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Wind tunnel investigations on a naturally ventilated barn

The air exchange rate regulating the climate inside of natural ventilated livestock buildings is hard to determine in the field due to the variability of time and space of the dominant processes. Experiments in a wind tunnel laboratory can produce sound statistical and representative data obtained under controlled boundary conditions to complete data sets from the field. In this study, measurements of the horizontal wind components within a model of a natural ventilated barn were performed in the wind tunnel. The approach flow was chosen with low turbulence in order to gain knowledge on the influence of the installed equipment on the air flow. In fact, the measured profiles were influenced by the installed equipment and the feeding alley.

Keywords
Ventilation, wind tunnel, air flow, barn climate

Abstract
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Nowadays, dairy cow barns are designed as open-fronted buildings with natural ventilation and wind netting as the only protection on the long sides, which means interior climate is directly influenced by the outdoor weather conditions (temperature, relative humidity and wind). The wind is the significant factor hereby with its components direction and velocity, through which is influenced the air exchange and its distribution and the removal of heat, air humidity, gases and other substances

Determining the air exchange within a naturally ventilated dairy cow barn is a difficult task in that the natural approach flow, the flow around obstacles and the throughflow processes are all variable because of the turbulent wind field. Accordingly, the main peripheral conditions continuously change the airflows at their inlet and outlet points. For direct identification of air exchange processes, wind velocity and direction must be measured as comprehensively as possible over the respective cross sectional areas of all the openings [1]. In practice this is only possible with a disproportionately high technological input. Because of this, more indirect methods such as the use of tracer gas [2] or CO_2 balancing [3] are usually applied for determining air exchange. The tracer gas method, whereby the decay curve of a tracer gas is determined, requires a perfect mixing of building interior air with the tracer gas, which is almost impossible to achieve [4]. For the CO_2 balance, the CO_2 concentration must be accurately recorded throughout the barn because the wind field causes significant variations in CO_2 concentrations [5]. Further, measurements have to take place over long periods of time in order to obtain statistically representative data. This is not only complicated but also associated with very high costs and almost impossible to carry out in practice.

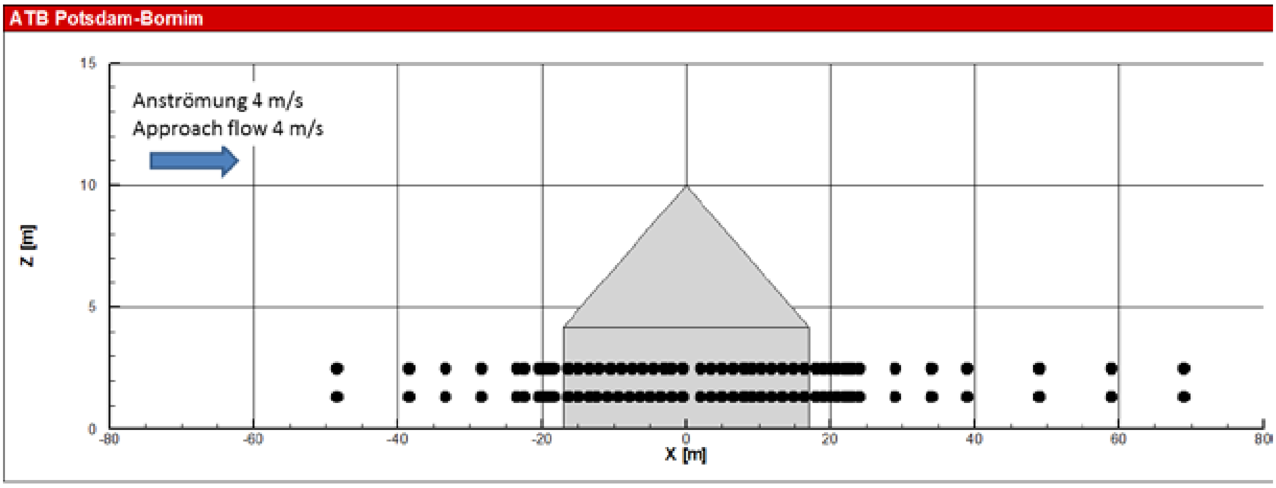
It is therefore effective to complement data recorded in practice with recordings made in a boundary layer wind tunnel. Using this method the complex flows and transport processes can be modelled under controlled conditions, allowing statistically representative results to be produced with a high resolution in terms of time as well as space. The transferability of the results into practice is secured through the compliance with physical similarity laws [6].

Material and methods

In the boundary layer wind tunnel of the Leibniz Institute for Agricultural Engineering Potsdam-Bornim measurements of wind velocity and turbulence were carried out on a model of a naturally ventilated dairy cow barn. The model was built to a 1:100 scale as a detailed replica of a dairy cow barn where long-term field measurements had been carried out in cooperation with the Institute for Animal Production of the State Research Institute for Agriculture and Fisheries, Mecklenburg-Vorpommern [7].

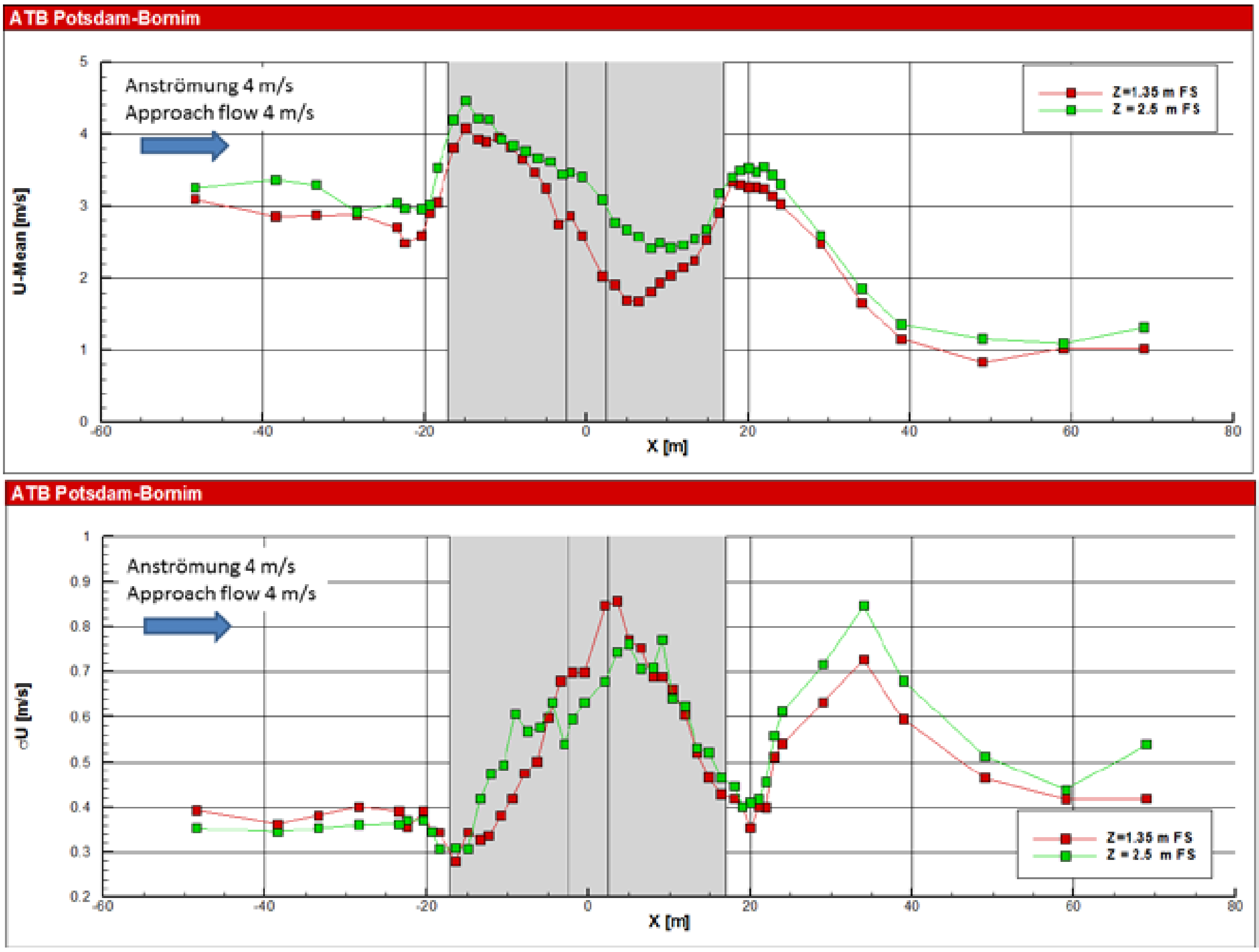
Measurement of the horizontal wind velocity components took place contact-free with a 2D Laser Doppler Anemometer (LDA) (Dantec©). Recorded at every measurement point in time series were the wind velocity component U (in X direction) and the wind velocity component V (in Y direction). The duration of the time series varied, with recording continuing until the standard deviation of average value σ showed less than 2 % fluctuations. This approach meant over 2500 individual readings were carried out.

Fig. 1



Sketch of measurement locations of the two lateral profiles

Fig. 2



Measured profiles oft he mean wind component U in x-direction (above) and the standard deviation σU (below). Grey area indicates area of the barn including feeding alley in the center.

For the air approach flow in this experiment no spires (turbulence generators) and ground surface roughness were applied so that the flow produced were as uniform and low-turbulence as possible. This sort of approach flow does not represent the conditions at the livestock barn in the field and so the results can only be partially applied in practice. However, the aim of these measurements was to achieve more precise information over the influence of interior equipment on the airflow profile.

The approach flow of air onto the model was perpendicular onto the open sides, which represents the flow in the prevailing wind direction. A lateral profile was measured in each case at heights of 1.35 and 2.50 m (**Figure 1**).

Results

In **Figure 2** is shown the recorded profile of the wind velocity component U (in X direction). The wind velocity component U profile shows a significant influence of the barn structure on the air throughflow. There occurs an acceleration of wind speed with air inlet as well as with air outlet whereby the acceleration with the air outlet is less. Because of the recirculation zone of the building, the wind velocity behind the model barn was less. The barn feeding alley was built slightly higher than the cattle passageways within the building and this proved to have an influence on the profiles of the wind velocity component U. The profiles of the standard deviation σU showed their maxima within the cow barn and immediately behind it. The standard deviation can be interpreted as a measure of the fluctuations appearing in a time series. Thus a particularly high number of fluctuations were identified behind the building (in the recirculation zone) but also within the building, because of the fitted equipment. An influence of the feeding alley can also be identified in the profile of the standard deviation.

Measurements of the wind velocity component V show, conversely, only very low average wind velocities (from -0.3 to 0.07 m/s) with very high standard deviations (0.24 to 0.69 m/s). The measured individual values of the velocities varied very strongly and distribution of the measurement values was therefore so widespread that the profile shape was less definite. The air flow was very turbulent and required markedly longer measurement times. This also applied for the measured profile of the turbulent momentum fluxes.

Conclusions

Measurements were carried out in a wind tunnel of lateral profiles at two different heights within a model dairy cow barn. A low-turbulence approach flow was used to ease identification of the influences from interior equipment on the measured profiles in the livestock building. The higher feeding alley, in particular, influenced the measured profiles of the wind velocity component U, acting as an obstacle in air flow direction. Through the interior equipment the fluctuations of the individual time series were increased, clearly indicating also increased turbulence. This indicates that interior equipment should also be considered in physical or numerical modelling of air flow processes in livestock barns.

The measurements also showed that fluctuations of < 2 % in the standard deviation as a criteria for the length of a recorded time series lead to a high variability in data. In order to reliably interpret the turbulence parameters, long-time series with more than 2500 individual measurements are necessary. This procedure has already been applied in following measurements.

In a second part of the study a location-based, scaled boundary layer air flow is modelled in order to improve transferability of the results and to compare them with data from recordings in the field. The location-based boundary layer is modelled according to the requirements of the VDI guidelines for physical modelling of flow and dispersion in the atmospheric boundary layer [8] and with own data from the investigated field location.

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