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Seasonal and diel variations of ammonia and methane emissions from a naturally ventilated dairy building and the associated factors influencing emissions

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HIGHLIGHTS

- Ammonia (NH_3) emission was varied seasonally following in and outside temperature.
- Methane (CH_4) emission did not show clear seasonal trend.
- Diel variation of CH_4 emission was less pronounced than NH_3 emission.
- Temperature, humidity, wind and time of the day significantly affected NH_3 emissions.
- Sine and cosine of the circular variables improved dynamic nature of the models.

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ABSTRACT

Understanding seasonal and diel variations of ammonia (NH_3) and methane (CH_4) emissions from a naturally ventilated dairy (NVD) building may lead to develop successful control strategies for reducing emissions throughout the year. The main objective of this study was to quantify seasonal and diel variations of NH_3 and CH_4 emissions together with associated factors influencing emissions. Measurements were carried out with identical experimental set-up to cover three winter, spring and summer seasons, and two autumn seasons in the years 2010, 2011, and 2012. The data from 2010 and 2011 were used for developing emission prediction models and the data from 2012 were used for model validation. The results showed that NH_3 emission varied seasonally following outside temperature whereas CH_4 emission did not show clear seasonal trend. Diel variation of CH_4 emission was less pronounced than NH_3. The average NH_3 and CH_4 emissions between 6 a.m. and 6 p.m. were 66% and 33% higher than the average NH_3 and CH_4 emissions between 6 p.m. and 6 a.m., respectively for all seasons. The significant relationships ($P < 0.0001$) between NH_3 and influencing factors were found including outside temperature, humidity, wind speed and direction, hour of the day and day of the year. The significant effect ($P < 0.0001$) of climate factors, hours of the day and days of the year on CH_4 emission might be directly related to activities of the cows.

1. Introduction

Emissions of ammonia (NH_3) and greenhouse gases, e.g. methane (CH_4) and nitrous oxide (N_2O), from livestock production systems are of great concern to livestock producers, environmentalists, and governments due to their negative impact on surrounding environment and global climate (Bull and Sutton, 1998; IPCC, 2001). Dairy cow farming is one of the largest sources of NH_3 and CH_4 within livestock production (FAO, 2006). Emissions from dairy cow production systems need to be reduced to limit environmental problems associated with livestock. Due to this fact, it is very important to understand seasonal and diel variations of NH_3 and CH_4 emissions from naturally ventilated dairy (NVD) buildings together with factors affecting these variations and emissions. These understandings may lead to the development of successful control strategies of emissions throughout the year according to the need of environmentalists and governments.

The emission from an NVD building directly depends on atmospheric influences under continuously changing conditions (Ngwabie et al., 2011; Snell et al., 2003). Several researches have been carried out to identify management and climate related factors influencing air change per hour (ACH) and emissions. Through their review, Monteny and

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Erisman (1998) reported that NH_3 emission reduction of up to 50% for cubicle houses with slated flooring can be achieved by flushing of floors with water or diluted formaldehyde, optimized feeding strategies and slurry acidification. Zhang et al. (2005) estimated emission rates of NH_3, CH_4 and N_2O from NVD buildings with different floor types and manure-handling systems; the lowest NH_3 emission was from buildings with solid floors. Ngwabie et al. (2011) concluded that daily CH_4 emission increased significantly with the activity of cows while daily NH_3 emissions were more influenced by the indoor air temperature than by the activity of the cows. They explained that feeding strategy increased the activity of the cows whereas higher indoor temperature decreased daily the activity of the cows. Factors affecting one gas may not influence others (Saha et al., 2011). The outside climate factors (e.g. outdoor temperature and relative humidity, wind speed and direction) were largely ignored in Ngwabie et al. (2011) study.

Schrade et al. (2012) quantified NH_3 emissions from 6 NVD buildings using tracer gas technique for measuring ventilation and found significant influence of wind speed, outside temperature and urea content of the tank milk on NH_3 emission. Fiedler and Mueller (2011) measured the NH_3 concentration from two naturally ventilated cow sheds and found that NH_3 emission rate strongly depended on the outside conditions e.g. wind direction. Wu et al. (2012) found, in their study in two NVD buildings, that external temperature and wind speed have a significant effect on NH_3 emission, but not the wind direction. Two different conclusions regarding wind direction effects on NH_3 emission indicate the requirement of further investigation. However, the aforementioned factors were not correlated with CH_4 emission in their studies. Moreover, Wu et al. (2012) mentioned that more inventories on NVD buildings are still needed to derive NH_3 emission rates based on influencing factors. In order to take account of the climatic variation in an NVD building influenced by the outside climate variables and identify/confirm management and climate related factors affecting emissions, several measurements spread throughout the year are required (Koerkamp et al., 1998). Although there have been previous studies mostly focused on NH_3 emission and limited studies on CH_4 emissions from NVD buildings, more case studies especially long term observations covering all seasons are still needed to develop successful emission control strategies and model development. Therefore, the objectives of this study were to i) quantify seasonal NH_3 and CH_4 emissions for an NVD building, ii) investigate diel variations of NH_3 and CH_4 emissions, iii) identify and evaluate factors affecting the variations of NH_3 and CH_4 emissions.

2. Materials and methods

2.1. Building and site description

Field experiments were carried out at a commercial NVD building, located in Mecklenburg-Vorpommern, Northeast Germany (217 km north-west Berlin, 54°1′0″N, 12°13′60″E, and altitude 43 m). The dairy building is 96.2 m long and 34.2 m wide (Fig. 1a). The height of the sheet metal roof varies from 4.2 m at the sides to 10.7 m at the gable peak. The internal room volume of the barn is 25499 m^3 (70 m^3 per animal), and the building was designed to accommodate 364 dairy cows in loose housing with free stalls. The building has an open ridge slot (0.5 m), space boards (11.5 cm width and 2.2 cm thickness of wood board having solid core and spaced by 2.5 cm) in the gable wall of the western side of the building and sheet metal wall of the eastern side; one gate (metal urethane core with thermal break; 4 m × 4.4 m) in each gable wall; and 4 doors with adjustable curtains (where two doors are 3.2 m × 3 m, and two doors are 3.2 m × 4 m) in each gable wall (Fig. 1). A draft of natural ventilation was introduced into the building through adjustable curtains (polyethylene film, 1 mm) on the long sidewalls (protected by nets). Three additional ceiling fans (Powerfoil® X2.0, Big Ass Fans HQ, Lexington, KY, USA) were used to enhance the uniformity of air distribution inside the building during the summer season. The fans were mounted to the ceiling along the building centreline and had a diameter of 7.34 m with a maximum discharge rate of 546000 $m^3\ h^{-1}$ (Fig. 1b).

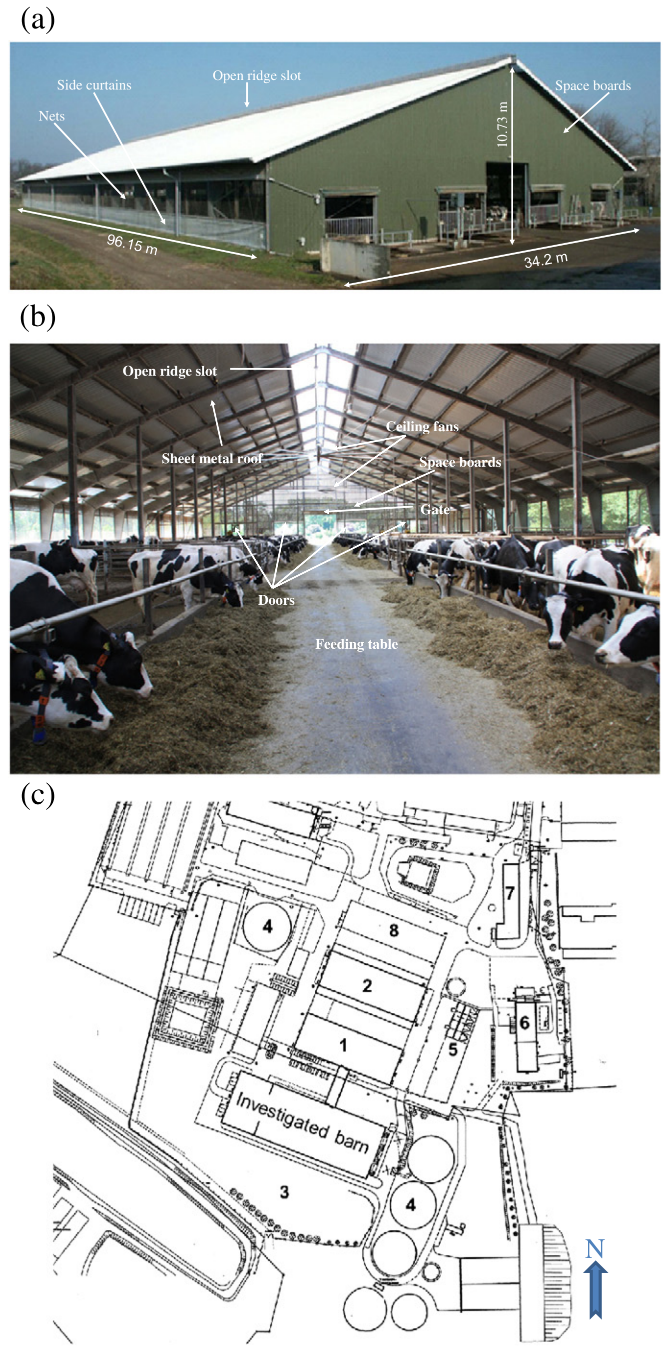

Fig. 1. (a) External and (b) internal views of the investigated barn, and (c) farmstead layout: (1) milking parlour, (2) another dairy barn, (3) open field, (4) manure tanks, (5) young stock housing, (6) workshop, (7) administration, and (8) forage storage buildings.

The manure handling system is equipped with a winch-drawn dung channel scraper. The solid concrete floor was cleaned with the scraper continuously with 10 min interval. The slurry was dumped into a partly covered pit outside of the east of the building and the pit was emptied daily between 12 p.m. and 4 p.m. depending on fullness of the pit.

The investigated NVD building is surrounded by a milking parlour, another dairy building, and forage storage building on the northern side, open fields on the southern and western sides, manure storage tanks on the eastern, south-eastern and north-western sides and a young stock house and workshop on the north-eastern side (Fig. 1c).