Energy and Buildings 82 (2014) 632–643

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Effect of climate parameters on air exchange rate and ammonia and methane emissions from a hybrid ventilated dairy cow building

Li Rong[a,*], Dezhao Liu[a], Erling F. Pedersen[b], Guoqiang Zhang[a]

[a] Department of Engineering, Aarhus University, Blichers Alle 20, 8830 Tjele, Denmark
[b] AGRIFARM Company, Agro Business Park, Niels Pedersens Allé 2, 8830 Tjele, Denmark

ARTICLE INFO

Article history:
Received 20 January 2014
Received in revised form 4 April 2014
Accepted 30 July 2014
Available online 7 August 2014

Keywords:
Hybrid ventilation
Ammonia emission
ACH
Climate parameters
Dairy cow building

ABSTRACT

Naturally ventilated dairy cattle buildings are one of the major sources for ammonia and greenhouse gas emissions to the atmosphere. Generally it is difficult to clean the air from naturally ventilated buildings. In order to reduce the emissions, a hybrid ventilation system, which is natural ventilation combining with mechanical partial pit ventilation, has been developed. By full-scale measurement, this study was to quantify ammonia and methane emissions and to investigate the impacts of climate parameters on gaseous emissions, air exchange rate (ACH) and concentrations at sampling locations in a dairy cattle building with hybrid ventilation. The results revealed that 64–83% of ammonia emissions were collected by partial pit ventilation while 10–50% of methane emission was collected. The results showed that ammonia emission through natural ventilation was around 60% lower than the value found in literatures. ACH was significantly influenced by wind speed and wind direction (wind angle in the range of 135–270°) in summer. The ACH increased generally with wind speed in winter while it hardly changed with wind speed when the windows opening ratio was 6% and even lower. The paper further investigated the impact of wind speed and outdoor temperature on ammonia emissions.

1. Introduction

Livestock buildings are a 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 [1–3]. 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 air is driven by wind or buoyancy force so that it does not cost any energy for fans [4,5]. However, it is a challenge to maintain appropriate thermal conditions in buildings with natural ventilation (NV) in cold weather due to the difficulty in controlling the momentum of air. In addition, it is extremely difficult (almost impossible) to clean the exhaust air from dairy cattle buildings with NV system, which results in the ammonia and other contaminant gases exhausted to the atmosphere directly.

In order to reduce the odor emissions in livestock production buildings, mechanical ventilation (MV) system is an alternative to collect the pollutant air and clean it at the exhausts. However, the primary disadvantage of mechanical ventilation system is energy consumption [6] 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. [7] studied the effects of a partial pit ventilation (PPV) system on indoor air quality and ammonia emissions from a fattening pig room. It showed that the ammonia concentration with PPV system was reduced 42.6% in the room comparing to the ventilation system without PPV system. The ammonia emissions was 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 presented that the indoor air quality has been greatly improved and the ammonia emissions has been further reduced. The similar results with PPV in pig buildings could also be found in [8]. In addition, Wu et al. [9,10] studied the efficiency of a PPV to reduce emissions by both experiments and numerical simulations. The measurements were conducted by using a 1:2 scale model of manure pit section of a dairy cattle house in a wind tunnel. They

* Corresponding author at: Department of Engineering, Aarhus University, Blichers Alle 20, Postboks 50, 8830 Tjele, Denmark. Tel.: +45 87157717.
E-mail addresses: Li.Rong@eng.au.dk, rongli1980@gmail.com (L. Rong).

http://dx.doi.org/10.1016/j.enbuild.2014.07.089
0378-7788/

concluded that the pit removal ratio for the pollutants emitted from pit manure could be up to 83%, depending on airflow condition above the slatted floor. To combine the advantages of natural and partial pit ventilation system, hybrid ventilation (HBV) system was proposed in NVD buildings.

The concept of HBV was originally applied in a fattening pig bars by Zhang et al. [11] in 1980s. It was based on an application of natural ventilation in most time and switching on the mechanical ventilation only when the temperature difference between indoor and outdoor was bigger than the setting value, aiming at increase of inlet air momentum to avoid draft in cold calm winter. However, the relevant full-scale experimental data in dairy cattle building with HBV was missing.

The objectives of this paper were: (1) to study the thermal conditions and indoor air quality in the cattle building with HBV; (2) to quantify the NH_3 and CH_4 emission; (3) to analyze the effects of climate parameters and air temperature on ACH; (4) to investigate the impacts of wind velocity (speed and direction) and air temperature on ammonia emissions and concentrations at different sampling locations.

2. Materials and methods

2.1. Cattle building with HBV

The measurements were conducted in the dairy cattle building with HBV located at Skjern, Jylland in Denmark. The dimensions of the building were shown in Fig. 1. The length of the building was 74.0 m and the width was 45.0 m. The heights measured from the floor to the eave, to the roof and to the ridge were 3.41 m, 8.61 m and 11.3 m. On the East, two rows of windows were on the sidewall, one row was on the roof and the ridge respectively. The arrangement of windows on the West was the same. All the windows were auto-controlled. The height of the window was 1.1 m on the sidewall and 1.0 m on the roof. The length of the window on the ridge was 1.4 m. There was another row of windows beside the opening windows on the ridge, which was used for day lighting so that it was not open. The windows on side walls, on the roof and the ridge could be fully opened at the position of 41.4°, 46.0° and 40.0°. The opening ratio of the windows was calculated by the window's opening position dividing the window's full open position.

There were two big gates on the North, where tractor supplied feeding materials to the feeding alley. The gates were typically kept close and were only opened when it was necessary, e.g. feeding time (see Fig. 1a). The walking alley area between cows' cubicles and feeding alley was slatted floor. The feeding alley and the cows' cubicles 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 slats connected to the milking building. The manure collected to the deeper slurry channel was pumped out to a manure separation system. Between the cattle and milking building, there was also a gate, which was only opened during the milking time.

The system consisted of natural and mechanical partial pit ventilation system. The aim of the PPV was to collect the air with higher ammonia concentration and clean them in order to reduce the ammonia emissions. In Fig. 1(c) and (d), there were four channels named as EA on the East and named as WA on the West respectively below the cows' cubicles. The cross section of each channel was 2.8 m × 0.6 m and the size and location of nozzles was shown in Fig. 1(d). These channels were installed horizontally along the width of the building and turned upward on the North to connect with the central air channel. At the end of the central channel, an acid filter was installed to absorb the ammonia from the exhausted air, see Fig. 1(b). There were also four channels below the cows' bed to supply fresh air to the slurry channel, named as SA. The supplied airflow rate was around 40% of the airflow rate in pit vent channel so that the air in the slurry channel hardly flowed to the space above the slatted floor. In this study, the mechanical PPV system (fans power in total of 2.2 kW) 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 25% of the designed maximum ventilation rate (450 $m^3\ h^{-1}$ $cattle^{-1}$). The opening ratio of windows was adjusted by a control system according to the data measured by the installed sensors, such as temperature, CO_2, wind speed, intensity of the rain, etc. For example, the opening ratio of windows on the West was reduced firstly with strong wind and the windows on the ridge were closed with hard raining. To maintain the indoor thermal conditions and air quality, the opening ratio of windows was reduced with lower indoor temperature. In winter, the bottom windows on both side walls were closed.

2.2. Production and feeding

There were 360 cows with an average weight of 650 kg. The average milk production per cow was 9500–10,000 kg/year. The percentage of the milk protein was around 4.1%. The daily feeding consumption per cow was 54.67 kg d^{-1}, which included 63.52% corn silage, 25.91% grass silage, 6.1% HP soya, 3.76% Rapskage, 0.25% saturated fat and 0.46% straw. The cows are milked twice per day (4:00–7:00 and 15:00–18:00). The feeding time for the cows was around 5:30 in the morning. At 15:00, the tractor would collect the feeding materials on the alley and put them closer to the cows. Therefore, the big gate between the cattle building and milk building was open between 4:00 to 6:00 and 15:00 to 17:00. The big gates to the feeding alley were open between 6:00 to 8:00 and 15:00 to 17:00 approximately. The data presented in this segment was useful to determine the heat and CO_2 production from the cattle building. To calculate the heat and CO_2 production, the number of cows, the weight and the milk production was needed [12].

2.3. Measurements

The measurements were performed from 20th February to 13th March in winter and from 15th of July to 16th of August in summer.

2.3.1. Gas concentration

Gases inside and outside the buildings were sampled along three 20 m lines using Teflon tubes (diameter was 8 mm). Each tube had 20 uniformly distributed sampling openings. The diameter of the openings was 1 mm so that the airflow rate through each sampling opening was the same. By using this method, the measured gas concentration was actually the average value of the 20 sampling openings. In this work, the gas sampling tubes outside the building were also installed instead of one point sampling. It was because big variance of outdoor gas concentration has been noticed by former measurements, especially when the manure management location was close to the sampling point.

The measuring locations of indoor gas concentration were at C2, C3 and C4, which were close to the windows opening, as well as outdoor at C1 and C5 as background concentration, see Fig. 1(c). One tube was also placed before the acid filter so that the gaseous concentration could be measured in the pit ventilation. The tubes of C2 and C4 were placed 2.0 m away from the windows and 8.4 m above the floor. The tube of C3 was installed in the center of the building and 10.3 m above the floor, see Fig. 1(c) and (d). The tubes of C1 and C5 were placed 1.0 m away from the building side walls and