INVESTIGATION OF THE EMISSION AND IMMISSION BEHAVIOUR OF LIVESTOCK BUILDINGS BY MEANS OF WIND TUNNEL MODELLING

H.-J. Müller, H. Krehl
Institute of Agricultural Engineering, ATB, Potsdam, Germ

ABSTRACT

The keeping of animals in livestock buildings requires the ventilation of these buildings. Good climate conditions for the animals have to be guaranteed as well as little emissions and immissions from the livestock buildings. An important role for both of these opposite requirements plays the airstream inside and outside of the building. For this reason wind tunnel modelling and digital imaging by using a laser light sheet is applied beside other methods at the Institute of Agricultural Engineering Bornim. The aim of these method is not only to make the flow pattern visible, calculating concentration fields from the frames is also targeted. On the example of cow barns typical ventilation systems are under investigation. Dependent on the shape of the building on self and the specific surrounding the distribution of the air born gaseous emissions in the atmospheric boundary layer is determined and presented. The measurement results will be used to create new guidelines for the specification of minimal distances required between livestock buildings and residential areas.

KEYWORDS

Livestock building, emission, immission, airflow

INTRODUCTION

Ventilation is necessary for both, the livestock building and the animals are kept in it. An air stream has to be forced trough the building, which is mainly dependent on the kind of animal kept, animal weight, building shape and the outside climate. Gaseous pollutants, water vapour, heat, dusts and germs are transmitted to the inside air and cause emissions when guided outside by means of livestock building ventilation. They may lead to environmental damage or annoyances in the surroundings. The extent of the effects is influenced by the emission flow as well as from the distribution conditions of the specific site. Above all the design of the foul air guiding system (i.e. place and shape of the outlets in the building, exhaust air speed), the surrounding topographical structure, the vegetation, the arrangement of the buildings at the specific site and the outside wind conditions (wind quarter, speed, turbulence structure) have the most impact on the distribution of the emitted substances.

A topic of specific interest for livestock buildings is the release of odours. Minimum distances have to be kept between livestock buildings and living areas in order to avoid annoyances.

Guidelines established in Germany to define these distances are the VDI-Guidelines 3471 and 3472 (Emission control – livestock management – pigs and Emission control – livestock management – hens). Currently these guidelines are being revised and extended. The research on the distribution processes of substances being conducted at the Institute of Agricultural Engineering Bornim (ATB) uses beside other methods wind tunnel modelling. The air flow patterns are made visible by applying laser-light-sheet technique and tracer particles. Image capturing and digital image processing is carried out to analyse the pattern.

METHODS

The distribution process of substances in the surroundings of livestock buildings can be investigated by:

- numerical simulation

- wind tunnel modelling
- real site investigations.

The ATB collaborates with different research partners for these investigations. The Institute of Biosystem Engineering of the Federal Agricultural Research Centre (FAL) is carrying out the numerical flow field simulation whereas the ATB investigates the emission behaviour of livestock buildings in practice on real sites and by using wind tunnel modelling.

The boundary-layer wind tunnel (Figure 1) has a 2 m long test section with a cross-section of 2 m × 1.25 m and six ventilation vans to initialize different wind speeds up to 3 m/s.

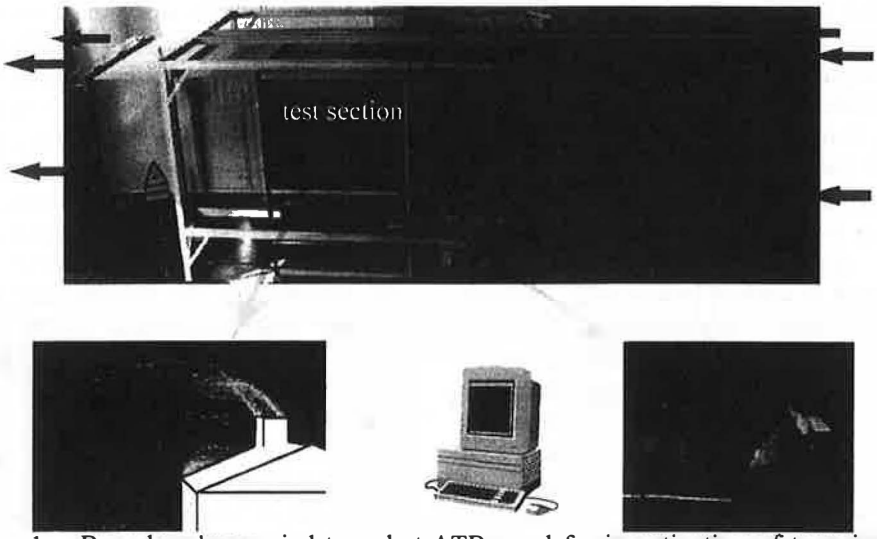

Figure 1 Boundary-layer wind tunnel at ATB, used for investigation of trasmission processes of gaseous air pollutants in the atmospheric boundary-layer applying laser light sheet techniques and digital image processing

An important fact for the transfer of the results to real sized buildings is the correct simulation of the natural wind profile (i. e. wind speed, wind quarter, turbulence structure). Therefore different fittings like roughness elements are applied in the presection of the tunnel. The respective wind profile is measured with a Hot-wire Anemometer. Figure 2 shows the principle of the applied laser-light-sheet technique.

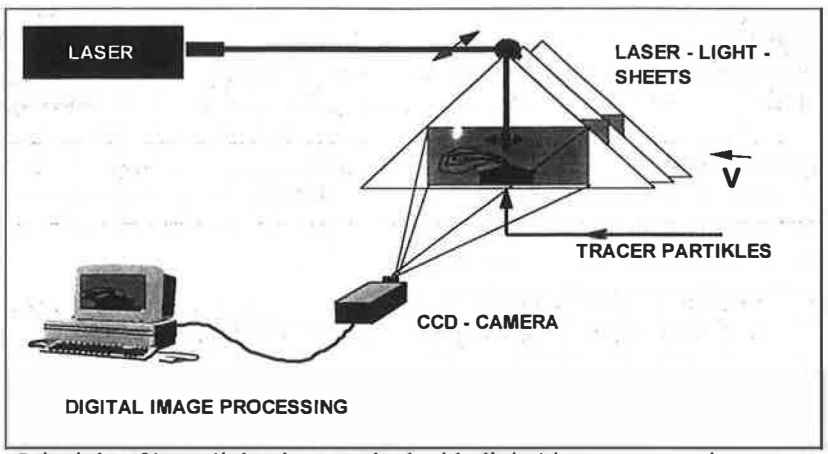

Figure 2 Principle of laser-light-sheet method with digital image processing

The structure of the air stream can be seen from single frames. A sequence of captured pictures is used to perform the visualization of distribution processes over time. Frame averaging over several hundreds of single frames lead to pictures which can be interpreted as a quasi steady-state flow and show the „mean distribution" locally resolved.

RESULTS

The air stream around a building shows a highly turbulent structure which has been proofed by various velocity measurement in the atmospheric boundary layer around them. It has also been pointed out, that the turbulence intensity is increasing at decreasing heights above ground level and has values of about 50 % at height levels of average livestock buildings.

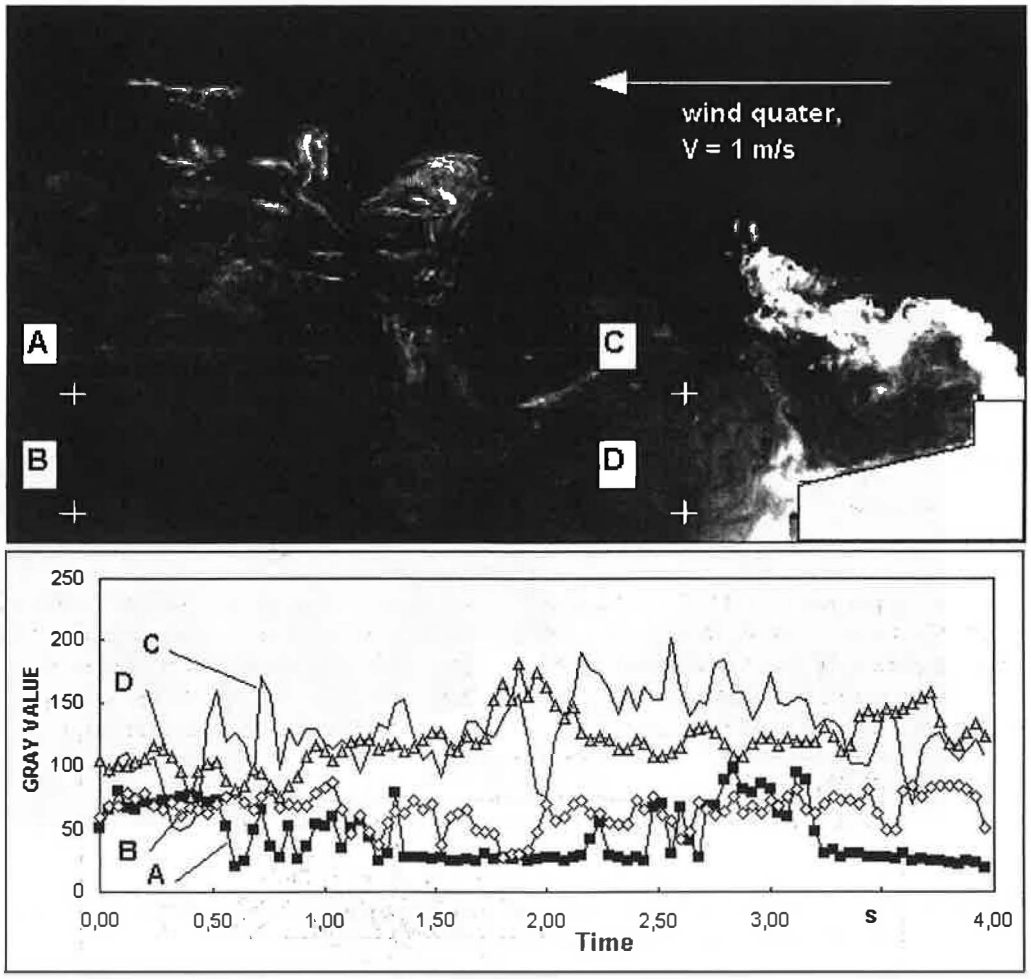

Figure 3 Fluctuation of gray values at points A, B, C and D at the lee region of a cross ventilated livestock building with natural ventilation

According to this, figure 3 below shows highly turbulent air pattern

Strong fluctuations of particle concentrations and a decrease of the concentration with increasing distance from the livestock can be seen. Here we have to say that up to now we do not have an algorithm to translate the observed particle concentrations into odour concentrations. These remark is concerning the following pictures too.

After averaging hundred single frames figure 4 is obtained by using digital image processing.

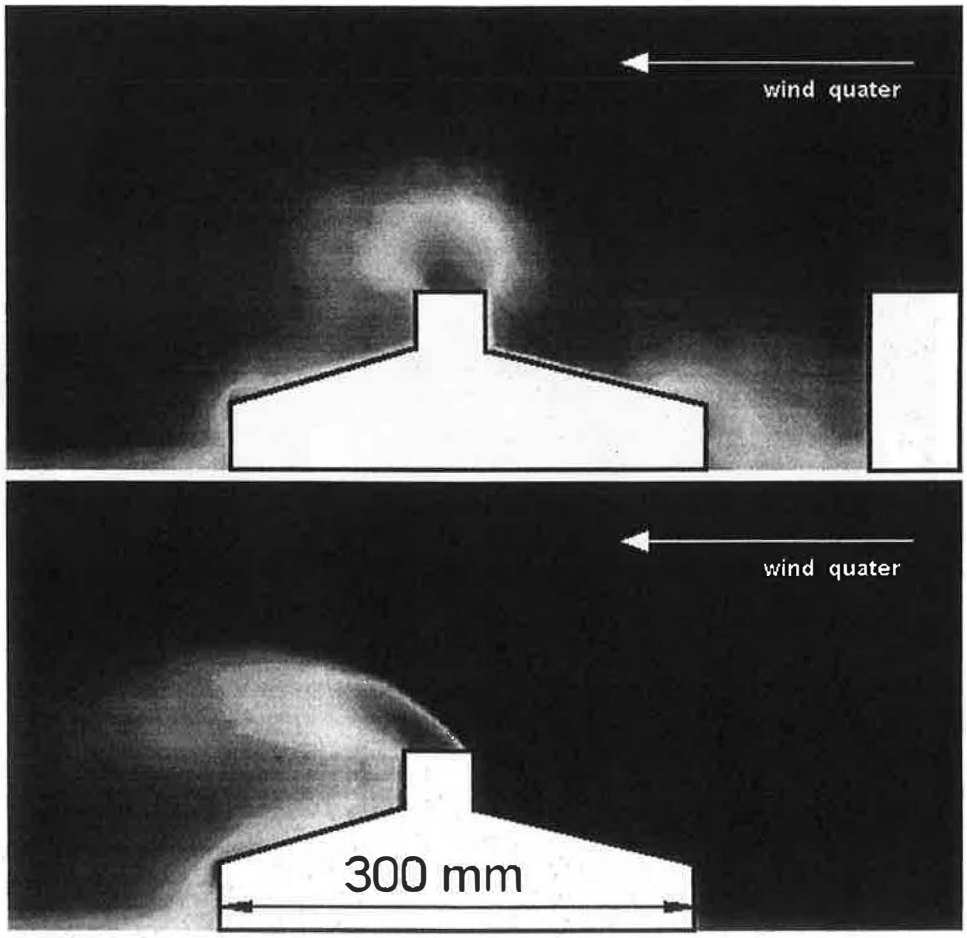

Figure 4 Laser-light-sheet frame (averaged frame, derived from 100 single frames) of a natural ventilated livestock building with single outlet

At the independent building (figure 4b) the emissions are distributed following the main wind direction of the tunnel. In figure 4a we can observe a completely different situation. The circulating flow between building and obstruction leeds to a predilution and a shortening of the emitted plume.

Figures 5 to 8 indicate the effect the waste air outlets and the topographic structure has on distribution.

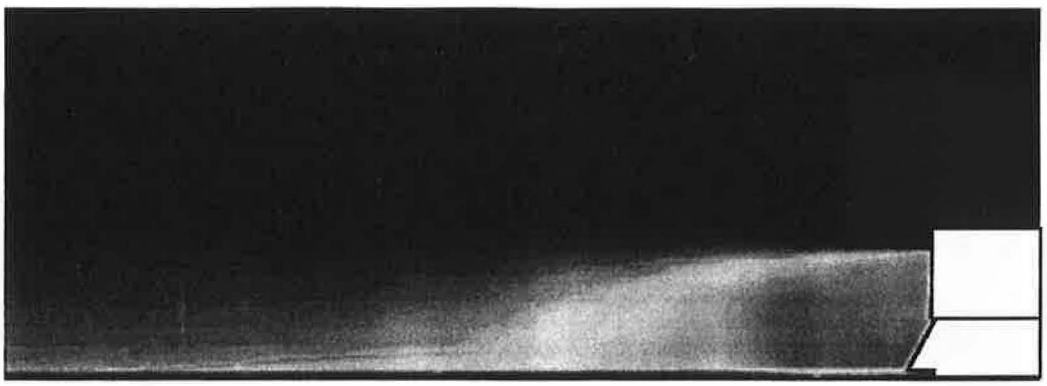

Figure 5 Building at longitudinal flow with outlets at the gable end, waste air guided towards ground

Figure 6 Same conditions as described for figure 5, additional barriers upwind and downwind with vegetative windbreaks planted on top of them

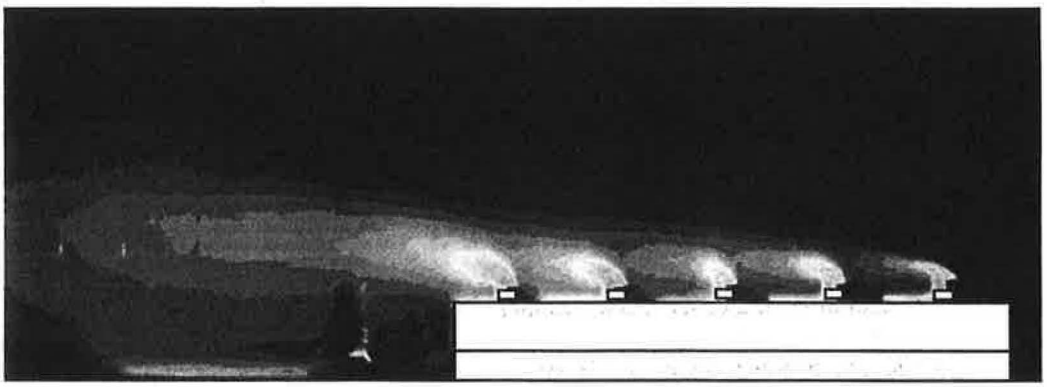

Figure 7 Same conditions as described in figure 6, except the roof outlet (1.5 m above ridge) instead of outlets at gables.

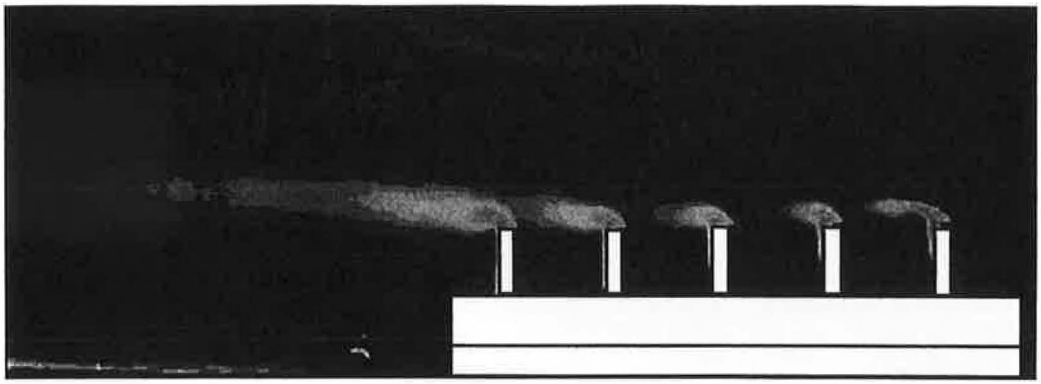

Figure 8 Same as figure 7, exhaust outlets at 6 m above ridge

Figures 5 to 8 show clear differences in there plume behaviour as a result of different exhausts. Figure 5 shows a plume near ground whereas barriers with planted vegetative windbreaks accelerate dilution by a more turbulent flow. At figures 7 and 8 the plume is formed by all stacks together after a fast dissolving process on every single stack. Obviously the barrier and the windbreaks show a loss of effect by increasing the height of the stacks.

DISCUSSION

The flow around livestock buildings can be investigated with a boundary layer wind tunnel by consideration of some rules. The quality of the simulation of the wind profile in the tunnel has te meet certain requirements. Especially the modellation of the turbulence structure is assumed to be important for the distribution process of emitted gaseous pollutants in air flows.

Images obtained from the visualization with laser-light-sheet methods are useful tools to get an insight into the transport process of the emitted gases.

The application of digital image processing and frame averaging allows the comparison and assessment of various waste air guiding systems. Results of the conducted research on this topic will be used for the evaluation and revision of the appropriate VDI guidelines.