Physical models

Investigations in physical models support the numerical flow simulation. The ventilation system including the air volume stream can be changed in a simple way also the reconstruction of the interior ele-ments is very simple in such models. Figure 2 shows an example of a model to investigate different venti-lation arrangements to reduce the emission streams.

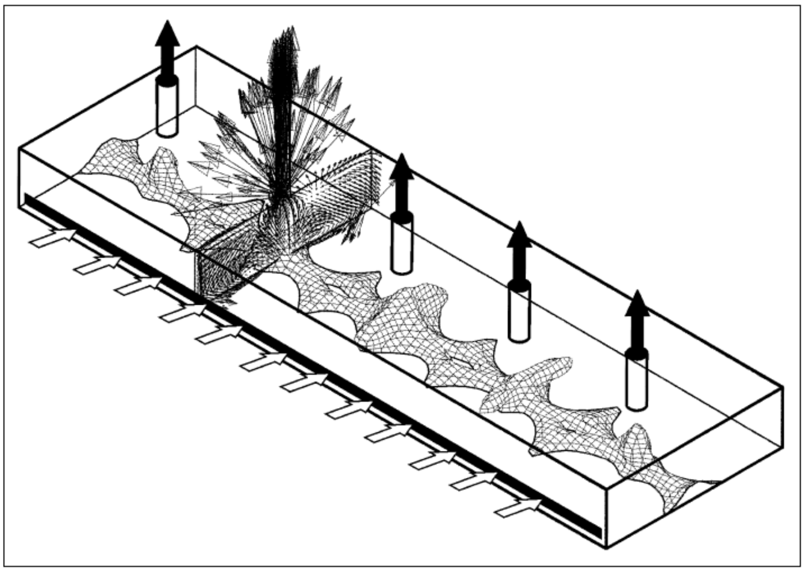


Figure 1 Distribution of ammonia and velocity in a broiler house. The geometrical measures are: 40 m length, 12 m width, 3.5 m height. The rate of air exchange amounts to 15 h^{-1}, the concentration at the bottom is set to 20 ppm.

The vertical cross section shows the two-dimensional air flow in this cut. The isoarea of ammonia refers to 1 ppm. There is a inhomogeneous distribution of ammonia dependent on the ventilation system: here with extraction at the ceiling and inlet air through side wall slots.

Figure 2 "Emission model" for investigation the influence of different versions of ventilation systems on the emission behaviour of a compartment for fattening pigs

To evaluate the dispersion behaviour of emissions from livestock buildings the ATB used an "boundary layer wind tunnel". This wind tunnel is equipped with air velocity measurement technique, laser-light-sheet technique and fast FID (gas analyser) to measure the fluctuation of gas concentrations.

c) Full-scale measurements

Full-scale measurements are necessary to confirm the results from numerical and physical models under real conditions. The climatic parameters (temperature, humidity, air velocity in the animal zone and gas concentrations) are measured inside and outside of livestock buildings. A special problem is the determination of air volume stream in naturally ventilated animal houses. The ATB has developed a tracer gas method using Krypton 85 as tracer gas. This method can be applied in small and large rooms with a high local and temporal resolution.

SELECTED RESULTS

Example 1

The application of the described methods is demonstrated at an example of a existing big pig farm with 60,000 pigs. This farm is located near a city and the aim was to reduce the emission streams and to improve the dispersion of the emissions in the vicinity of the farm.

The reduction of the source concentration requires an intrusion upon the ventilation system for all animal houses with pig fattening. That may have consequences to the animal growth and welfare in positive or negative direction. Therefore investigations with care were done by simulation of the fluid flow and concentrations fields with regard to numerical models and physical experiments in laboratory. As a solution began to emerge two stables were involved as reference and as a new system. By an intelligent fluid flow regulation the stable room can be divided into two areas: upper floor and under floor. Figure 3 shows the concentration field in the cross area as a result of a 3D simulation. Fresh air is sucked into to the room under the ceiling from the side walls. In addition air is sucked from the stable room beneath the slatted floor in Figure 3 (Krause et al., 2005).

The original ventilation is an under floor suction system. Fresh air is sucked through the stable and leaves the system under floor with the result that the concentration in the stable room is low (best conditions for the pigs) and the concentration in the exhaust area is highest (worst conditions for the environment). The idea of the new ventilation system is to subdivide the stable room in two areas (upper floor and under floor). This idea was realised in a compartment of the real farm building to measure the upper floor and the under floor emission streams. The under floor stream should be fed into a scrubber. With this system improved climate conditions for the animals can be achieved and the emission stream of the farm can be reduced. The investigations in the model and in the real building substantiate the theoretical approach.

Example 2

The negative effect of the emissions in the surrounding of animal houses can be reduced by dilution of source concentration and by suitable design of the conditions of the outgoing air. Every case is to observe individually. Not in all cases high exhaust stacks (compare Figure 1) are the best solutions. Investigations in wind tunnel experiments show that a wall leeward of the building produces higher turbulence and a better dilution of emitted substances than it is measured in the atmosphere. The plume is shorter in comparison with the system without a wall (see Figure 4, Part A with a wall and Part B without a wall). The measured gas concentration in Part B is much more lower than in Part A at distance of 360 m in the real situation (Figure 5). Figure 6 shows an application of mechanically induced turbulences.

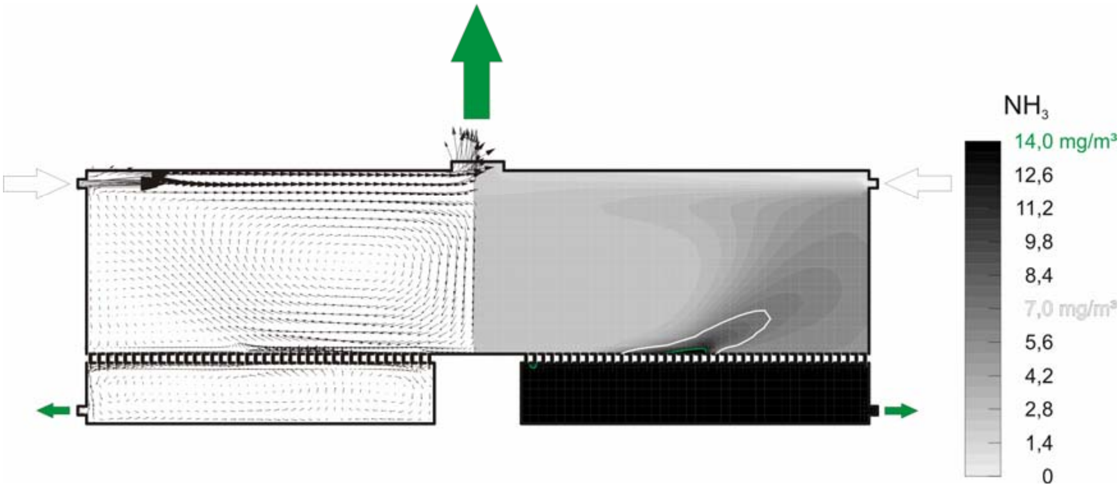
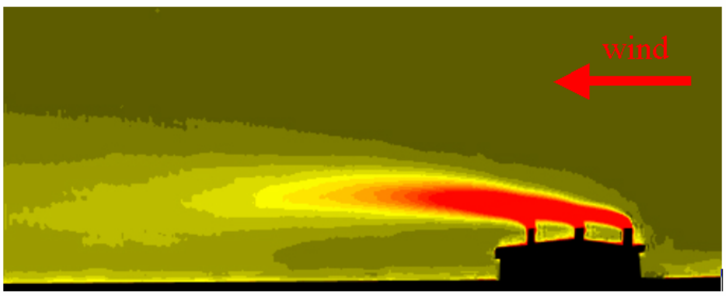


Figure 3 Cross section of the fattening stable. A great circulation zone is formed in the cross section above the dung grid, smaller zones of circulating flows are generated beneath the slatted floor as can be seen in the velocity vector plot (left side of the picture). By that a moderate transport of ammonia occurs from the air space beneath the dung grid into the air space above it (right part of the picture). The white isoline shows where the concentration in the stable is diluted to 2 ppm = 1,39 mg/m^3, when the bottom concentrations is set to 13.9 mg/m^3= 20 ppm. Partly exhausting some air from the area under the floor reduces the ammonia concentrations above the floor. That means an improved climate. It is recommended by veterinary surgeon to reduce the ammonia concentration to 10 ppm at the breathing zone of the animals. Nothing is said about the time scale.

CONCLUSIONS

In livestock farming the climate within a livestock building is a dominant factor for animal welfare. The necessary ventilation of animal houses leads to emissions which should be minimized. The design of the structure of animal houses including ventilation system and discharge conditions of the exhaust air requires not only heat and mass balance calculation but also the investigation of the air flow behaviour inside and outside the building. Every special case must be evaluated and discussed separately. Nevertheless one essential aspect is to avoid the destruction of the boundary layer of ammonia above the manure or litter surface by an “intelligent fluid flow system”. If it is not possible to reach this aim the stable room must be divided into zones with different concentration areas by producing opposed circulation of air motion. The guiding system for the exhaust air should consider the conditions in the surrounding of living houses including ecosystems. Different simulation methods make it possible to develop housing systems with a comfortable biological climate inside and low impact in the surrounding.



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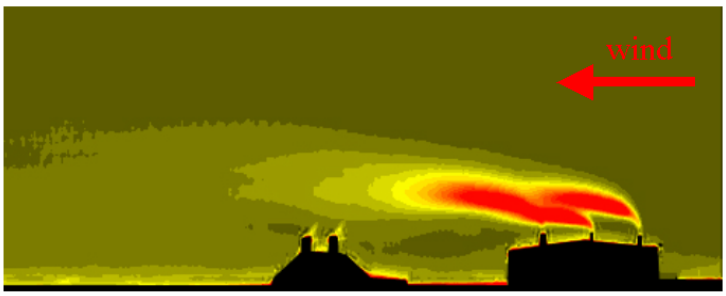

B

Figure 4 Average images of plumes – effect of a wall on the leeward side (Part A without and Part B with a wall) – wind tunnel measurements; exhaust air velocity: 0.46 m/s; wind velocity 0.47 m/s (in 150 mm height in the wind tunnel according to 45 m in the nature).

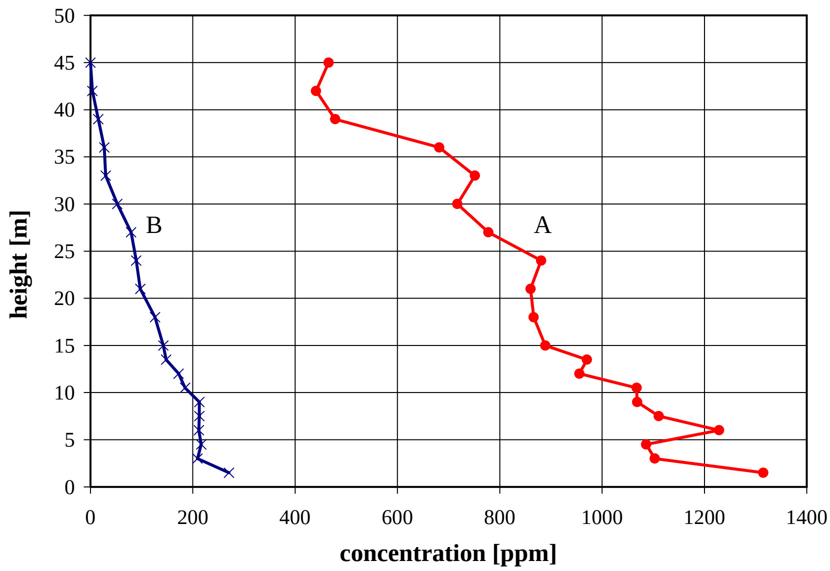

Figure 5. Tracer gas concentration in a distance of 360 m from the building versus different heights above surface (results from wind tunnel measurements – wall leeward – conditions like in Figure 4)

Figure 6 Realized removal of the air of a piggery on the gable side. Side wall fans blow out stable air on the leeward ground, which has an effect like a baffle. Mechanically induced turbulences are produced. This effect is supported by a wall of earth in front of the gable. The immission of odour 200 m behind the end of the animal house (left side) is lower in comparison with the situation of emission by stacks on the roof.

REFERENCES

Albright, L.D. (1990): Environment Control for Animals and Plants. American Society of Agricultural Engineers.

Desta, TZ, Janssens, K, Van Brecht, A, Meyers, J, Baelmans, M, Berckmans, D (2004): CFD for model-based controller development. Building and Environment 2004;39(6):621–633.

Janssens, K, Van Brecht, A, Desta, TZ, Boonen, C, Berckmans, D (2004): Modeling the internal dynamics of energy and mass transfer in an imperfectly mixed ventilated airspace. Indoor Air 2004;14(3):146–153.

Krause, K-H, Müller, H-J, Linke, S (2005) Gaseous emissions from livestock buildings and the dispersion of these emissions in the surroundings. Indoor Air 2005. Peking.

Müller, H.-J. (1992): Theoretical and practical aspects of natural ventilation in animal houses. AgEng; Uppsala, Sweden, June 1-4, 1992, Paper No. 9202 15.

Pedersen, S., Sällvik, K. (2002): Climatization of Animal Houses – Heat and moisture production of animal and house levels. 4th Report of Working Group, Published by Research Centre Bygholm, Danish Institute of Agricultural Science, P.O Box 536, DK-8700, Horsens, Denmark.

Team of Authors (1987): Lüftung und Klimatisierung – Grundlagen zur Stallklimagestaltung – Freie Lüftung in Pavillonbauten. Katalog L/8607/RAL. VEB Landbauprojekt Potsdam.