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Tracer gas technique to estimate the ventilation rate through a naturally ventilated dairy barn

Twenty nine field experiments were carried out to study the ventilation rate in a naturally ventilated dairy barn during summer and winter seasons from 2006 to 2010. The air exchange rates (AER) were determined by the tracer gas technique (TGT), and the CO_2-balance was set as reference method (RM). During each field experiment, continuous measurements of the gaseous concentrations (NH_3, CO_2, CH_4 and N_2O) were carried out inside and outside the building. Additionally, ^{85}Kr tracer gas experiments were performed inside the building during every field experiment. The TGT was evaluated with respect to the gas release location and the calculation method.

Keywords

Tracer gas technique, CO_2-balance, ventilation rate, gaseous emissions

Abstract

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Excessive levels of NH_3 emissions contribute to eutrophication and acidification. CH_4 and N_2O are greenhouse gases (GHG) with global warming potentials of 23 and 296 times that of CO_2, respectively [1]. Therefore, a reduction of these emissions is demanded. For this purpose, it is necessary to quantify the gaseous emissions from livestock buildings. The quantification of gaseous emissions from naturally ventilated animal houses is complicated and shows large uncertainties; especially by the determination of ventilation rates. Therefore, the implemented methods to determine the ventilation rate should be further investigated and improved [2].

This paper aims at specifying the best combination of influencing factors of the tracer gas method on the quantification of the air exchange rate for summer and winter.

Methodology

The investigated dairy barn is located in Mecklenburg-Vorpommern, north-east Germany. The barn is naturally ventilated and designed to house 364 dairy cows in freestalls. The measurements were conducted over 2-week period per season, where the concentrations of CO_2, NH_3, CH_4, and N_2O were continuously measured, using a multi-gas monitor (INNOVA 1312), inside the barn at eight uniformly distributed sampling points (MP) and outside the barn at four points. Additionally, ventilation measurements were carried out with the tracer radioactive isotope Krypton-85, between five and six times per campaign, i.e. per investigation period. The tracer gas was released inside the building in order to determine the air exchange rate using the decay method. The decrease of radioactive impulses was measured for each release using 20 radiation counters (Z). The air exchange rate is then the result of an exponential relation between the recorded impulses and the time. The tracer gas releases varied in location: (1) as a continuous line in the middle of the building over the feeding bunk, (2) a continuous line in the windward side of the building over the manure alley, and (3) a fixed-point source. For all release locations four different calculation procedures of the α-values (α is the AER per second calculated using the impulses of one radiation counter) were compared and they are: (1) average α-values of selected radiation counters, (2) average α-values of all radiation counters, (3) the sum of impulses of selected radiation counters, and (4) the sum of impulses of all radiation counters. The emission mass flow from the livestock building was calculated as the product of both the concentration difference between emitted and fresh air and the volumetric flow rate. The results were compared with each other by performing a Pearson correlation analyses and developing linear regression models. The differences between the TGT and the reference method were tested using the ANOVA model regarding the best combination of influencing factors.

Results

The best combinations of influencing factors, having the highest R^2 values and the most reliable parameter estimates, were during the summer period (1) release of the tracer gas over feeding bunk considering the sum of all impulses recorded by all of the radiation counters (R^2=0.94; 1.63±0.14), and during the winter period (2) a point release source considering the sum of all impulses recorded by all radiation counters (R^2=0.91; 1.19±0.15). The average gaseous emissions through summer seasons, by the reference method were 124, 538, 45610, and 28 g d^{-1} AU^{-1} for NH_3, CH_4, CO_2, and N_2O respectively. On the other hand, they were average of 64, 348, 42760, and 39 g d^{-1} AU^{-1} through winter seasons. The emissions factors, subject to the reference method, were 34.4, 161.7, 16127, and 123 kg yr^{-1} AU^{-1} for NH_3, CH_4, CO_2, and N_2O respectively. They were calculated as average of the summer and winter values.

Discussion

The evenly dosing of ^{85}Kr in a line over the southern manure alley was compared to the continuous release over the feeding line and the release of a fixed-point source. Where, the southern manure alley was selected because it faces the prevailing winds, which blows from the south and south-west. There the air enters the building allowing better ^{85}Kr mixing with air

Table 1

Air exchange rates and gaseous emissions by both methods through 4 summer seasons

Experiment	LWR/*AER*		NH_3 g $d^{-1}GV^{-1}$/*g d^{-1} AU^{-1}*		CH_4 g $d^{-1}GV^{-1}$/*g d^{-1} AU^{-1}*		CO_2 g $d^{-1}GV^{-1}$/*g d^{-1} AU^{-1}*		N_2O g $d^{-1}GV^{-1}$/*g d^{-1} AU^{-1}*	
	TGM/*TGT*	RM	TGM/*TGT*	RM	TGM/*TGT*	RM	TGM/*TGT*	RM	TGM/*TGT*	RM
1	64	90	342	481	1 104	1 552	82 684	116 275	55	77
2	42	23	218	120	625	342	50 696	27 762	37	20
3	185	41	537	119	2 418	536	201 345	44 622	137	30
4	61	51	117	98	665	556	63 819	53 357	46	38
5	79	59	224	167	865	646	80 579	60 179	63	47
6	25	30	61	73	355	427	28 326	33 992	14	17
7	27	18	103	68	557	371	35 262	23 509	16	10
8	106	53	295	148	1 605	803	136 843	68 421	71	36
9	51	26	168	86	922	470	66 392	33 847	35	18
10	76	36	247	117	1 068	506	89 184	42 245	52	25
11	97	49	128	65	685	346	100 790	50 914	67	34
12	29	27	70	65	355	330	34 601	32 215	20	18
13	20	19	66	63	323	307	26 490	25 166	13	12
14	18	20	64	71	307	341	23 429	26 033	12	13
Mittelwert/*Average*	63	39	189	124	847	538	72 889	45 610	46	28

Table 2

Air exchange rates and gaseous emissions by both methods through 3 winter seasons

Experiment	LWR/*AER*		NH_3 g $d^{-1}GV^{-1}$/*g d^{-1} AU^{-1}*		CH_4 g $d^{-1}GV^{-1}$/*g d^{-1} AU^{-1}*		CO_2 g $d^{-1}GV^{-1}$/*g d^{-1} AU^{-1}*		N_2O g $d^{-1}GV^{-1}$/*g d^{-1} AU^{-1}*	
	TGM/*TGT*	RM	TGM/*TGT*	RM	TGM/*TGT*	RM	TGM/*TGT*	RM	TGM/*TGT*	RM
1	39	33	59	50	432	363	51 694	43 440	53	45
2	37	31	56	47	450	378	49 523	41 616	51	42
3	31	26	47	39	374	314	43 897	36 888	42	36
4	45	38	63	53	416	350	57 207	48 072	62	52
5	39	33	51	43	328	276	51 265	43 080	53	45
6	18	15	43	36	418	351	30 816	25 896	21	18
7	14	12	35	29	352	295	26 304	22 104	17	15
8	17	14	50	42	399	335	30 274	25 440	20	17
9	20	17	47	40	346	291	32 558	27 360	27	22
10	17	14	41	35	337	283	29 702	24 960	23	19
11	61	51	153	128	465	390	77 483	65 112	72	60
12	55	46	121	102	414	348	69 429	58 344	65	54
13	88	74	206	173	741	623	110 956	93 240	101	84
14	41	35	48	40	369	306	53 521	44 976	48	40
15	38	32	126	106	377	317	48 638	40 872	44	37
Mittelwert/*Average*	37	31	76	64	415	348	50 884	42 760	47	39

and hence a better distribution of the tracer gas throughout the barn. This was confirmed by the observation of the radiation counters where all of the 20 radiation counters detected the tracer gas when it was released over the manure alley in comparison to a maximum of 15 radiation counters detected the tracer gas when released over the feeding bunk, and 10 radiation counters when the tracer was released from a fixed point. This concept agrees with that stated by [3]. The results of our study show that the best factor combinations of TGT overestimates the air exchange rate by about 1.63 and 1.19 compared to the air exchange rate estimated by the CO_2-balance through summer and winter seasons, respectively. One reason for this overestimation can be attributed to the fact that there are also airflows between the different zones inside the building [4].

The gaseous emissions were calculated using the AER determined by the reference method. Moreover, the emission factors were calculated as average of the winter and summer measurements to be representative for the whole year. Nevertheless, due to different climate and microclimate conditions in spring, autumn, summer and winter actual yearly emission factors might vary. According to our study, the average NH_3 emission factor was 45.8 kg yr^{-1} cow^{-1} which agrees with [3]. However, [5] specified the constant NH_3 emission factor as 15.79 kg yr^{-1} cow^{-1} which is one third our value.

Conclusions

It can be concluded that the sum of impulses leads to better results than an average of α-values. The air movement is best represented if the readings of all the radiation counters are considered (and not only selected counters) and furthermore it is easier to calculate the air exchange rate. The tracer gas released over the manure alley was detected by all radiation counters emphasising a better mixing of tracer gas with air and a more uniform distribution of this mixture inside the barn. However, within the statistical analysis no benefit of the better mixing was found yet. More experiments should be performed to verify the improvement perceived by the visual inspection. The tracer gas technique is a promising method; however, it overestimates the air exchange rate. On the other hand, the CO_2-balance has several error sources. Therefore, this technique should be further developed by focusing on the ^{85}Kr release method, the release location inside the barn and the calculation method.

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