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Validation of the Tracer Gas Method for Air Volume Flow Measurement

To determine the emission mass flow from livestock buildings, it is necessary to measure the concentration of the target substance and the air volume flow. For naturally ventilated buildings tracer gas methods are useful; they can be used to determine the air volume flow based on the dilution of the tracer gas concentration. In this study, the concentration dilution method was compared to the reference method, using a measuring fan in a forced ventilated broiler house.

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Summarized contribution to LANDTECHNIK. You will find the long version under LANDTECHNIK-NET.com

Keywords

Ventilation rate, tracer gas, measuring fan

Immission forecasts are becoming increasingly important in permission procedures for the construction of new livestock houses or for the modernisation of existing ones. To determine the emission mass flow rates of gases, odours or dusts, it is necessary to carry out concentration measurements as well as air flow measurements. For measurements in forced-ventilated livestock houses there are simple and precise methods, e.g. measurements by means of calibrated measuring fans. By contrast, the methodology of determining the air volume flow rate in naturally ventilated livestock houses poses a great problem. So-called balancing methods are used, because in most instances it is impossible to determine air volume flow rates directly.

Basic principles

Volume flow rates are determined on the basis of a materialís mass balance or analogously to its energy balance (thermal balance). In the process, it is possible to use either system-inherent material flows or foreign materials. Tracer gas methods utilise tracer gases that do not normally occur in the livestock house. Thus, one uncertainty in determining the material sources is eliminated [1]. Sulphur hexafluoride (SF_6) and krypton 85 are among the tracer gases that are widely used in practice. An overview of the different balancing methods can be found in [2].

One tracer gas method is the so-called concentration decay method in which the gas supply is switched off after a single dose of tracer gas. The exponential decaying behaviour of the gas concentration serves as the basis for calculating the air volume flow rate. One basic condition of this method is that the tracer gas is mixed thoroughly with the air. This condition is regarded as particularly problematic [3]; especially dead zones - in which in the exchange with the surrounding air is minimal and short-circuiting flows - with the supplied air taking the shortest route out via the exhaust air openings - have been identified as important error sources [3].

Objective of investigation

Before the tracer gas method is employed in naturally ventilated livestock houses, where it is impossible to verify that the tracer gas method is in agreement with recognised methods, the concentration decay method was intended to be validated in a forced-ventilated building by means of the reference method using measuring fans. The measuring fan method is regarded as a very precise and inexpensive reference method for determining volume flow rates in force-ventilated buildings [4].

Description of the building used in the experiment

The building used in the experiment was a conventional broiler house 74.8 m in length, 17.3 m in breadth, with an eaves height of 3 m and with a ridge height of 5.3 m. The volume of the broiler house is 5370 m^3.

The measurements were carried out during the service period when the broiler house was empty because the ventilation settings were intended to be varied during the test. The ventilation system is a negative pressure system with vent stacks distributed along the axis of the roof ridge. Twelve of the exhaust air fans are on/off controlled, whereas one fan has variable speed control.

The supply air enters through commercially available ventilation flaps that are distributed at regular intervals along both sides of the broiler house. Except for the six drinking lines and the four feed lines customary in broiler fattening, its interior is completely empty.

Measurement methods

A measuring fan that had been calibrated on a DLG test bench was successively placed on each of the vent stacks, with great care being taken that the measuring unit was flush with the openings of the vent stacks. The volume flow rate in each of the vent stacks was determined at the different ventilation settings. The sum of these individual flow rates is the total volume flow rate.

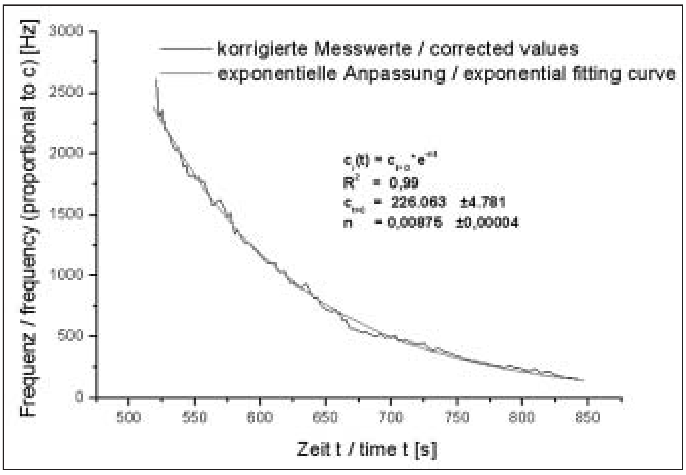

Bild 1: Gemessene Tracergasabklingkurve mit exponentieller Anpassung

Fig. 1: Measured decay-function with exponential fitting curve

Before the tracer gas method was employed, the air flow in the livestock house was made visible by means of a fog generator. The interior air of the livestock house was demonstrated to mix thoroughly with the fog without any visible short-circuit flows.

For injecting the tracer gas, cascaded tube systems were installed at both sides of the building. Tube openings were installed near the supply air flaps at intervals of approximately 9 m.

The air was sampled in the axis of the roof ridge, approximately 0.8 m below the fan openings. The tube ends were attached to the drinking lines and lifted to the ceiling by means of the building's rope system. Thus, the samples were taken at 6 points at intervals of approximately 12 m and in immediate proximity with the exhaust air openings.

A modified Leakmeter 200 (Meltron Qualitek Messtechnik GmbH, now: USON, Neuss) was used to determine the SF_6 concentration. It uses an electron capture detector (ECD) to detect the gas. Designed as a leak detector, it has a high temporal resolution (1 second).

By means of a statistical program, the exponential function $c_i(t) = c_{t=0} \bullet e^{-nt}$ was then fitted to the corrected values (*Fig. 1*), with $c_i(t)$ describing the mass concentration in the room air [g m^{-3}] at the time t and $c_{t=0}$ describing the mass concentration at the time t = 0 [g m^{-3}]. The n in the exponent is the air change rate [s^{-1}], t is time [s]. The air volume flow rate can be calculated by multiplying the air change rate with the volume of the building.

Results and discussion

The deviation of the repeated measurements is lower than 2.5 % of the air change rates. This shows that the repeatability of the measurements is high under conditions as constant as they are in a force-ventilated livestock house. The individual results are in good agreement due to the following factors:

- The large number of metering and sampling points in the building leads to a thorough mixing of the air with the tracer gas and to a homogeneous composite sample being fed to the measurement device.
- With a measuring interval of one second it is possible to record the time course of the tracer gas concentration continuously; this also yields unique exponential decay functions even for high air changes in naturally ventilated buildings.
- It was possible to achieve a high degree of repeatability in interpreting the measuring data by fitting the decay function to the measured values with a statistical program.

The results of the comparison measurements show that both methods are in good agreement (*Fig. 2*). In comparison to the measuring fan method, the tracer gas method underestimates the air change rate by a maximum of 1.4 %.

Conclusions and outlook

With the measuring methods used it could be demonstrated to be in good agreement for the force-ventilated livestock house used in the test. The building's ideal conditions with regard to air flow and mixing gave the measurements a high degree of repeatability. Especially due to its high temporal resolution, the SF_6 measuring device is very suitable for this type of measurement. The expenditure of time and money for these measurements is relatively low.

As there are no reference methods for the validation of the tracer gas method in naturally ventilated livestock houses, the validation had to be carried out in a forced-ventilated building. The results cannot be transferred to naturally ventilated buildings because the air flows in both building types are very different. The air flow in livestock houses with natural ventilation is subject to climatic influences from outside, which makes it less directional than in forced-ventilated buildings. Especially the condition of the complete mixing of the tracer gas with the interior air cannot generally be assumed to be fulfilled. Besides, a clear designation of the ventilation openings as supply air and exhaust air openings respectively is impossible. This leads to high demands on the dosage of the tracer gas, on the air sampling technique, and on the interpretation of the measured values [6].

The transferability of this method to naturally ventilated livestock houses has to be determined in further research.

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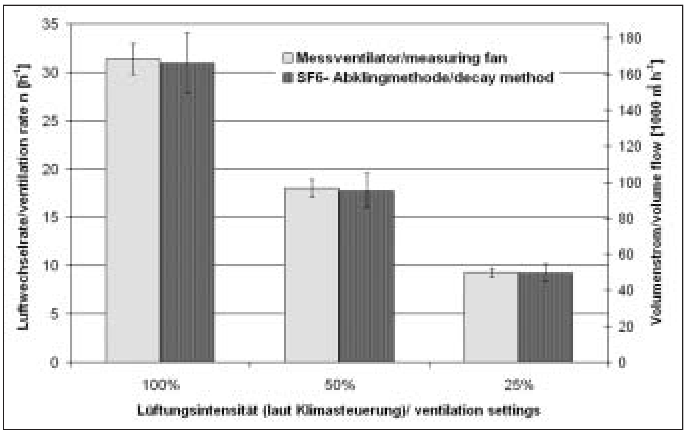

Fig. 2: Comparing measuring methods of different ventilation settings