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Automated Volume Flow Measuring in Naturally Ventilated Dairy Cow Houses with Eaves-Ridge Ventilation

A 'concentration decay' method with SF_6 for measuring ventilation rates in naturally ventilated animal houses – applied in short term tests by the Institute of Agricultural Engineering – was automated and successfully tested in preliminary measurements. With its simple measurement setup and the validation of the 'concentration decay' method through measuring fans, this measuring system is a viable alternative to previous continuous measurement methods for the ventilation rate throughout the day. The system can work almost continuously for at least 12 hours, without requiring any supervision.

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Keywords

Air volume flow, air exchange rate, tracer gas, sulphur hexafluoride, dairy cow houses

Literature

Literature references can be called up under LT 06607 via internet http://www.landwirtschaftsverlag.com/landtech/local/literatur.htm.

The air flows in naturally ventilated livestock houses are very complex, making the determination of volume flow rates considerably more difficult than in mechanically ventilated buildings. The usual approach is to use balancing methods in which volume flow rates are determined on the basis of a building's CO_2 or water vapour balance. Methods using tracer gases also belong to this type of method; they work with mass balances of tracer gases which do not normally occur in the room under test (e.g. sulphur hexafluoride, ^{85}Krypton [1, 2] or carbon monoxide [3]). The class of tracer gas methods consists of continuous methods on the one hand and of the 'concentration decay' method on the other. The Institute of Agricultural Engineering routinely uses the 'concentration decay' method because it has been successfully validated in a mechanically ventilated broiler house using the measuring fan method [4]. In the 'concentration decay' method, tracer gas is abruptly injected into a room, where upon injection is stopped and the concentration decrease is measured. The ventilation rate is then calculated on the basis of the resulting decay curve. Producing air change data relating to the limited time span of the decay curve, this method is not a continuous measuring method. A practicable method in itself, the 'concentration decay' method has been automated in order to turn it into a quasi-continuous measuring method. All steps from the injection of the tracer gas to the washing of the measuring chamber with clean air can now be controlled via a computer. Captured at variable intervals, the resulting decay curves add up to a representative picture of the volume flow developments in the course of one day.

Measuring methods and the building used in the experiment

The dairy cattle barn used in the experiment is a four-row cubicle house with eaves-ridge ventilation. It is 32 m long and 24 m wide, and it has an eaves height of 2.50 m and a ridge height of 9 m. A tracer gas mixture (SF6 and N) was injected via a cascaded tube system with openings distributed along both long sides of the building at intervals of 1.5 m. The air inlet openings of the building are 70 cm high. The samples were taken along the axis of the roof ridge, also using a cascaded tube system in order to guarantee uniform exhaust air samples. The injection and extraction tubes are made of PE and have an inner diameter of 4 mm. The SF_6 concentration in the exhaust air was determined using a modified Leakmeter 200 (Mestron Quantilek Messtechnik GmbH, now: USON, Neuss), an instrument developed for leak detection. Its measuring range extends from 0 to 5 ppm. Argon is used as the tracer gas. With a measuring interval of one second, the instrument has a high temporal resolution. An ultrasonic anemometer (Metek, Elmshorn) was installed parallel to the ridge axis in order to record the temperature, the speed

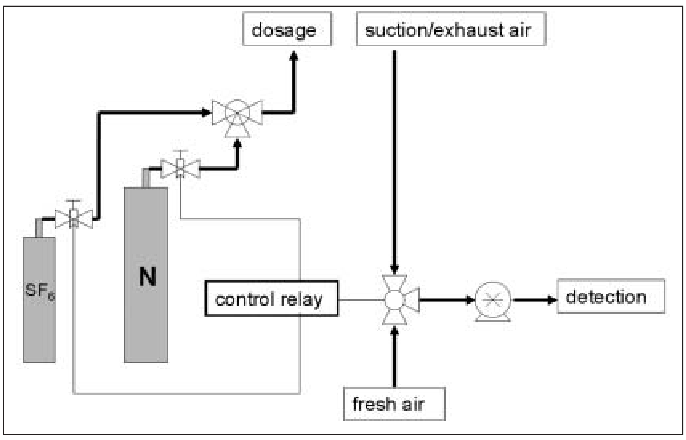

Fig. 1: Measurement setup

and the direction of the incoming wind. The set-up for the tracer gas measurements is depicted in *Figure 1*. SF_6 being a very dense gas, a mixture of SF_6 and N is injected into the building. The mixture ratio can be regulated by means of pressure reducers on the gas bottles. In addition, both gas bottles are equipped with solenoid valves which can be activated via a relay card. Fresh air is ducted to the measuring instrument after every decay measuring cycle in order to free the detector and the pump of indicator gases. The switch from extraction to fresh air supply is also affected by activating a solenoid valve by means of the relay card. Moreover, it is important to make sure that the sampled air is transported away from the measuring chamber after measuring. By this means, contamination of the air surrounding the SF_6 measuring instrument can be avoided.

The relay card is controlled by means of software developed specifically for that purpose. It is possible to enter time intervals for injection, measuring and slow-down. The software can also be used to test the operability of the valves. One measuring cycle consists of slow-down, injection and measurement. The number of measuring cycles can be set via the software. The link to the measuring computer is established via USB. At its present stage of development, the settings of the automated measuring system have to be changed according to different climatic conditions or building sizes. The system being a time-controlled one, automatic adaptations to changes in the speed or direction of the incoming wind are not possible yet. Adaptations to greater changes of that kind would have to be made manually. In the conditions existing during the experiments, the injection time setting was constant at three minutes. This interval is long enough for injecting a sufficient amount of indicator gas and for obtaining exact decay curves for higher ventilation rates as well. In order to make sure that the indicator gas concentration could decay to 0 ppm, the point of reference for the measuring time had to be phases with low ventilation rates. With these settings it was possible to successfully measure ventilation rates every 25 minutes.

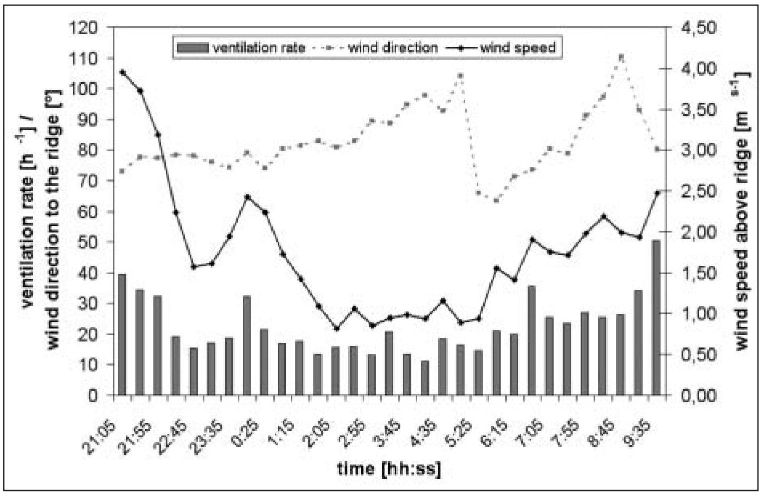

Fig. 3: Ventilation rate, wind speed and wind direction over 12 hours

The data from the SF_6 detector and the ultrasonic anemometer can be stored in parallel so that the indicator gas concentrations can be synchronised with the corresponding climate data.

Results and discussion

The gathered data demonstrate the operability of the automated tracer gas measuring system. Over a measuring time of 12 hours, it was possible to measure 12 ventilation rates without having to change a single setting. *Figure 2* shows a typical measuring cycle from the dairy cattle barn used in the experiments. SF_6 is injected for three minutes after the measuring chamber has been flushed with fresh air in the slow-down phase. As a result, the detected tracer gas concentration reaches a relatively constant plateau. During the measuring phase, the exponential decay behaviour of the SF_6 concentration becomes evident. After correction of the collected data by shifting the zero line, this decay curve is used to calculate the ventilation rate ($c_i = c_{t=0} \cdot e^{-n \cdot t}$, with n = ventilation rate in s^{-1}). After completion of the measuring cycle, another slow-down phase follows in which the measuring chamber is washed with fresh air.

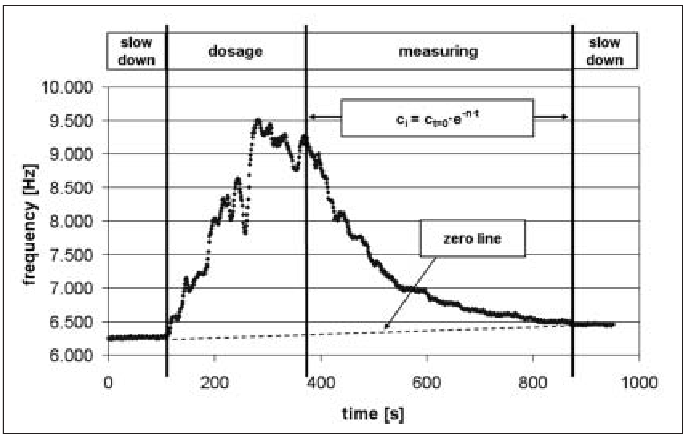

Fig. 2: Measurement cycle to calculate the ventilation rate

The results of the measurements spanning twelve hours are depicted in *Figure 3*. Expected variations between individual ventilation rates are evident but can be explained with reference to changing wind speeds over the axis of the ridge. With a coefficient of determination of r = 0.76, the ventilation rate and the wind speed are closely correlated. By contrast, the wind direction, which was relatively constant on the day the measurements were taken, had little effect on the ventilation rate. With the control software settings used in the experiments it is possible to measure ventilation rates between 10 h^{-1} and 50 h^{-1} (approx. 40,000 to 200,000 m^3h^{-1}). The measuring phases were long enough to allow the measuring of even lower ventilation rates.

Thus, with this measuring system it is possible to carry out measurements over periods of 24 hours, thus producing data with which it is possible to calculate the daily course of emissions as well as average emissions. It is impossible, however, to extend the measuring time even further because the SF_6 detector must be serviced at intervals of about 24 hours.

Conclusion and outlook

The shortest analysis interval for measuring pollution gases should be one day. One-hour random sampling leads to considerable deviations from real daily averages. Changes in the level of animal activity or farm activities, such as feeding, milking and cleaning, lead to emission peaks which deviate from the daily average by a factor of up to 7. For reliable statements about pollution gas emissions, it is necessary to capture ventilation rates over a period of 24 hours. The automated 'concentration decay' system, which operates quasi-continuously, fulfils this requirement. The measurement set-up is very simple and compact and less expensive than other continuous methods of measuring ventilation rates. Further measurements will show whether the system works in winter conditions as well. An attempt will be made to eliminate possible sources of error.