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Ammonia and methane emission from a hybrid ventilated dairy cow building in Denmark

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Abstract

Naturally ventilated cattle buildings are one of the major sources for ammonia and greenhouse gas emissions to the atmosphere. Generally, it is difficult to clean the pollutant air from naturally ventilated buildings. In order to reduce the emissions from dairy cattle buildings, a hybrid ventilation system has been installed in a dairy cow building in Denmark. The hybrid ventilation system consists of an auto-controlled natural ventilation (NV) system and a partial pit mechanical ventilation system. In this system, a small amount air with higher gaseous concentration, e.g. ammonia, can be cleaned at the pit exhausts. The concept of applying hybrid ventilation system in cattle building to reduce the gaseous emissions to the atmosphere is novel. It is therefore necessary to study the performance by field experimental measurements.

The objectives of this paper are: (1) To present the hybrid ventilation system installed in the dairy cattle building; (2) To measure the gaseous concentration and temperature in the winter and summer; (3) To quantify gaseous emissions of ammonia and methane and compare with those from naturally ventilated dairy cattle buildings published in other literatures.

The results showed that the ammonia average concentration was around 2-3 ppm in the cattle building in summer and winter. The methane average concentration was 25.5 ppm in summer and 74.1 ppm in winter. The ammonia concentration in the pit was around 24 ppm in summer and 12 ppm in winter while the methane concentration in the pit showed no significant difference from the concentration in the building. The ammonia average daily emission was 4.53 g HPU^{-1} d^{-1} in winter and 17.72 g HPU^{-1} d^{-1} in summer by NV. Methane average daily emission was 129.3 g HPU^{-1} d^{-1} in winter and 246.9 g HPU^{-1} d^{-1} in summer. The results revealed that 64%-83% ammonia emissions were collected by partial pit ventilation.

Keywords: ammonia, methane, hybrid ventilation, dairy cow building, emission

1 Introduction

Livestock buildings are major source of ammonia (NH_3), methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) emission. Ammonia is responsible for eutrophication and soil acidification, while CO_2, CH_4 and N_2O are identified as greenhouse gases that contribute to global warming (Samer et al., 2011; Zhang et al., 2005; Samer et al., 2012). Generally, the traditional dairy cattle buildings are naturally ventilated in mild climate regions. The naturally ventilated dairy (NVD) cattle buildings usually have large side openings and roof and /or ridge openings. The ventilation air is driven by wind or buoyancy force so that it does not cost any energy for fans (Koinakis, 2005; Schulze and Eicker, 2013). However, it is a challenge to maintain appropriate thermal conditions in the building with natural ventilation (NV) in cold weather due to the difficulty in controlling the momentum of ventilation air. In addition, It is extremely difficult (almost impossible) to clean the exhaust air from dairy cattle building with

NV system, which results in the ammonia and other contaminant gases exhaust to the atmosphere directly.
In order to reduce the odor emissions in livestock production buildings, mechanical ventilation (MV) system is an alternative method for collecting the pollutant air and cleaning it at the exhausts. However, the primary disadvantage of mechanical ventilation system is energy consumption and noise. In addition, it requires high investment and running cost to clean the whole volume of ventilation air. In this context, the concept of partial pit ventilation system has been developed. The partial pit ventilation rate is usually 10%-30% of the maximum ventilation rate. This concept has been tested successfully in fattening pig bars in Denmark. Saha et al. (2010) have studied the effects of a partial pit ventilation system on indoor air quality and ammonia emissions from a fattening pig room. It shows that the ammonia emissions can be reduced up to 53% when the partial pit ventilation rate was 10% of the maximum ventilation rate and only this 10% of the airflow would be cleaned by the filter. The promising results present that the indoor air quality has been greatly improved and the ammonia emissions has been further reduced. The similar results with partial pit ventilation in pig buildings can also be found in Hansen et al. (2012). To combine the advantages of natural and partial pit ventilation system, hybrid ventilation (HBV) system is proposed in NVD buildings. The objectives of this paper are: (1) To present the hybrid ventilation system installed in the dairy cattle building; (2) To measure the gaseous concentration and temperature in the winter and summer; (3) To quantify gaseous emissions of ammonia and methane and compare with those from naturally ventilated dairy cattle buildings published in other literatures.

2 Materials and methods

The building was located in Skjern, Jylland in Denmark. The dimensions of the building were shown in Figure 1, in which the length was 74.0m and the width was 45.0m. The heights measured from the floor to the eave, to the roof and to the ridge were 3.41m, 7.6m and 11.3m. On the east, two rows of windows were on the sidewall, one row of windows was on the roof and one row was on the ridge. The arrangement of windows on the west was the same. All the window openings were auto-controlled. The windows on side walls, the roof and the ridge can be fully opened at the position of 41.4^{o}, 46^{0} and 40^{0}.
There were two big gates on the north, where tractor could supply feeding materials to the feeding alley. The gates were closed as possible as it could be (see Figure 1a). The walking alley area between cows' beds and feeding alley was slatted floor. The feeding alley and the cows' beds were slightly higher than the slatted floor. Below the slatted floor, the manure was scraped to the deeper slurry channel on the South, above which there was a walking alley in slatted floor connected to the milking building. Between the cattle building and milking building, there was also a gate which was only open for milking time.
The system consisted of natural and partial mechanical pit ventilation system. The aim of the partial pit ventilation system was to collect the higher concentrated air and clean them in order to reduce the ammonia emission. In Figure 1 (d), there were four channels named as EA on the east side and four channels named as WA on the west side below the cows' beds to exhaust the air to the central air channel. At the end of the central channel, an acid filter cleaner was installed to absorb the ammonia in the exhaust air, see Figure 1 (b). There were also four channels to supply fresh air to the slurry channel, named as SA. The supplied airflow rate was slightly lower than the airflow rate exhausted by the fan so that the air in the pit ventilation could not flow to the space above the slatted floor. In the system investigated in this paper, the mechanical pit ventilation system was run through the year. In winter, the pit ventilation rate was controlled by indoor air temperature and CO_2 concentration until it arrives at minimum ventilation rate. In summer, the pit ventilation rate was around 25% of the designed maximum ventilation rate (450 m^3 h^{-1} cow^{-1}).

Gases inside and outside the buildings were sampled along three 20 m lines using Teflon tubes (diameter was 8mm). Each tube had 20 uniform distributed sampling openings. By using this method, the measured gas concentration was actually the average value of the 20

Figure 1 Layout of the hybrid ventilated dairy cow building and locations of measuring points. The ‘blue’ lines represent sampling positions of concentration. The ‘read’ squares represent locations of therocouples.

sampling openings. Concentration of CO_2, NH_3 and CH_4 were continuously measured by INNOVA. The measurements were recorded six times at one channel before it was switched to another channel. The average of these six measurements was used for CO_2 and CH_4 data analysis. The odor compounds were also measured by Proton Transfer Reaction-Mass Spectrometry (PTR-MS) in order to analyze the odor compound distribution in the building and the pit. During the measurements, it was found that the cross interference from some compounds in the cattle building has an important effect on the ammonia concentration measurements by INNOVA. Therefore, the data of CO_2 and CH_4 in this paper was from measurements by INNOVA while the data of NH_3 was from measurements by PTR-MS. The principles of infrared photo-acoustic analyzer and PTR-MS can be referred to Christensen (1990a and 1990b) and Blake et al. (2009).

In order to quantify the emission rate, it was necessary to determine the ventilation rate. The ventilation rate at each channel for the partial pit ventilation was measured by a measuring fan. For determination of ventilation rate via NV openings, the CO_2 production model for dairy cows was used (Pedersen and Sallvik, 2002). According to the mass conservative, this ventilation rate can be calculated by the following equation:

$$Q = \frac{10^6(E_{CO_2} - E_{CO_2,pit})}{C_{CO_2,in} - C_{CO_2,out}} \quad (1)$$

Where Q was ventilation rate of NV, m^3/h; E_{CO_2} was the total CO_2 production from the measured cattle building, kg/s; $E_{CO_2,pit}$ was the CO_2 emission exhausted by pit ventilation system, kg/s; $C_{CO_2,in}$ was the CO_2 concentration inside the building, mg/m^3; $C_{CO_2,out}$ was the upwind CO_2 concentration outside the building, mg/m^3. In this paper, the CO_2 production from manure was neglected in the mass balance model.

To compare the emissions between this newly-built cattle building with hybrid ventilation system with the other measured cattle building in literature, the emission rate per heat producing unit (HPU) was used. The HPU was defined as 1000 W total heat produced by animals at an environmental temperature of 20 ℃. The detailed description of HPU can be found in literature (Zhang et al., 2005). The emission rate per HPU was thus expressed as:

$$E_{i,HPU} = \frac{Q(C_{i,in} - C_{i,out})}{H_{total}} \quad (2)$$

Where $E_{i,HPU}$ was the gas emission rate per HPU of gas i, mg/h; H_{total} was the total HPU produced by the animals; i represented the measured gases, NH_3 and CH_4; $C_{i,in}$ was the average concentration of gas i inside the building, mg/m^3; $C_{i,out}$ was the upwind concentration of gas i outside the building, mg/m^3.

3 Results

3.1 Gaseous concentration and temperature

Table 1 Indoor and outdoor gas concentration

Period (MM/DD/YYYY)		gas concentration (ppm)							
		Indoor				outdoor			
		Mean	SD	Max	Min	Mean	SD	Max	Min
02/20/2013-03/13/2013	CO2	1350	385	2716.5	463	471	19	555	432
	NH3	2.6	0.9	13	0.9	0.8	0.2	2	0.4
	CH4	74.1	31.8	219.4	2.1	2.9	1.7	11.1	1.1
	N2O	0.31	0.06	0.83	0.19	0.3	0.02	0.36	0.23
07/15/2013-08/16/2013	CO2	795	229	1632	418	463	21	646	402
	NH3	2.35	1.15	15.5	0.38	0.93	0.57	3.36	0.2
	CH4	25.5	17.6	106.8	5.6	5.85	1.24	7.8	4.6
	N2O	0.37	0.04	0.56	0.29	0.34	0.02	0.43	0.28

The averaged concentration of CO_2, NH_3, CH_4 and N_2O indoor and outdoor was shown in Table 1. The averaged concentration of NH_3 during the measuring period in summer and winter (2.35ppm and 2.6 ppm respectively) were both slightly lower comparing to 3.03 ppm and 3.3 ppm in a recent relevant study (Wu et al. 2012). On the other hand, the CO_2 and CH_4 concentrations measured in summer were comparable to the ones in the literature (795 ppm and 25.5 ppm comparing to 668 ppm and 27.4 ppm respectively (Wu et al. 2012)). However, the concentrations of CO_2 and CH_4 measured in winter were higher than the values in the literature, 1350 ppm and 74.1 ppm comparing to 892 ppm and 43.6 ppm (Wu et al. 2012). The difference of N_2O concentration between outdoor and indoor was quite small and the level of N_2O concentration was very low, with the maximum concentration of 0.83ppm in winter and 0.56ppm in summer respectively. The averaged indoor NH_3 concentration from the summer and the winter did not differ significantly from each other. The concentration of CH_4 followed the change of CO_2 concentration both in summer and winter. Fig. 2 gave an example of the relationship between CO_2 and CH_4 concentration in winter. The ratio between indoor CH_4 and CO_2 concentration was around 0.08 (R^2=0.945) by linear fitting.

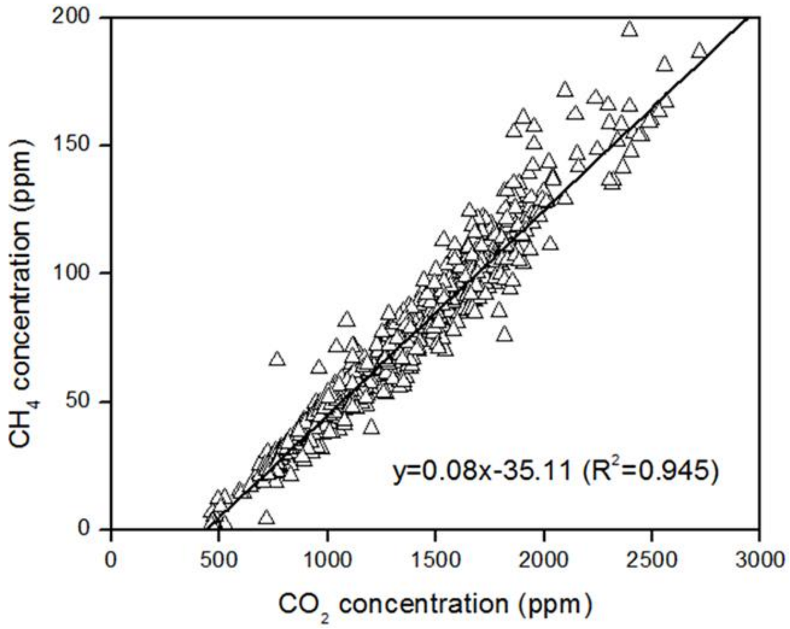

Figure 2 correlation of CH_4 and CO_2 concentration

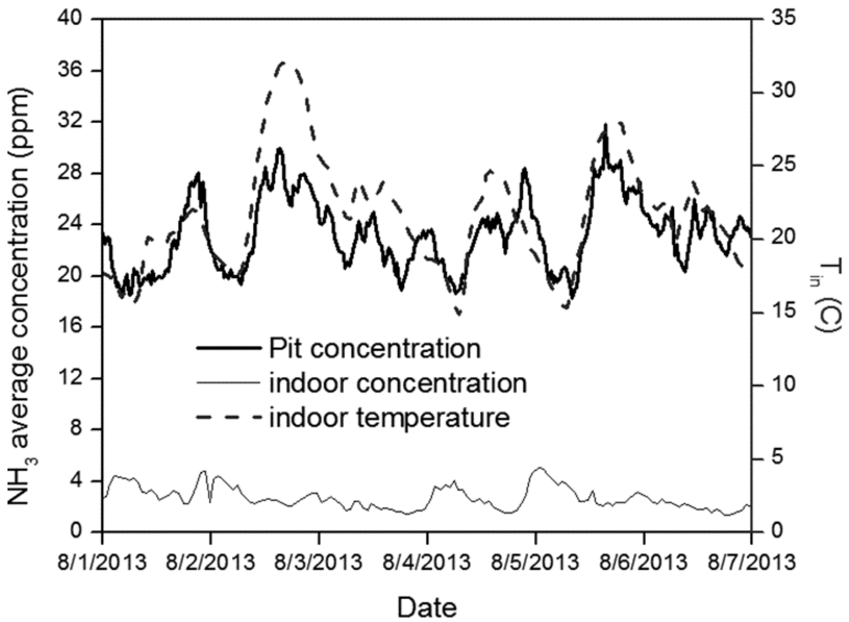

Figure 3 Variation of NH_3 concentration and indoor temperature with time

In winter, the average ammonia concentration in the pit was around 12.0 ppm. It varied along with indoor air temperature in summer and the average value was 23.0ppm with air temperature of 20.0 ℃, see in Fig. 3. The averaged ammonia concentration in the pit was around 5 times as that inside the building in winter and 11 times in summer. On the contrary, the averaged CO_2 concentration in the pit was 759 ppm, which was close to the averaged concentration in the cattle building. Meanwhile, the averaged CH_4 concentration in the pit was 19.46 ppm, which was slightly lower than that in the cattle building in summer. Similar results were also found in winter.

3.2 NH_3 and CH_4 emissions

Table 2 presented the average emission rate in three units, per HPU, per LU (Livestock Unit) and per m^2 of slatted floor. The mean emission rate of NH_3 via NV during the whole measuring period was 4.53 g HPU^{-1} d^{-1} with indoor average air temperature of 7.8 ℃ in winter and 17.72 g HPU^{-1} d^{-1} with indoor average air temperature of 19.9 ℃ in summer. The average emission rate of CH_4 through NV was 129.25 g HPU^{-1} d^{-1} and 246.97 g HPU^{-1} d^{-1} in winter and summer respectively. The average ammonia emission rate collected by the pit ventilation was 35.14 g HPU^{-1} d^{-1} in summer and 21.77 g HPU^{-1} d^{-1} in winter. Through pit ventilation, in average 83% of NH_3 emissions was collected in winter and it reached 95% on 12th March 2013. In summer, in average 64% of NH_3 emissions was collected by the pit ventilation and it reached 81% on 6th of August. The pit ventilation collected 50% of CH_4 emissions in winter while only 10% of CH_4 emissions were collected in summer.

Table 2 Average daily emissions

Period		Gas	Emission ($g\ HPU^{-1}\ d^{-1}$)		Emission ($g\ LU^{-1}\ d^{-1}$)		Emission ($g\ m^{-2}\ d^{-1}$)*	
			Mean	SD	Mean	SD	Mean	SD
02/20/2013-	Building	NH_3	4.53	1.49	4.95	1.63	1.58	0.52
03/13/2013		CH_4	129.25	34.11	141.34	37.3	45.24	11.94
	Pit**	NH_3	22.12	1.24	24.17	1.35	7.71	0.43
		CH_4	129.63	35.38	141.76	38.69	45.37	12.38
07/15/2013-	Building	NH_3	17.72	8.47	19.38	9.26	6.2	2.96
08/16/2013		CH_4	246.97	73.6	270.07	80.48	86.44	25.76
	Pit	NH_3	32.23	4.19	35.06	4.62	11.22	1.48
		CH_4	28.31	5.65	30.95	6.12	9.91	1.96

* The emission was summarized as gram per day per square meter of slatted floor, which was 1421.5 m^2 in the cattle building

** During the winter experiments, the concentration in the pit was not measured continuously. The average value was calculated according to the data obtained from 20/2, 27/2, 8/3 and 13/3.

Ammonia daily averaged emission rate ranged from 1.27 g HPU^{-1} d^{-1} to 7.9 g HPU^{-1} d^{-1} in winter and from 3.86 g HPU^{-1} d^{-1} to 55.69 g HPU^{-1} d^{-1} in summer, as shown in Fig. 4. Similarly, the daily averaged emission rate of CH_4 ranged from 74.96 g HPU^{-1} d^{-1} to 217.74 g HPU^{-1} d^{-1} in winter and from 100.3 g HPU^{-1} d^{-1} to 612.8 g HPU^{-1} d^{-1} in summer. The diurnal variations of NH_3 and CH_4 in winter were not as large as those in summer. The peak of emissions during the day could occur either after the noon time or during the milking and feeding hours in winter. There was a high peak of emission rate in summer measurements for both NH_3 and CH_4.

4 Discussions

The NH_3 concentrations both in summer and winter were slightly lower while the CO_2 and CH_4 concentrations in winter were higher in this study than the values measured by Wu et al (2012), who performed measurements in two traditional naturally ventilated cattle buildings in Denmark. One of the explanations was the difference of the ventilation and control systems. In this study, the partial pit ventilation had collected 83% of the ammonia in winter so that the NH_3 concentration in the building was low even though the ventilation rate was lower because of the auto-controlled NV. However, CH_4 and CO_2 were mainly produced by cows

(Monteny et al. 2006) and thus a limited portion of these gases could be removed via partial pit ventilation. In the same reason, the indoor concentrations of CO_2 and CH_4 were higher. Under a relatively stable ventilation rate in the pit, the ammonia concentration of the pit increased with higher indoor temperature, as seen in Fig. 3. This indicated that higher temperature may cause the increase of ammonia emissions from manure surface, as has been found in literatures (Ngwabie et al. 2011, Pereira e al. 2011). The ratio between CH_4 and CO_2 found in this study was 0.08, which was the same to the value found by Ngwabie et al. (2011). The ratio between CH_4 and CO_2 concentration thus could be used to predict CH_4 concentration by measuring CO_2 concentration, which was simpler to employ.

As expected, the animal activity had apparent impact on the gaseous emissions. Results revealed that the NH_3 and CH_4 emission rates were typically higher during the milking and feeding hours. It was also shown that the NH_3 emission rate was higher after the noon time due to the higher outdoor temperature resulting in higher indoor temperature. The gentle variation of NH_3 emission rate in winter might due to relatively stable indoor temperature and lower air exchange rate (ACH) via adjusting the opening ratio of windows. But in summer with big opening ratio of windows and larger ACH, the emission rate of NH_3 was highly dependent on the indoor temperature, that was, the outdoor temperature.

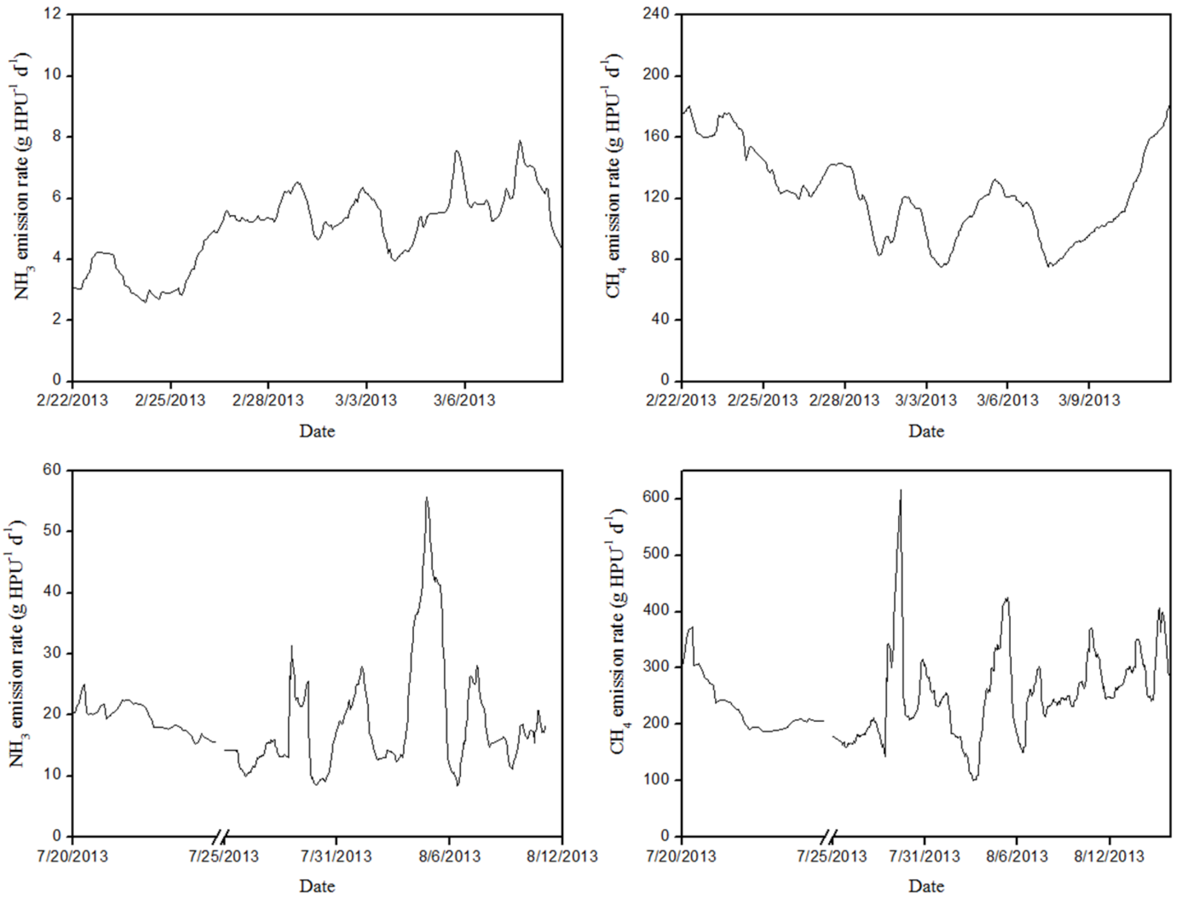

Figure 4 Daily emissions of NH_3 and CH_4

5 Conclusions

Continuous summer and winter measurements were conducted in a hybrid ventilated dairy cattle building in Denmark, the following conclusions were drawn:

- Because partial pit ventilation could collect 64%-83% of ammonia emissions, the hybrid ventilation system proposed in this study was effective to reduce the ammonia emission from cattle buildings to the atmosphere as the ammonia emissions collected by partial pit ventilation could be cleaned via a high efficient cleaner.

- CH_4 concentration had a strong correlation to CO_2 concentration. The ratio between CH_4 concentration and CO_2 concentration was 0.08. This implied that CH_4 emissions could be evaluated according to CO_2 production model.

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