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Emissions from naturally ventilated livestock housing

Tracer gas methods for quantifying gaseous emissions from cross-ventilated natural-climate housing for feeding pigs

The behaviour of emissions from naturally ventilated housing has been barely investigated up until now and is therefore the object of current research activity. Within this context, the dynamic investigation of current airflows from naturally ventilated houses causes considerable difficulties. Middle point in the following trial presentation is the development of a tracer gas measurement configuration for continuous determination of air flow from two selected natural-climate feeding pig houses with cross-ventilation.

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Keywords

Outside-climate pig fattening houses, air exchange rate, tracer gas-technique, gaseous emissions

The main part of air volume flow calculations on practical farms is based, however, on tracer mass balancing according to the regressive method. The limits to this measuring technique's uses lie in its characteristics as a discontinual point-form measuring technique as well as the assumption that the airflow during the total regression interval remains constant. This has led to a measurement configuration being developed allowing continual short-interval recording of airflows.

Developed measurement configurations

The measurement configuration – a comprehensive presentation is contained in [2] – comprises a collection system for house interior air and a tracer gas application system. The former offers continuous determination in the house interior of average concentrations of the gases NH_3, N_2O, CH_4 and CO_2 and the tracer gas SF_6. PTFE pipelines fitted with critical glass capillaries are attached along the whole house length at three separate levels at height gaps of 0.5 m onto the permanently installed perforated plastic sheeting on both outer sides. Within a single level, the gap between the capillaries is 1.5 m. Each pipeline is attached to a separate vacuum pump whereby the vacuum in each pipeline level means the same amount of air is inducted. The air exiting the house via the ridge/chimney is sampled according to the same principle. The vacuum pumps transport the air mixture from each side pipeline and the air mixture from the ridge/chimney into an open 51-PTFE collection bottle out of which the connected multigas monitor 1302 (Innova AirTech Instruments; Denmark) withdraws the sample to be analysed. The sample is then analysed photo-acoustically for concentrations of the four selected gases and for SF_6 and water vapour. A measurement cycle period of 125 s was achieved. Trials with a fogger („Mini-Mist“, type MicroFog, Brook, Jade) in trial housing on measurement day before recording started gave information on the actual intake and exhaust situation. Only the pipelines lying within the previously defined exhaust air area were chosen and sampled for determination of emission flows. For this, a choice of measurement day is required that allows a

Table 1: Characteristics of the two experimental outside-climate pig houses (VS I, VS II)

Characteristics	VS I	VS II
House design	Nürtinger-system	Nürtinger-System
Size (length • breadth • height)	65 m • 18 m • 6,5 m	36 m • 17 m • 6,5 m
Eaves height	3 m	3 m
Roof pitch	18°	18°
Direction	340° NW	310° NW
Places	800	450
Management system	continuous	continuous
Effective air volume in house 1)	5213.5 m^3	2710,4 m^3
Natural ventilation system	1.5 m	1.8 m
Height of side		
openings by 1 m over floor level		
Curtain	manuelly closable PE curtain	
Closing action	from bottom to top	
Permeability of windbreak net	50 %	50 %
Air outlets/roof	closable ridge ventilation	8 gravity ventilators
Manure pit (length•breadth•depth)	3 pits, each: 65 m • 1.6 m • 0.75 m	3 pits, each: 36 m • 1.5 m • 1 m
Emitting surface		
[m^2/MP]	0.36	0.37
[% net surface]	28	29

1) Effective house air volume = gross air volume of naturally ventilated house – total of volumes within the resting boxes

clear through flow of air in the houses and this is only possible on days with stable weather conditions and a house airflow angle of 90° (vertical house airflow) to ± 45°. The number of collection points depends on house size and previously defined exhaust air area.
The developed tracer gas dosing system comprises two components:

A ring pipeline with integrated critical glass capillaries as injection module offers a continuous and wide-ranging fan-shaped introduction of tracer gas/air mixture in the house interior. This is permanently installed in the house interior following fogging trials and after modelling various climate situations and their effect on the ventilation performance within the house (e.g. roller building).

The equipment for the production of a tracer gas/air mix of a defined and consistent concentration is situated in the fore-chamber of the house. From the flow meter of an SF_6 pressure flask, a defined amount of pure SF_6 runs continually over a PE pipeline in a closed 5 l wide-necked. The SF_6 pure gas is mixed with a defined amount of fresh air which is sucked out of the lee side of the building by a pressure-stable displacement pump and processed into a homogenous gas mixture of stable concentrations. This moves into the dosage pipeline and from there is injected into the house interior.

Calculation basis

The airflow exiting the house is calculated (equation 1) on the basis of the constant tracer injection method which is known for high precision and very good reproducibility [1]. Through the two-minute concentration-sampling rate of the multigas monitor, the average airflow of a house can also be calculated in two-minute intervals.

$$\dot{V}_e = \dot{V}_T \bullet c_T / (c_e - c_i) \qquad (1)$$

Whereby: $\dot{V}_T << \dot{V}_i$ und $\dot{V}_e \equiv \dot{V}_i$

with:

- $\dot{V}_e$: Airflow emitting from the house [m³/h]
- $\dot{V}_i$: Airflow entering the house [m³/h]
- $\dot{V}_T$: volume flow of injected tracer gases [m³/h]
- c_e: tracer gas concentration in the exhaust air [mg/m³]
- c_i: tracer gas concentration in the inlet air[mg/m³]
- c_T: concentration of the injected tracer gases [mg/m³]

Measuring procedure/trial housing

Measurements took place from May 1998 until February 1999 in each case during one day in the week for maximum 24 hours in the trial houses 1 (VS 1) and 2 (VS II). Both houses followed the Nürtinger design variant for natural ventilation without straw bedding. *Table 1* gives an overview of trial-relevant data for both trial houses and systems.

Carried out at the same time as the analyses of gas concentrations was the recording of climate parameters in and around the buildings at one-minute intervals. A detailed description of the trial measuring equipment technology is given by [2].

Results

Regression analyses
A separate airflow model for each house on the basis of accumulated daily measurements with optimum air approach conditions proved very successful in both cases ($R^2_{model} > 0.86$). In this the parameters „intake air area", „exhaust air area", and „temperature difference: house air – exterior air" emerged as significant main airflow influence factors. More detail over the choice of the regressors and the evaluating statistics is available at [2].

Quantifying gaseous emissions
The continuous recording of concentrations and corresponding airflows enabled the recording of daily emission gas profiles. The measurements were classified, depending on exterior climate conditions, as summer ($ØT_{exterior\ air} > 15\,°C$) or winter situation ($ØT_{exterior\ air} < 15\,°C$). *Table 2* gives the measured gas concentrations, airflows and emission mass flows of both trial buildings as calculated, and also as corrected averages on the basis of results from a validating trial [2]. Notable are the very high airflows which are many times more than the DIN 18910 required minimum air rates. The calculated NH_3 emissions, in comparison to literature values for forced ventilated fully slatted floored housing, showed an emissions reduction potential of around 20%. The emission levels determined for N_2O and CH_4 were comparable to the emission potential of the forced ventilation slatted flooring housing. Influence of time of year on the CH_4 emissions is substantial and this can be attributed to the strong temperature dependency of the methane-producing organisms.

Table 2: Average concentration and computed as well as corrected emission of the gases NH_3, N_2O, CH_4 and CO_2 during selected days from the measuring period May 1998 to Feb. 1999, VSI and VSII

Variable	Unit	VSI Summer (6 days) measured	VSI Summer (6 days) corr.	VSI Winter (9 days measured	VSI Winter (9 days corr.	VSII Summer (11 days) measured	VSII Summer (11 days) corr.	VSII Winter (12 days) measured	VSII Winter (12 days) corr.
Concentration									
NH_3	[mg/m³]	1.64		4,5		3.9		6.62	
N_2O	[mg/m³]	n.d.3)		0.68		n.d.		0.77	
CH_4	[mg/m³]	5.13		5.47		7.52		5.55	
CO_2	[mg/m³]	1185		2095		1395		1919	
Air exchange rate									
	[m³/h]	148870	89322	82190	49314	55915	33549	48264	28959
	[m³/LG1)h	1045	627	575	345	837	502	679	407]
Emissions									
NH_3	[g/LG h]	40.3	23,41	46,35	27.81	71.75	43.05	95.61	57.36
	[g/MP² d]	7.12	4,27	8.39	5.04	10.78	6,47	15.05	9.03
N_2O	[g/LG d]	n.d.3)	n.d.3)	4.61	2.77	n.d.	n.d.	6.27	3.76
	[g/MP² d]	n.d.3)	n.d.3)	0.84	0.50	n.d.	n.d.	0.98	0.59
CH_4	[g/LG d]	120.61	72.37	71.96	43.18	140.08	84.05	105.37	63.22
	[g/MP² d]	22.26	13.36	12.88	7.73	21.10	12.66	16.71	10.02
CO_2	[g/LG d]	28.61	17.17	23.61	14.17	27.21	16.33	29.41	17.64
	[g/MP² d]	5.15	3.09	4.24	2.54	4.06	2.43	4.64	2.78

1)LG = liveweight, 2) MO = feeding place, 3) n.d. = not significant

Literature

Books are signified with •

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